TOPOCLIMATIC INFLUENCES ON HEATING DEGREE DAYS IN COMPLEX TERRAIN

A Thesis

by

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ABSTRACT

TOPOCLIMATIC INFLUENCES ON HEATING DEGREE DAYS
IN COMPLEX TERRAIN. (May 1984)

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The relationships between temperature and topographic variations are examined in a small area of complex terrain located within Watauga County, North Carolina. Temperatures were recorded and heating degree days were computed for an eighty day observation period in late winter and early spring at five sites with different combinations of the physical elements: (1) altitude, (2) aspect, and (3) slope.

The hypothesis, that there are significant differences in heating degree days within the study area due to variations in altitude, aspect, and slope, was rejected. This conclusion was based upon results obtained from a one-way analysis of variance test. It was also supported by comprehensive graphic analyses of the heating degree day distribution among study sites.

A secondary objective was to demonstrate a practical application of a topoclimatic analysis. This was

accomplished by incorporating the total number of observed heating degree days from each site into a formula used to determine the average energy consumed by a household for heating purposes. By utilizing an economic means of comparison, the advantages or disadvantages of the physical characteristics of each study site were placed in a context which is comprehensible to home energy consumers.

ACKNOWLEDGEMENTS

I would like to express appreciation to my thesis committee members, Drs. William Imperatore, H. Daniel Stillwell, and Roger Winsor. Thanks are also due to Dr. Gary Kader, who provided statistical assistance, and those members of the community who allowed me to place a thermometer shelter on their property. Finally, I would like to thank my wife Carol, for her encouragement and support throughout this endeavor.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION AND OVERVIEW

Introduction

In middle and high latitude mountainous areas terrain complexity often results in marked climatic variations over short distances. The primary objective of this study is to examine how one climatic element, temperature, is influenced by variations in slope, altitude, and aspect in a small area of dissimilar terrain.[1] Relating temperature variations within this area to energy consumed for home heating will provide some insight into the effects topoclimatic influences can have on people who reside in complex terrain.[2]

Local Relief and Climate of the Study Area

Local Relief

As can be seen in Figure 1.1, the study area is situated within a 5.25 square mile area of Watauga County, North Carolina, one of the western most counties of the state. Located in metamorphic mountain terrain of the Blue Ridge physiographic province, the county is dissected by numerous creeks and rivers. Variations in slope, altitude, and aspect of the ridges and valleys

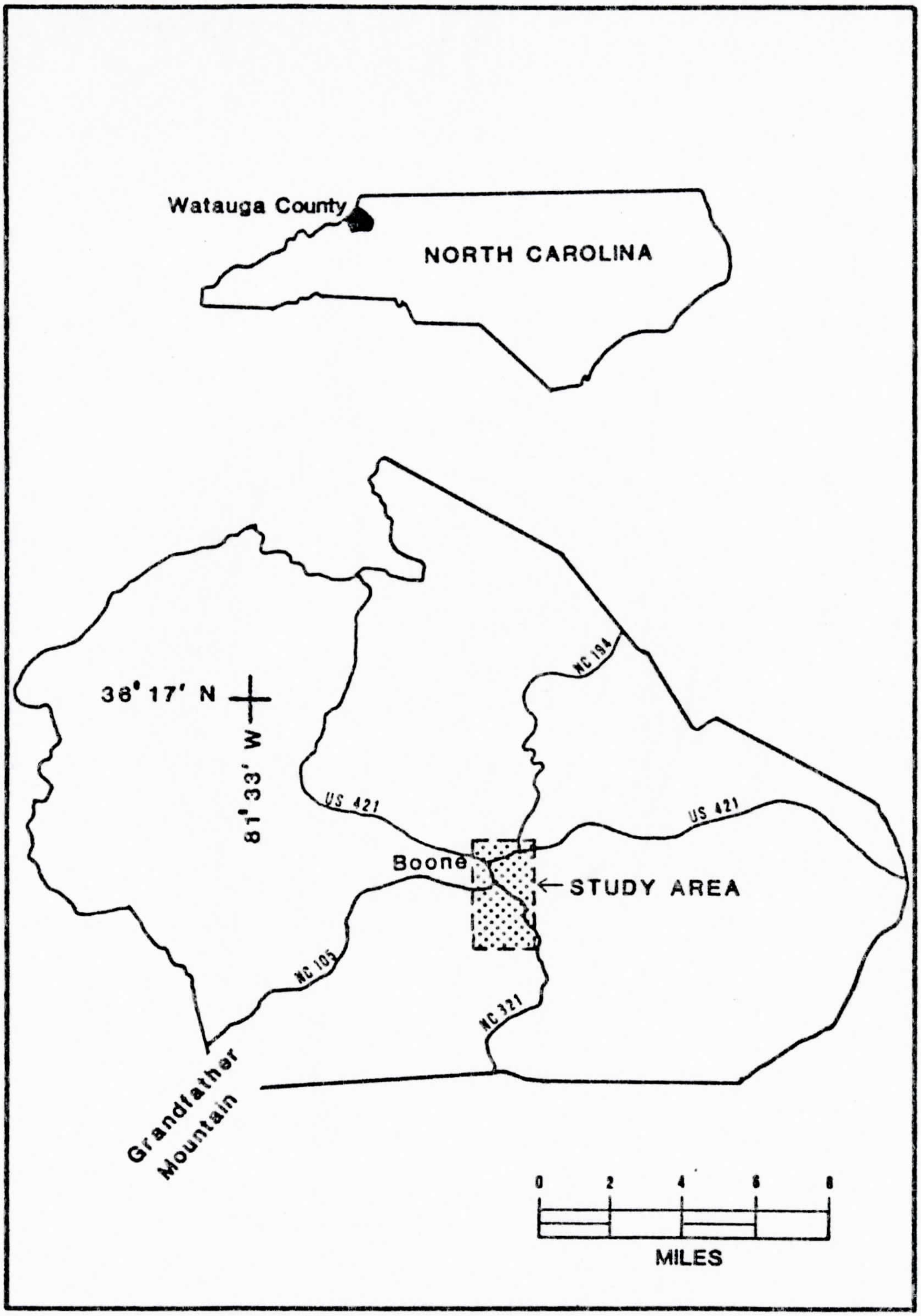

Figure 1.1. Location of the Study Area in Watauga County
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

in the county are a result of the erosion of rock strata by the drainage system and create a terrain which can be classified as complex.

Elevations within the study area range from 3,120 to over 4,000 feet. The western portion of the Happy Valley, which is aligned from southeast to northwest, contains the majority of the flat land in the study area. The northern portion is dominated by slopes with a gradient of less than 20 percent while the southern portion has slopes with gradients of greater than 21 percent. Slope percentages are shown in Figure 1.2.

The complex nature of the terrain within the study area becomes evident when the alignment of ridges and valleys is examined. At this large scale (small area) no definite patterns are detected. This heterogeneous terrain results in slopes with aspects representing many of the cardinal and intermediate directions.

Climate

The climate of the study area is generally mild and humid. Average temperatures in Boone (which lies partially within the study area) range from 33 degrees Fahrenheit in January to 68 degrees Fahrenheit in July.[3] Precipitation is well distributed throughout the year

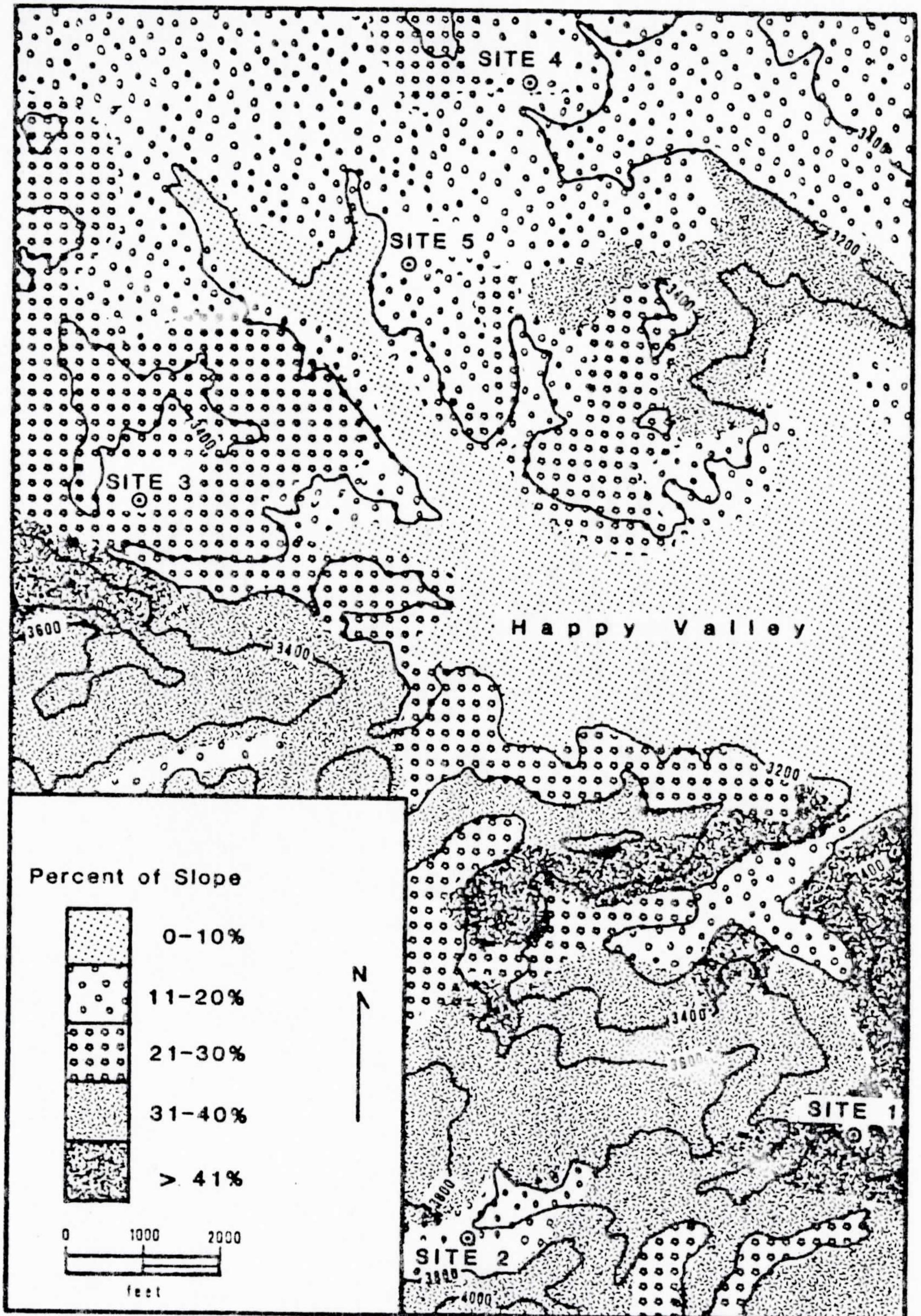

Figure 1.2. Slope Gradients Within the Study Area
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

and averages 53 inches (see Figure 1.3).[4] The dominant wind direction, occurring an average of 53 percent of the time, is west.[5] Eastward moving cyclonic storms occur in all seasons and are the prime controllers of the regional climate.

Because altitudinal influences are not always taken into account in climatic classification, variations occur in the description of climate for the region in which the study area is located. The Strahler system of climatic classification recognizes the influence of altitude and classifies the regional climate as an undifferentiated highland which can exhibit "narrow belts of rapid climate change".[6]

Utilizing the Koppen-Geiger system of classification and five years of data, an analysis of the macroclimate of the region surrounding the study area showed that rapid climatic change does occur. Approximately seventeen miles and less than 2,000 feet of altitude separate the official recording stations at Boone and Grandfather Mountain. Based on the data Boone is classified as a mild, humid (mesothermal) climate, and Grandfather Mountain is classified as a snowy-forest (microthermal) climate.[7]

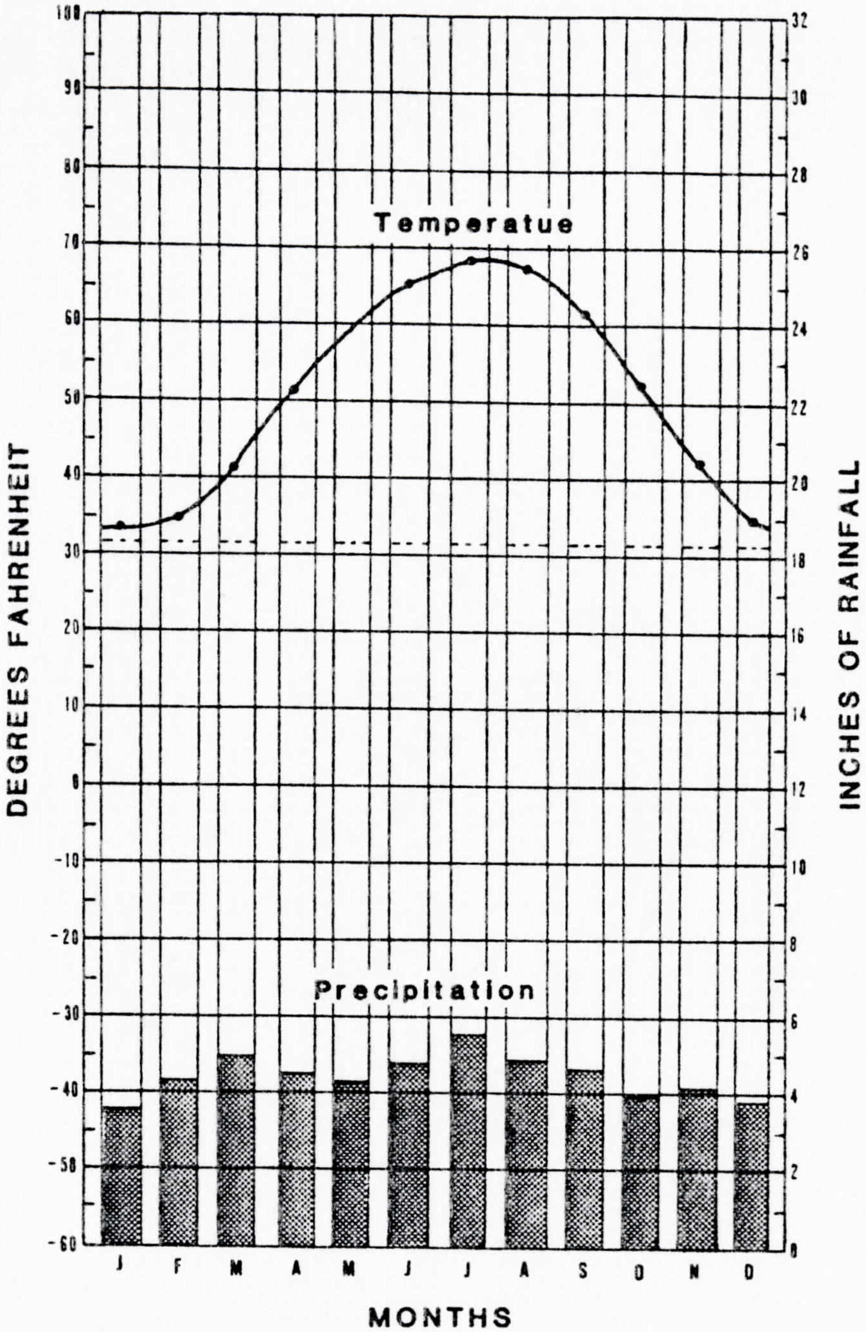

Figure 1.3. Thirty-one Year Average of Monthly Temperatures and Precipitation for Boone, N. C.

Source: U.S. Department of Commerce, Annual Summary of Climatological Data for North Carolina, 1979.

Caution must be used when describing the climate of a region or micro-region because topographic variations can cause rapid changes in meteorologic and climatic elements over short distances.[8] This investigation focuses on the variation of one climatic variable, temperature, over a much smaller area than that covered by the macroclimatological network.[9] By utilizing a small study area the influence of topography on temperature can be looked at in greater detail.

Literature Review

Introduction

Research dealing with: (1) climates, microclimates, and topoclimates, and (2) the relationship between climate and energy usage are the two main themes found in the literature. A discussion of these themes follows.

Climates, Microclimates, and Topoclimates

The first theme can be divided into sub-themes which include: (1) direct observation of the temperature variations caused by topoclimates and microclimates, (2) analysis of the influence of slope, aspect, and altitude on temperatures, and (3) mapping, classification, and simulation of climatic variables and zones.

Studies included in the first sub-theme involved measurement of climatic data at a series of stations to study the effects of topoclimatic variations in complex terrain. Although their objectives were different, Olson and Gill, Brazel and Outcalt, Brazel, and Marcus all employed the same basic technique to examine variations in temperature. Thermographs and minimum/maximum thermometers were placed at from five to eleven sites which offered a variety of topographic conditions. With the exception of Olson and Gill, all of the research was conducted in alpine and periglacial terrain in the Chitistone Pass and St. Elias Mountains of Alaska. Data was collected over a two week to three month period. One of the main conclusions reached by all the researchers is that the dominant factors which control surface temperatures are slope and aspect.[10]

The second sub-theme deals with the influence of slope, aspect, and altitude on temperature variations. Altitudinal influences were examined by Harding, Lyall, Brazel, and Geiger.[11] Comparing minimum and maximum temperatures in the Northern Pennines, England, it was found that maximum temperatures were greatly affected by changes in altitude, but minimum temperatures were more a function of small scale variations in topography.[12] Brazel found that normal lapse rates could be used to describe the distribution of average and maximum temperatures but could not be used to describe the distribution of minimum temperatures.[13]

According to Barry and Van Wie, the principal factors influencing the temperature component of topoclimates are slope and aspect.[14] This point was supported almost unanimously by all researchers. Garnier and Ohmura have developed a formula which stresses the importance of incorporating slope angle and aspect into evaluations of solar radiation incomes.[15] An ability to predict variations in the amount of solar radiation received at a site is important for evaluations of solar energy applications, agriculture, and water use.[16]

The third sub-theme, mapping, classification, and simulation of climatic variables and zones, takes many forms. Cohen and Alsop used data collected over a long period (thirty-three and twenty-eight years respectively) to derive their climate classifications. Cohen's work was based on upper-air circulation patterns and was applied to the entire United States.[17] Alsop dealt with the spatial distribution of mean temperatures over a smaller area (the Pacific Northwest).[18] On a much larger scale (small area) the classification of microclimatic zones has been accomplished by analyzing the effects of four major factors: (1) slope, (2) vegetation, (3) season, and (4) recurring weather types.[19]

The problem of accurately representing climatic zones and temperature data on maps of mountainous areas was discussed by Marcus, and Pielke and Mehring.[20] A technique has been devised by Peilke and Mehring whereby predicted temperature data is substituted for altitude on topographic maps. This technique has been applied in such areas as weather forecasting, insulation engineering, and forestry.[21]

Climate and Energy Use

The second theme in the literature focuses on the relationship between climate and energy usage. Influences of climatic variability on a regional basis were examined by Sherrill and Stackhouse.[22] Besides showing that regional climatic differences cause variations in energy consumption, Stackhouse also found, after looking at a number of climatic variables, that the degree day variable was the most significant.[23] According to Nelson, the climate of an area (determined by the average yearly number of heating degree days) "was the most important explanatory variable for per capita fuel demand".[24] The need for understanding local temperature conditions when choosing an energy efficient home location, and how these temperatures are related to topography, airflow, and aspect was discussed by Wright.[25]

In summary, two major points can be drawn from the literature surveyed: (1) slope and aspect play a major role in the variation of air temperatures in complex terrain, and (2) the number of heating degree days received is the principal determinant of energy consumption.

There were two apparent research gaps in the pertinent literature: (1) no studies could be found which dealt with the relationships between topoclimatic variations of air temperature and energy used for home heating, and (2) none of the research was based upon a scale as large (small area) as that utilized in this study.

Limitations

There were three general limitations of this study. The first limitation was time. It was felt that an eighty day observation period in the late winter to early spring transition period would yield meaningful results about the temperature variations among sites. With an observation period of a year or more long-term trends could have been analyzed. The second limitation was the lack of instrumentation. Financial constraints prohibited the use of more minimum/maximum thermometers or the utilization of more sophisticated instruments such as thermographs, recording wind systems, barographs, and hygrographs which would have allowed the collection of continuous temperature, wind speed and direction, barometric pressure, and relative humidity data. If any or all of these instruments could have been obtained, a more comprehensive topoclimatic study would have been undertaken. The third limitation, that of areal coverage, relates to the second. More instrumentation would have enabled a denser observation network permitting the testing of a greater variety of sites. In keeping with the methodology used in similar research, vegetation and soils were not considered in this study.

Statement of the Hypothesis

The research hypothesis is: There are significant differences in heating degree days within the study area due to variations in slope, altitude, and aspect.

Methodology

Introduction

The study area was selected on the basis of the complex nature of the terrain. In order to test the hypothesis minimum/maximum thermometers were placed at locations with varying altitude, aspect, and slope characteristics. Figure 1.4 shows the location of the thermometer sites within the study area in relation to main roads. The research design was to have sites representing: (1) a north aspect, (2) a south aspect, (3) an east aspect, (4) a west aspect, and (5) an altitude at least 250 feet greater than the other four. Five general locations were chosen on the basis of these criteria. Within these locations the final site selection was modified by: (1) accessibility, and (2) willingness of land owners to cooperate. Deviations from the initial design were kept to a minimum.

Data Collection

Minimum and maximum temperatures were recorded over an eighty day period. This interval (February 21, 1983 to May 11, 1983) was chosen to represent a transition from cold to warm weather. Recorded temperatures were

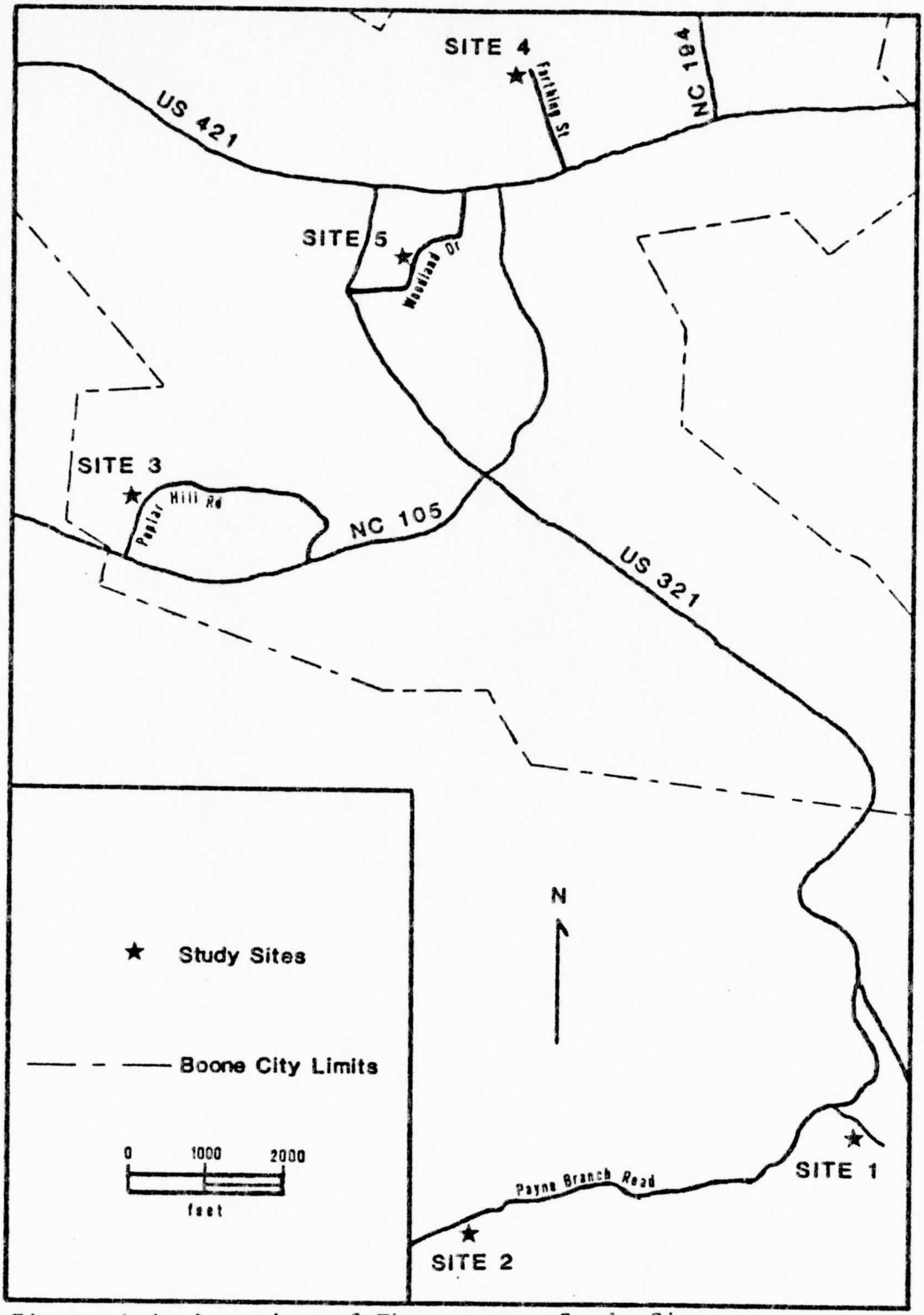

Figure 1.4. Location of Thermometer Study Sites
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

used to compute average temperatures and heating degree days for each site. An average daily temperature is the sum of the minimum and maximum temperatures divided by two. The number of heating degree days is computed by subtracting the average temperature from sixty five degrees Fahrenheit. If the average temperature is greater than sixty five degrees, zero heating degree days are recorded.

Meteorological instrumentation consisted of five identical minimum/maximum thermometers. The thermometers were mounted in white wooden shelters and were situated so that they would constantly remain in the shade. All thermometers faced due north and were at a uniform height above the ground of five and one-half feet.

Slope measurements were taken with an optical reading clinometer. Aspect measurements were taken with a hand held compass. Altitudes were obtained from a seven and one-half minute series topographic map and checked with a pocket altimeter.[26]

Site Analysis

Analysis and comparison of the physical characteristics of the study sites was based on: (1) field observation, (2) contour mapping, and (3) three-dimensional mapping. Site analysis, in conjunction with the graphic analyses and hypothesis test, forms the basis of the final conclusions of this study.

Data Analysis and Hypothesis Testing

Collected temperature data is analyzed statistically and graphically. The research hypothesis was tested primarily by means of statistical procedures. Graphic analysis is used because: (1) similarities and differences between sites, and general trends within the data set are clearly represented and more easily analyzed when presented in graphic form, and (2) these graphs are used to verify conclusions based on the statistical tests.

The primary statistical test utilized in this study is the one-way analysis of variance (ANOVA). This test can be used to compare a number of samples simultaneously to determine if there are any differences among them at a prescribed level of significance (the 0.05 level of significance in this case). The samples to be tested consist of the mean number of heating degree days for each of the five sites.

The one-way analysis of variance will be used to analyze the variation within the entire data set and determine a critical value which will then be compared to a given critical value at the 95 percent confidence level. If the computed critical value for the data set is larger than the given critical value (which is based on the size of the data set) then the evidence would strongly suggest that the null hypothesis (There are no significant differences in heating degree days within the study area due to variations in slope, altitude, and aspect) be rejected and the alternate hypothesis (There are significant differences in heating degree days within the study area due to variations in slope altitude, and aspect) be accepted.

The one-way analysis of variance can only determine if there is a significant difference between one or more of the means, it can not pinpoint which means out of the sample account for the difference. If the null hypothesis is rejected the Scheffe Procedure, which is a form of a least significant difference test (LSD), will be used. The least significant difference test can compute the relationship between all possible pairs of sample means and determine the extent of differences between pairs.[27] If differences do occur the information obtained from LSD will be valuable in comparing sites. It must be noted that LSD is only valid, and will only be utilized, if the null hypothesis is rejected by ANOVA.

Practical Application

A secondary objective of this thesis is to demonstrate a useful application of a topoclimatic analysis. This is accomplished by incorporating the total number of observed heating degree days from each site into a formula to determine the average energy consumed by a household for heating purposes. The formula used was modified from a Home Weatherization Audit Checklist used by the Blue Ridge Electric Membership Corporation (BREMCO).[28] To utilize this formula it was assumed that a hypothetical "average" house existed at each of the observation sites. The dimensions of this house remained constant, the only variable which changed in the formula was the observed number of heating degree days.

The cost of heating these hypothetical houses for the eighty day observation period is the final result obtained from this formula. An economic method of comparison is utilized to present the results of this study in a context that is comprehensible to home energy consumers.

In summary, each site chosen for use in this study has a different combination of altitude, aspect, and slope. The problem for this study is to determine how these variations in physical characteristics among sites influenced the distribution of recorded temperatures and heating degree days during the eighty day observation period. In the following section, Chapter II, the five study sites are analyzed on the basis of their specific physical characteristics.

NOTES

[1]Throughout this study: (1) "altitude" is used to denote the vertical distance above mean sea level, (2) "aspect" is used to describe the orientation of an inclined land surface in respect to the compass, and (3) "slope" is used to describe the deviation of a land surface from the horizontal; This thesis was conducted entirely in english measurements. An english to metric conversion table is provided in Appendix I.

[2]For the purposes of this study "topoclimate" is defined as the influence of topography on the distribution of climatic elements.

[3]James Freeman, "Feasibility of Air Transportation: The Case of Watauga County, North Carolina" (Master's thesis, Appalachian State University, 1977), p. 18.

[4]Ibid.

[5]Ibid, p. 22.

[6]Arthur Strahler and Alan Strahler, Elements of Physical Geography (New York: John Wiley and Sons, 1979), p. 167.

[7]The Koppen-Geiger system of climatic classification is based on temperature and precipitation. The data was collected from the United States Department of Commerce, National Oceanic and Atmospheric Administration, Annual Summary of Climatological Data for North Carolina, (Washington, D. C.: Government Printing Office, 1965 to 1969).

[8]Melvin Marcus, Climate-Glacier Studies in the Juneau Ice Field Region, Alaska (Chicago: Department of Geography, the University of Chicago, 1964), p. 17.

[9]North Carolina's official macroclimatological network consists of 205 meteorological stations which are distributed among its 100 counties. Two official meteorological stations are operated within Watauga County, one in Boone, the other in Blowing Rock (approximately eight miles separate the two).

[10]P. R. Olson and D. Gill, "A Preliminary Analysis of Microclimatic Variations in a Small Mountain Valley of Western Alberta during Warm and Cool Weeks in Summer," in Contemporary Geography in Western Canada: The Calgary Papers, ed. Nigel M. Waters (Vancouver: Tantalus Research Limited, 1980), pp. 37-51; Anthony Brazel and Samuel Outcalt, "The Observation and Simulation of Diurnal Surface Thermal Contrasts in an Alaskan Alpine Pass," Archives for Meterology, Geophysics, and Bioclimatology, Series B 21 (Spring, 1973): 156-174; Anthony Brazel, "A Note on Topoclimatic Variation of Air Temperature, Chitistone Pass Region, Alaska," in Icefield Ranges Research Project, Scientific Results: Volume 4, eds. Vivian Bushnell and Melvin Marcus (New York: American Geographical Society, 1974), pp. 81-88; and Melvin Marcus, "Summer Temperature Relationships Along a Transect in the St. Elias Mountains," in Icefield Ranges Research Project, Scientific Results: Volume 1, eds. Vivian Bushnell and Richard Ragle (New York: American Geographical Society, 1969), pp. 23-32.

[11]R. J. Harding, "The Variation of the Altitudinal Gradient of Temperature Within the British Isles," Geografiska Annaler 60 (1978): 43-49; I. T. Lyall, "Some Local Temperature Variations in Northeast Derbyshire," Weather 32 (April, 1977): 141-145; Brazel, "A Note on Topoclimatic Variation," pp. 81-88; and Rudolf Geiger, The Climate Near the Ground (Cambridge: Harvard University Press, 1973).

[12]R. J. Harding, "Altitudinal Gradients of Temperature in the Northern Pennines," Weather 34 (May, 1979): 194.

[13]Brazel, "A Note on Topoclimatic Variation," p. 83; According to normal lapse rates, air temperature will decrease at a rate of 3.5 degrees Fahrenheit per 1000 feet in calm conditions. Air that is being forced to rise will cool at a rate of 5.5 degrees Fahrenheit per 1000 feet below the dew point (point where condensation occurs), at a rate of 2 degrees Fahrenheit per 1000 feet above the dew point.

[14]Roger Barry and Claudia Van Wie, "Topo- and Microclimatology in Alpine Areas," in Arctic and Alpine Environments, eds. Jack Ives and Roger Barry (London: Methuen and Co., 1974), p. 76.

[15]B. J. Garnier and Atsumu Ohmura, "The Evaluation of Surface Variations in Solar Radiation Income," Solar Energy 13 (1970): 21-34.

[16]Ibid, p. 33.

[17]Stewart Cohen, "Climatic Influences on Residential Energy Consumption" (Ph.D. dissertation, University of Illinois, 1981).

[18]Ted Alsop, "Topothermal Climatic Zones on the Surface of the Pacific Northwest in Oregon and Washington" (Ph.D. dissertation, Oregon State University, 1979).

[19]Orton Butler, "Microclimates of Neotoma, a Small Valley in Southern Ohio: Their Elements, Controls, and Classification" (Ph.D. dissertation, Ohio State University, 1969).

[20]Marcus, Climate Glacier Studies, 1964; and Roger Pielke and Peter Mehring, "Use of Mesoscale Climatology in Mountainous Terrain to Improve the Spatial Representation of Mean Monthly Temperatures," Monthly Weather Review 105 (January, 1977): 108-112.

[21]Pielke and Mehring, "Use of Mesoscale Climatology," p. 108.

[22]Robert Sherrill, "Population, Climate, and Residential Energy Consumption for Heating and Air Conditioning" (Ph.D. dissertation, Pennsylvania State University, 1977); and Linda Stackhouse, "The Effect of Climatic Variability on Variations in Residential Energy Consumption for Sites in the Eastern United States" (Master's thesis, University of Georgia, 1981).

[23]The heating degree day measurement"...is a cold season index and is based on the assumption that a temperature of sixty-five degrees Fahrenheit within a building is the minimum thermal threshold for normal human comfort. Developed by heating engineers, this index permits a relatively accurate measurement of fuel consumption, and removes the guesswork from the calculation of fuel needs."; James Clay, Douglas Orr, and Alfred Stuart, North Carolina Atlas: Portrait of a Changing Southern State (Chapel Hill: The University of North Carolina Press, 1975), p. 95.

[24]Jon Nelson, "Climate and Energy Demand: Fossil Fuels," in The Urban Costs of Climate Modification, ed. Terry E. Ferrar (New York: John Wiley and Sons, 1976), p. 136.

[25]R. Wright, "Designing Thermally Efficient Buildings for the U. S. Midwest," Sunworld 3 (1979); 13.

[26]United States Geological Survey, Boone Quadrangle, (Reston, Virginia: United States Geological Survey, 1978).

[27]Henry Alder, Introduction to Probability and Statistics (San Francisco: W. H. Freeman and Co., 1964), p. 251.

[28]Blue Ridge Electric Membership Corporation, "Home Weatherization Audit Checklist," Boone, N. C., 1982.

CHAPTER II

SITE ANALYSIS

Introduction

The general physical characteristics of the five study sites are given in Table 2.1. These sites were chosen primarily on the basis of their aspect and elevation. Figure 2.1 depicts the variation in aspects between sites. Altitudinal differences are shown in Figure 2.2. Slope profiles for all of the sites can be seen in Figure 2.3. Numerous combinations of aspect, altitude, and slope gradient can be found within the study area. The final sites which were chosen for use in this study are a representative sample of these possible combinations. It should be noted that other elements of the physical environment, principally vegetation and soils, were not used as factors in the site selection process.

Site One

Site One is located along Payne Branch Road and has an altitude of 3360 feet (see Figure 1.4). Chosen to represent a north aspect, the aspect of this site is 26 degrees or approximately north-northeast. The area surrounding Site One is dominated by slopes with

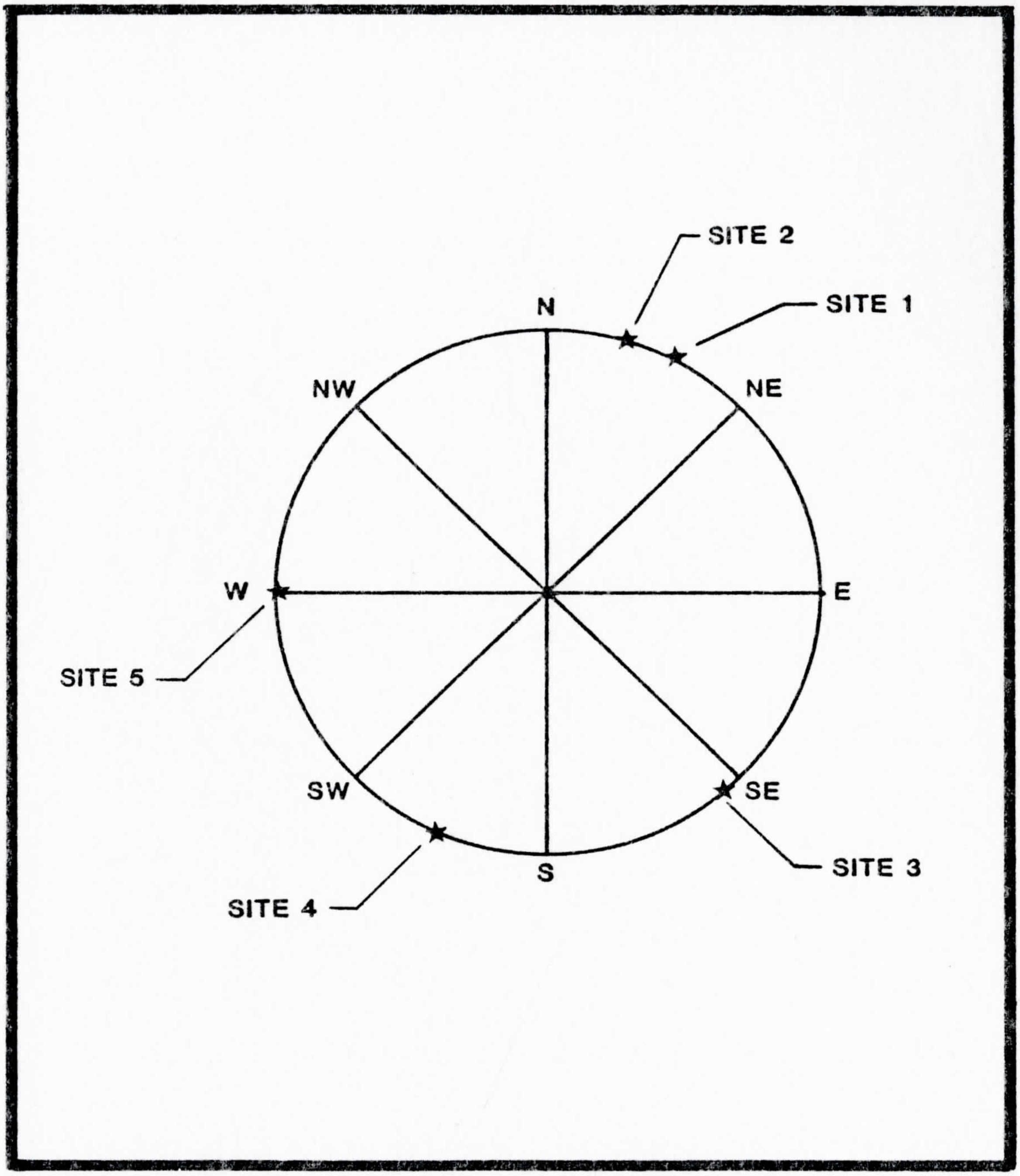

Figure 2.1. Variation in Aspect Bearing Among the Five Study Sites

Source: By Author.

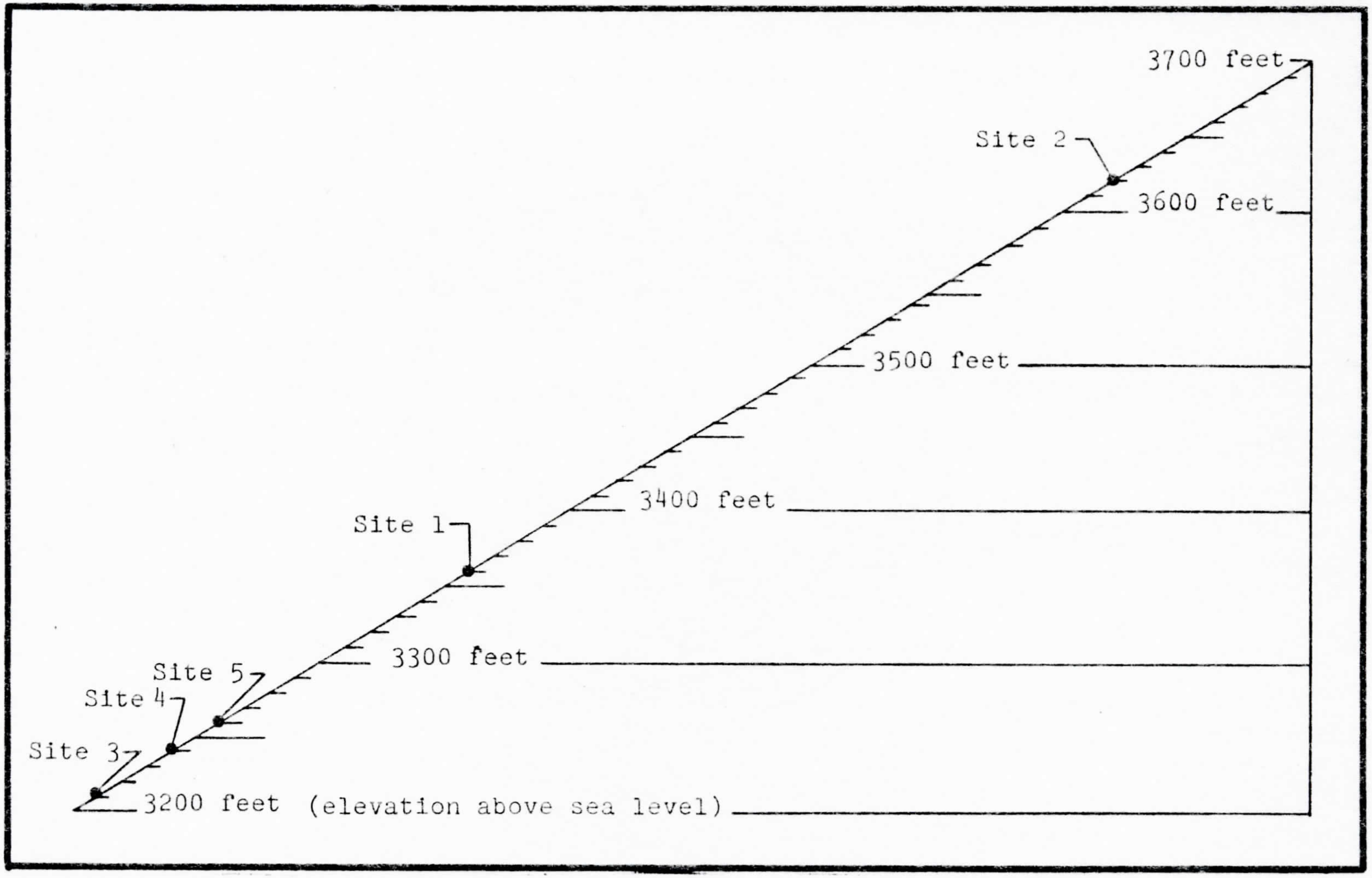

Figure 2.2. Altitudinal Distribution of the Five Study Sites
Source: By Author.

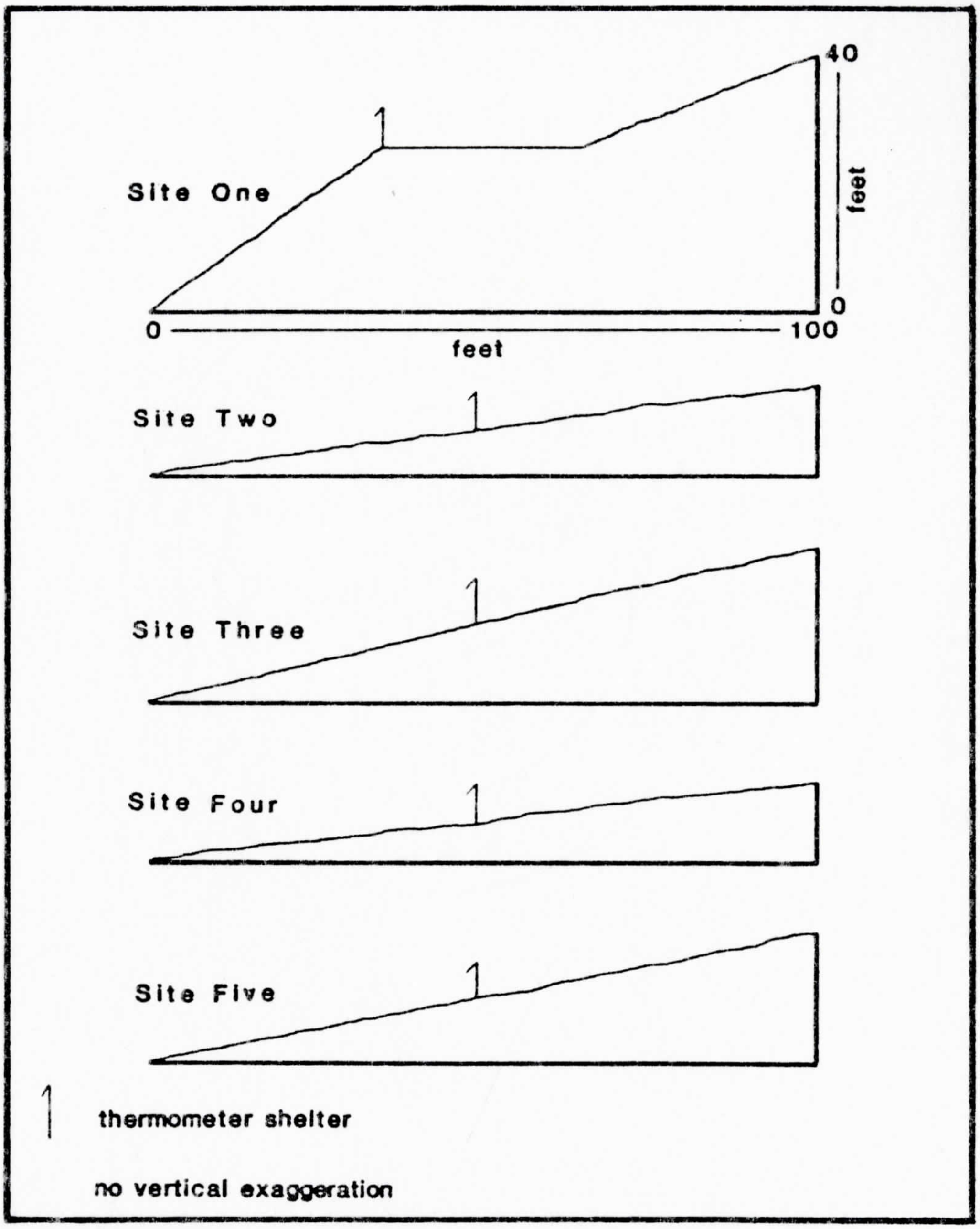

Figure 2.3. Slope Profiles of the Five Study Sites
Source: By Author.

gradients of 41 percent or more (see Figure 1.2). The actual slope was found to be 70 percent below the thermometer shelter, 38 percent above the shelter, for an average gradient of 54 percent. The position of the thermometer shelter at Site One in relation to the specific characteristics of the adjacent area is shown in Figure 2.4, a photograph of the site.

Table 2.1

GENERAL PHYSICAL CHARACTERISTICS OF THE STUDY SITES

Site	Altitude (feet)	Average Slope (percent)	Azimuth (degrees)	Aspect Bearing
One	3360	54	26	NNE
Two	3620	14	18	NNE
Three	3220	24	137	SE
Four	3240	12	210	SSW
Five	3260	20	270	W

Source: By Author.

Figure 2.5 is a large scale topographic map of the area surrounding Site One. The steep slopes which dominate this portion of the study area can be primarily

Figure 2.4. Photograph of Site One
Source: Photography by Author.

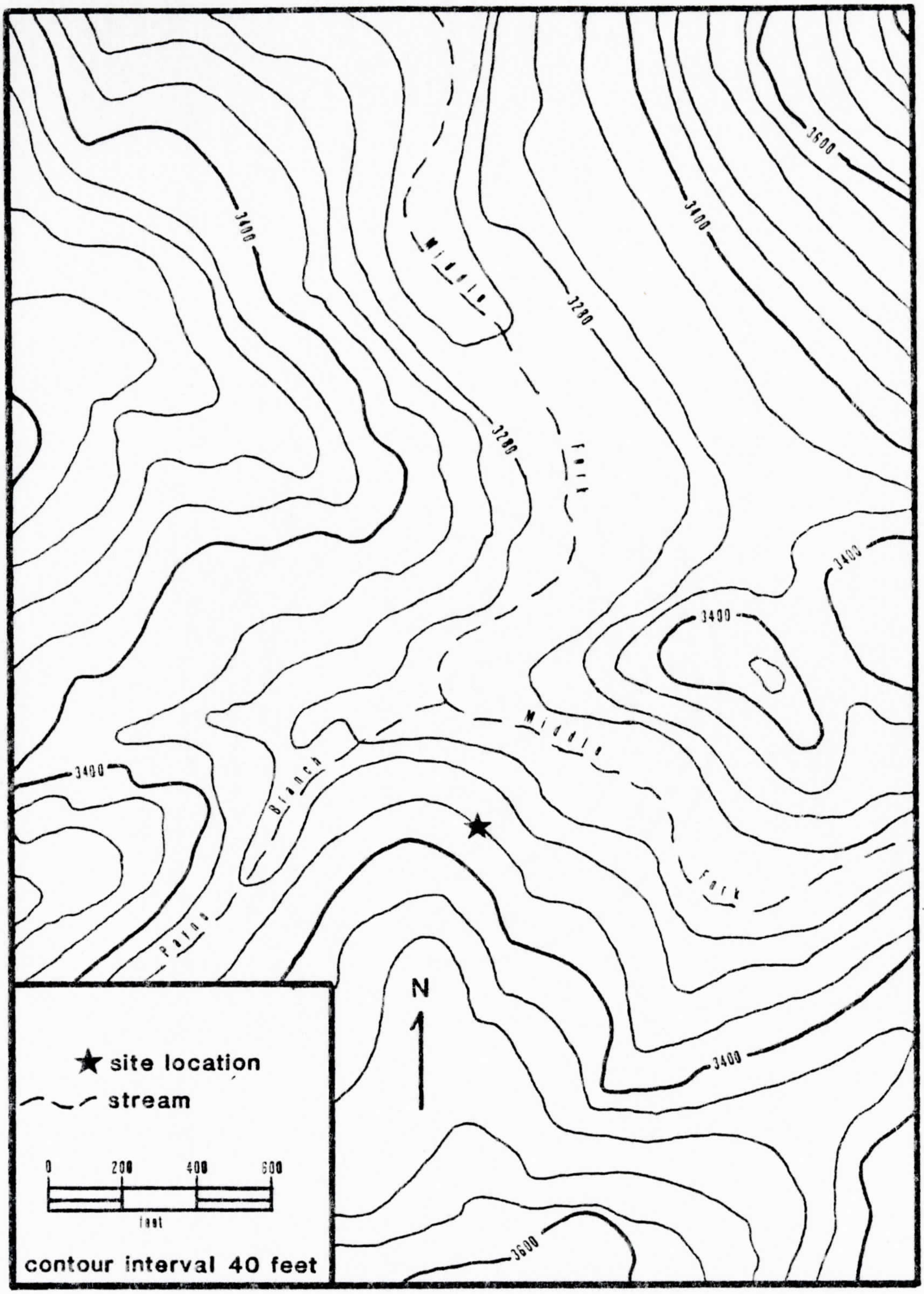

Figure 2.5. Topography Surrounding Site One
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

attributed to the erosive action of the Payne Branch and Middle Fork of the New River. Differences in altitude are sharp and range from 3280 to 3800 feet. Site One is located near the bottom of a slope with an aspect of north-northeast. One would expect the principal factor controlling the temperature regime at Site One to be the small amount of direct solar radiation received here during the low sun period of the year due to the combination of north-northeast aspect and steep slope.

To help visualize the nature of the topography surrounding each of the sites, three-dimensional perspective views were created.[1] Figure 2.6 is a three-dimensional view of the area surrounding Site One. It can be directly compared to Figure 2.5 because the areal coverage is identical.

Site Two

Site Two is located along Payne Branch Road at an altitude of 3620 feet (see Figure 1.4). This site was chosen on the basis of its altitude, which was at least 250 feet higher than the other sites. Situated at the apex of a small valley in which the Payne Branch of the New River begins its flow, the site is immediately surrounded by slopes with gradients of between 11 and 20

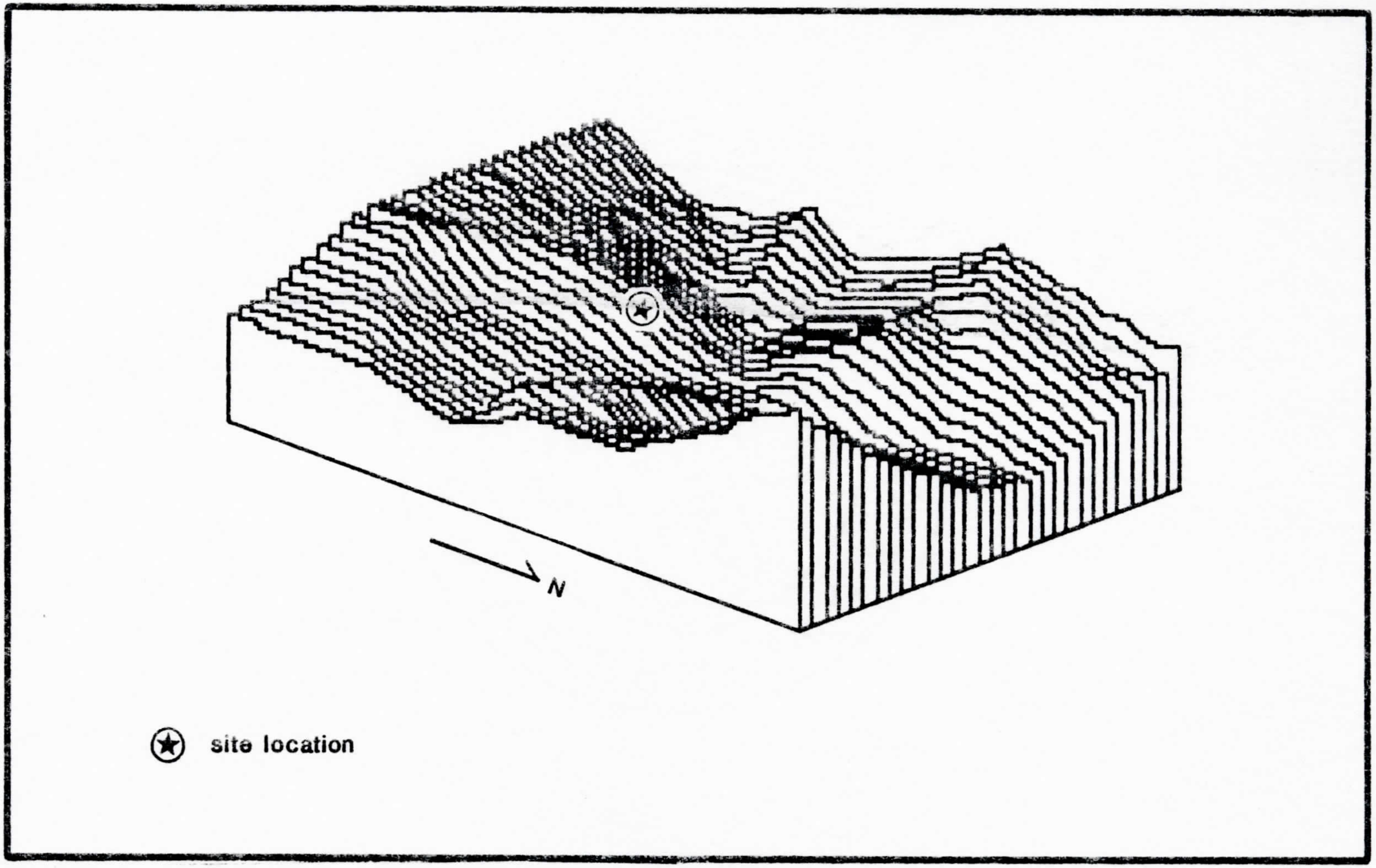

Figure 2.6. Digital Terrain Matrix of Site One
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978, Terrain Matrix by Author.

percent (see Figure 1.2). Beyond this area slope gradients increase to between 31 and 40 percent. The actual slope at Site Two, shown as a profile in Figure 2.3, was found to be 14 percent. The aspect of Site Two was 18 degrees or approximately north-northeast. Figure 2.7 shows the position of the thermometer shelter in relation to the specific characteristics of the site.

The general physical characteristics of the area surrounding Site Two are shown in Figure 2.8, a large-scale topographic map, and in Figure 2.9, the corresponding three-dimensional view. North, southeast, and south facing slopes lead into the apex of the valley occupied by the Payne Branch of the New River. Site Two is located at the base of the north-facing slope which comprises more than half of the area shown. The altitude and north-northeast aspect were expected to be the main locational factors controlling the temperature regime at this site during the observation period.

Site Three

Site Three is located along Poplar Hill Road at an altitude of 3220 feet (see Figure 1.4). Chosen to represent an east aspect, the actual aspect of this site is 137 degrees or approximately southeast. Slopes with a

Figure 2.7. Photograph of Site Two
Source: Photography by Author.

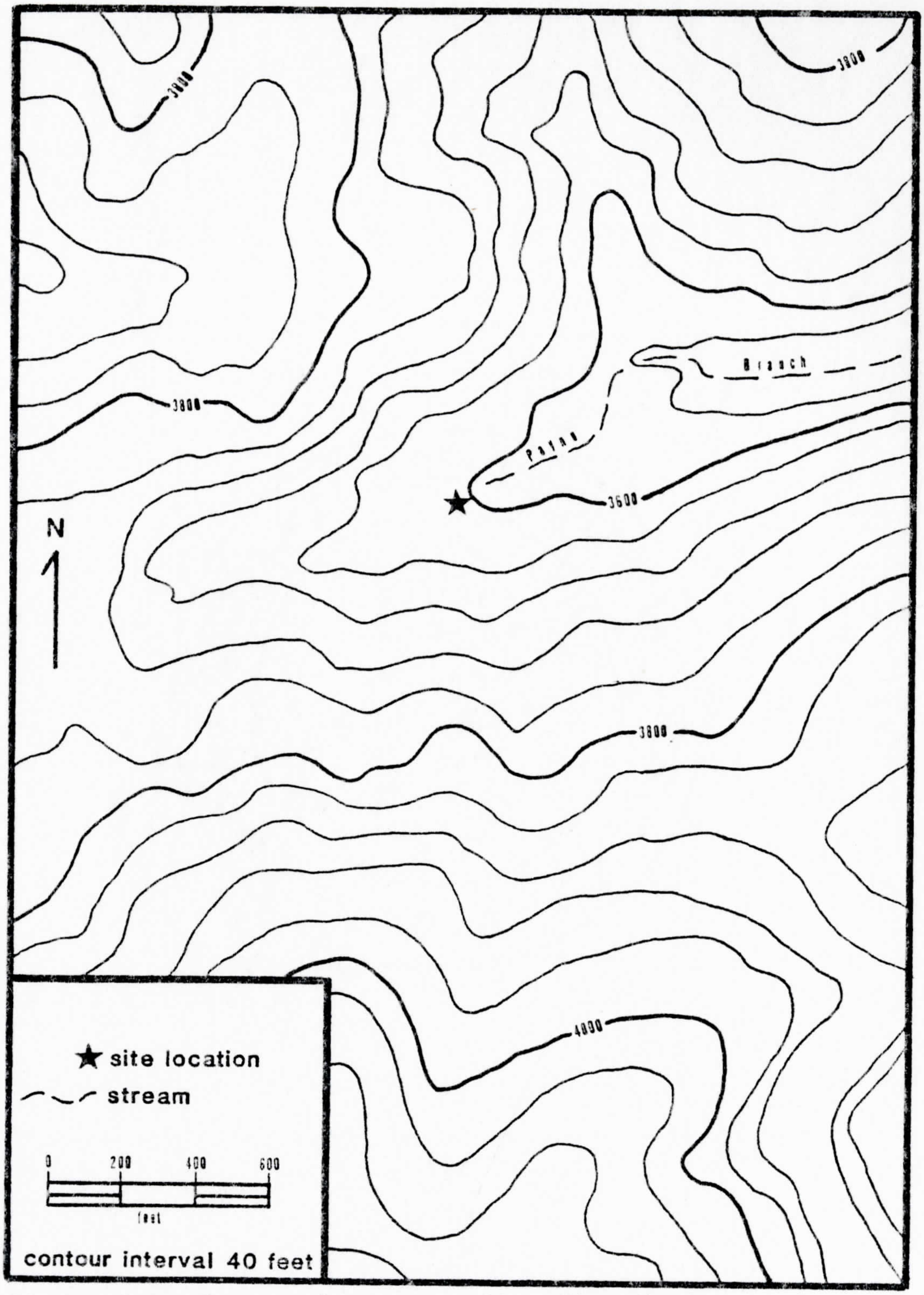

Figure 2.8. Topography Surrounding Site Two
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

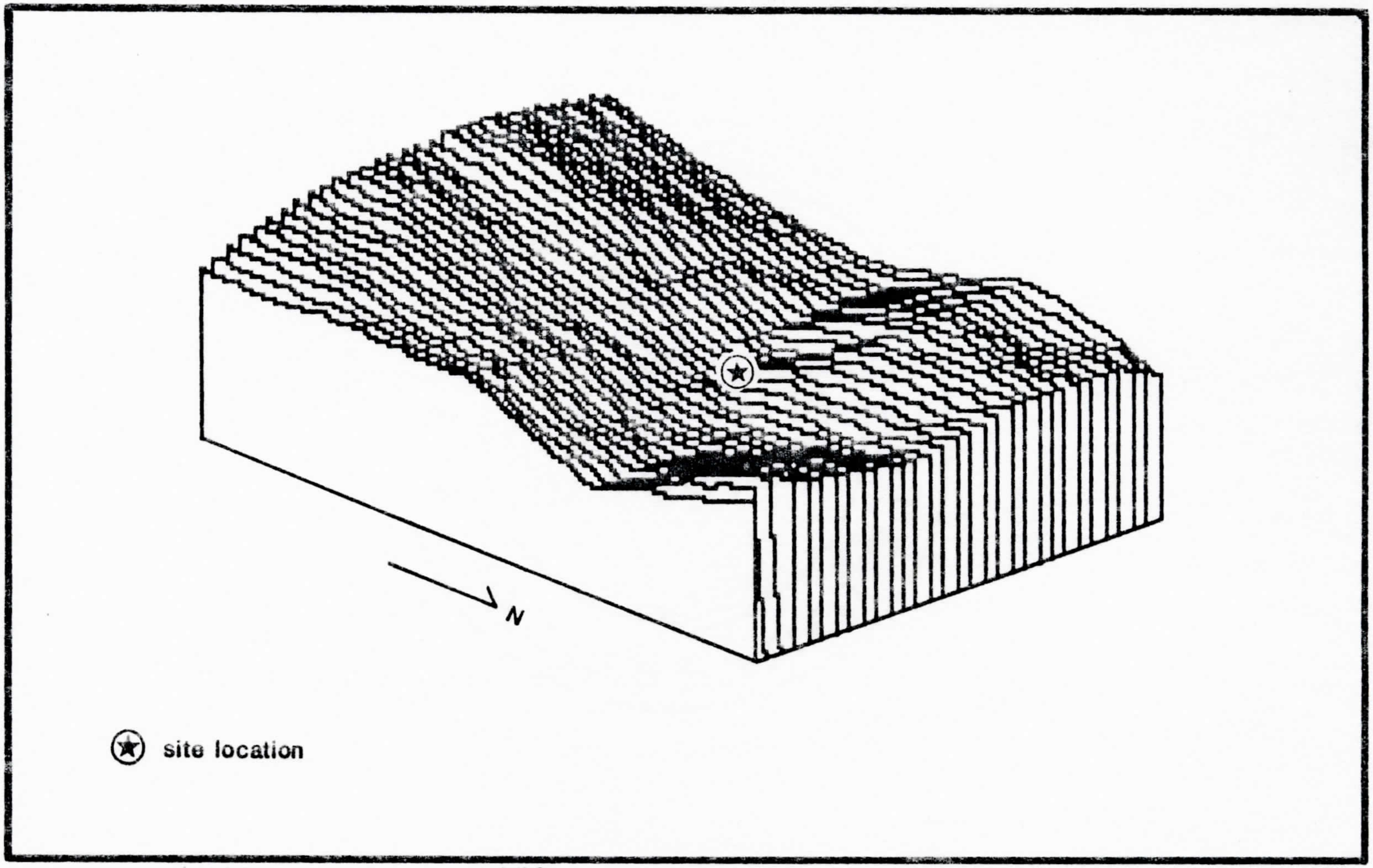

Figure 2.9. Digital Terrain Matrix of Site Two

Source: U.S.G.S. Topographic Map, Boone, N.C., 1978, Terrain Matrix by Author.

gradient of between 21 and 30 percent were found over the majority of the area surrounding the site (see Figure 1.2). The actual slope, shown as a profile in Figure 2.3, was found to have a gradient of 21 percent. The position of the thermometer shelter in relation to the site specific characteristics is shown in Figure 2.10.

Figures 2.11 and 2.12 show the diversity of the topography surrounding Site Three. Located near the base of a southeast facing slope which forms part of a three-sided sloping valley, Site Three has the lowest elevation of the five study sites. Because of the altitude and location in relation to adjacent slopes, it was suspected that Site Three would be more susceptable to cold air drainage than the other four sites.[2] The southeast aspect of Site Three was expected to have a positive influence on the temperature regime because a southern exposure is the most favorable for receiving direct solar radiation. The receipt of direct solar radiation at Site Three is, however, partially blocked during the low sun period of the year by an adjacent ridge to the southeast.

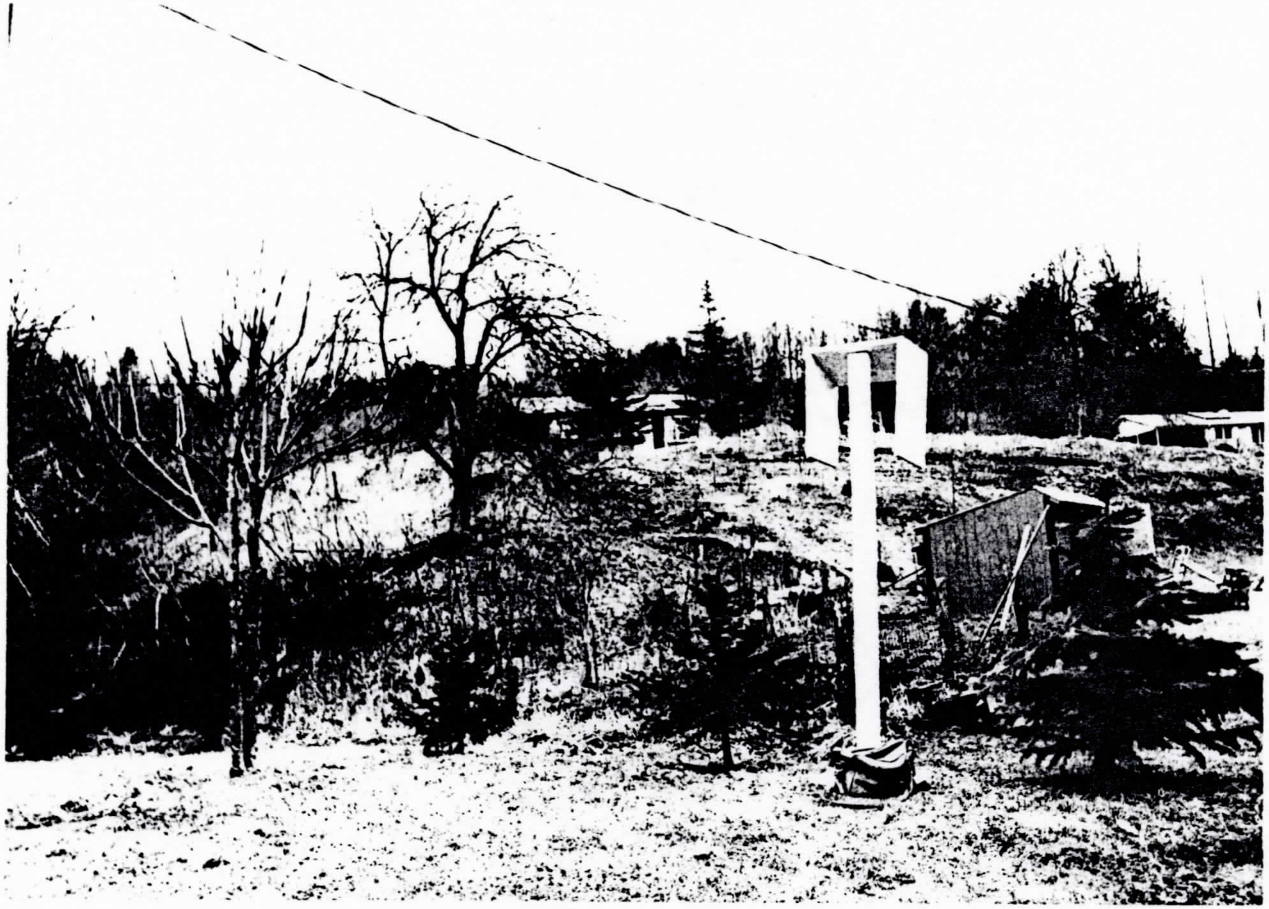

Figure 2.10. Photograph of Site Three
Source: Photography by Author.

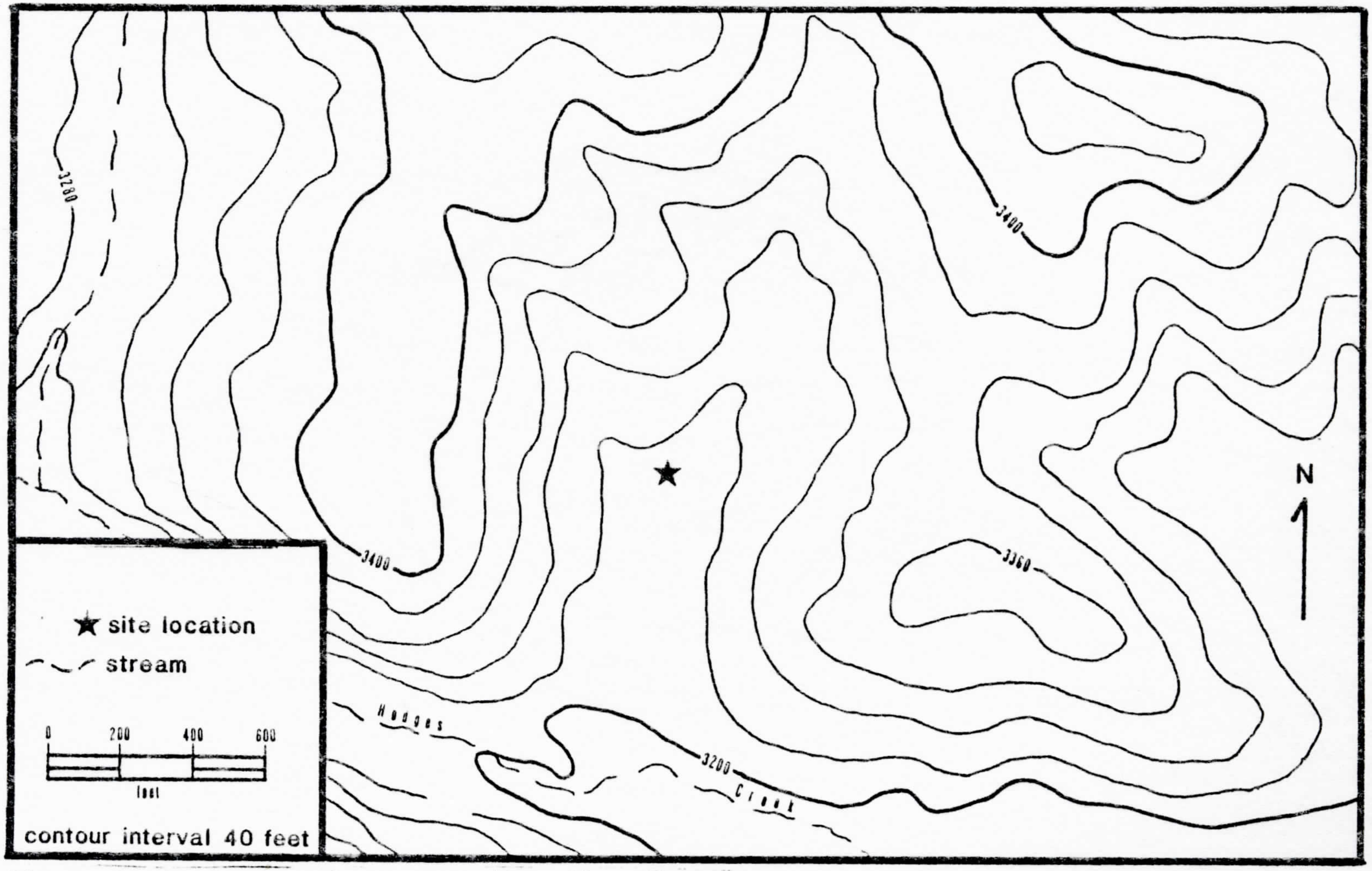

Figure 2.11. Topography Surrounding Site Three
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

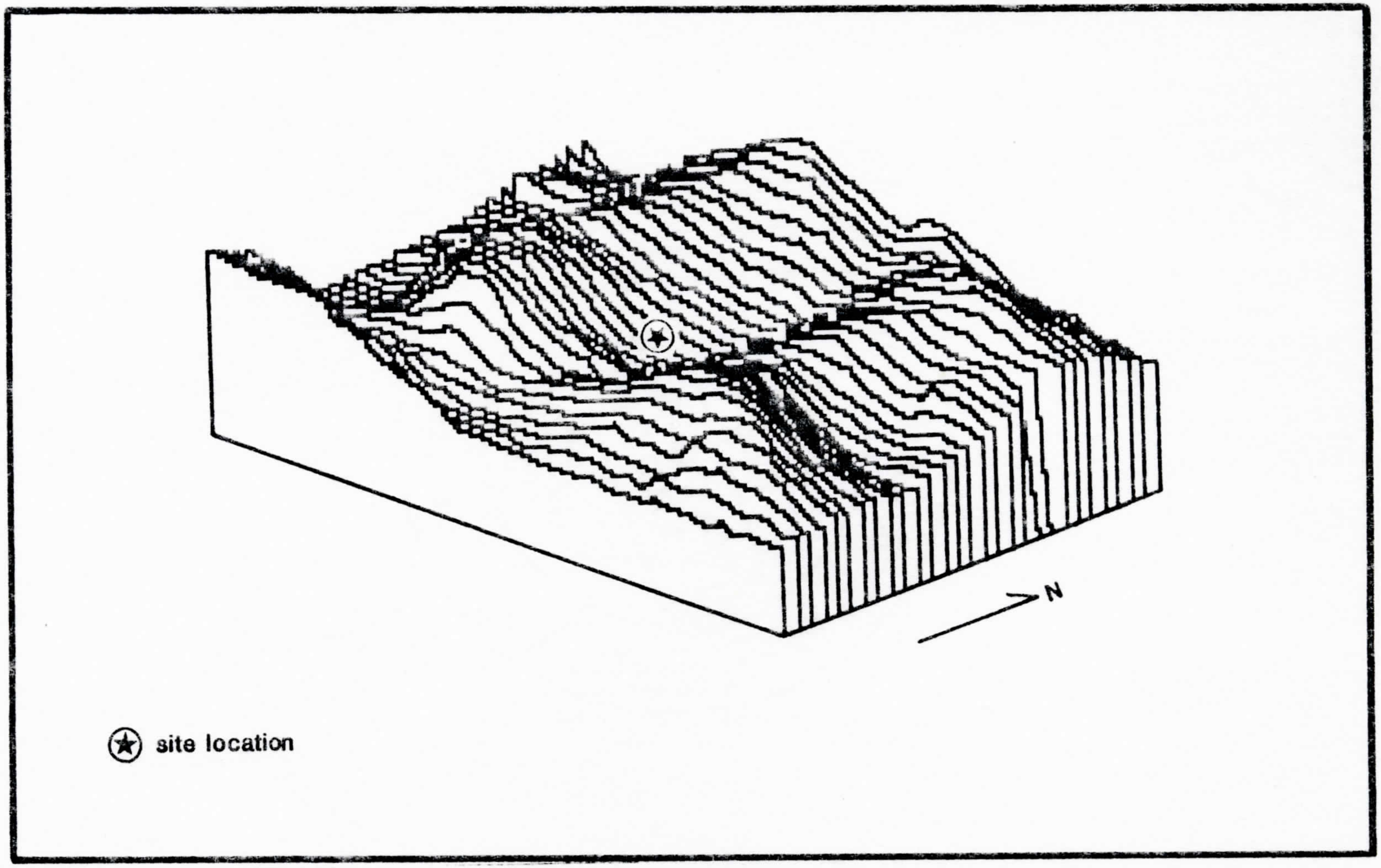

Figure 2.12. Digital Terrain Matrix of Site Three

Source: U.S.G.S. Topographic Map, Boone, N.C., 1978, Terrain Matrix by Author.

Site Four

Site Four is located along Farthing Street at an altitude of 3240 feet (see Figure 1.4). Chosen to represent a south aspect, the aspect of this site is 210 degrees or approximately south-southwest. Surrounding slopes have average gradients of between 11 and 20 percent (see Figure 1.2). The actual slope, shown as a profile in Figure 2.3, was found to have a gradient of 12 percent. Chosen to represent a south aspect, the measured aspect of this slope was 210 degrees or south-southwest. Specific characteristics of the area adjacent to the thermometer shelter are shown in Figure 2.13.

The nature of the topography surrounding Site Four can be seen in Figures 2.14 and 2.15. Site Four is located about midway up a shallow, south-southwest facing slope. The grade of this slope is the least among the five sites. With its south-southwest aspect, Site Four is in a favorable location for the receipt of direct solar radiation. Unlike Site Three, there are no adjacent hills to block the receipt of direct solar radiation during the low sun period of the year. It was expected that the south-southwest aspect and lack of obstacles would have a strong influence on the temperature regime at this site.

Figure 2.13. Photograph of Site Four
Source: Photography by Author.

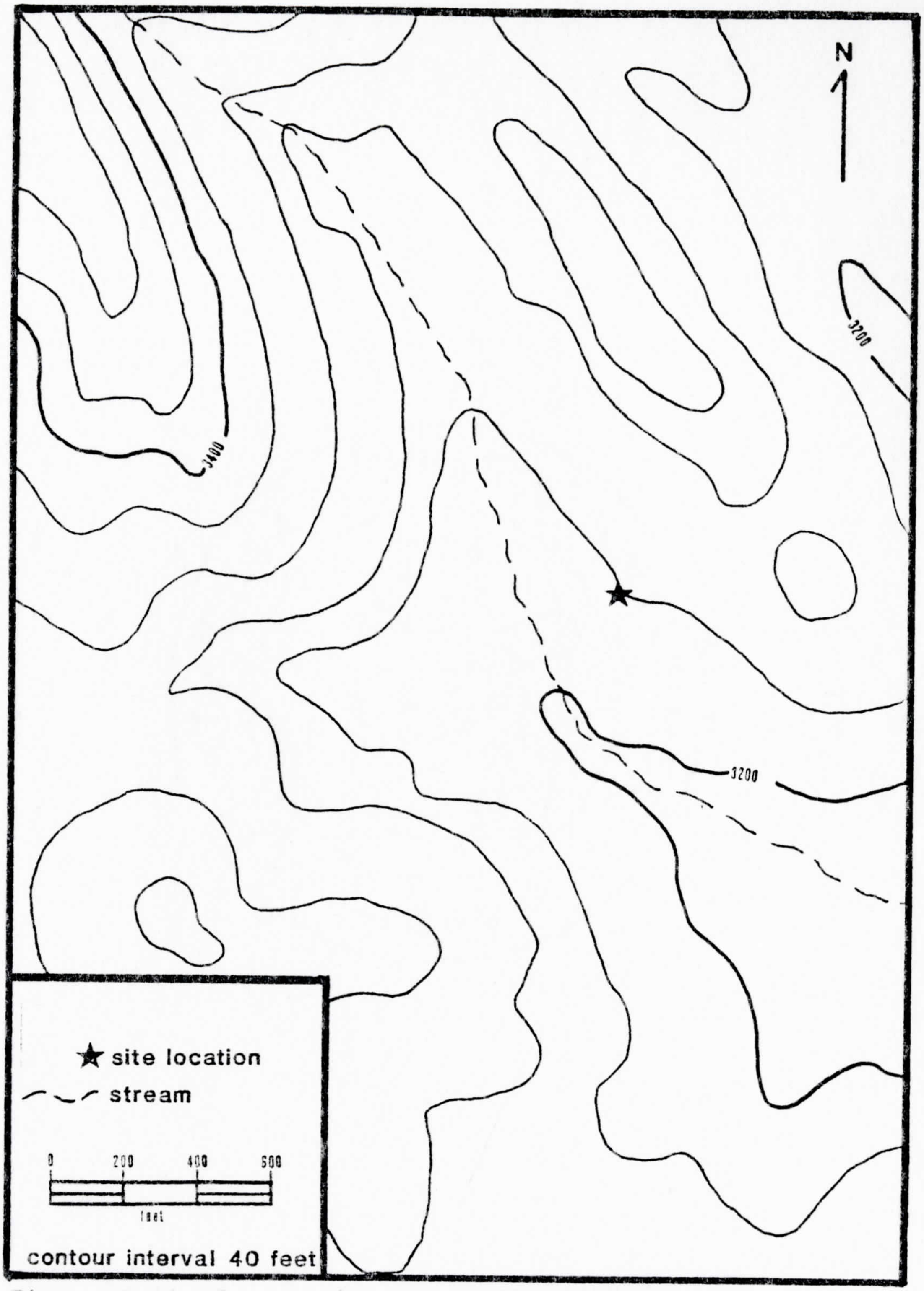

Figure 2.14. Topography Surrounding Site Four
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

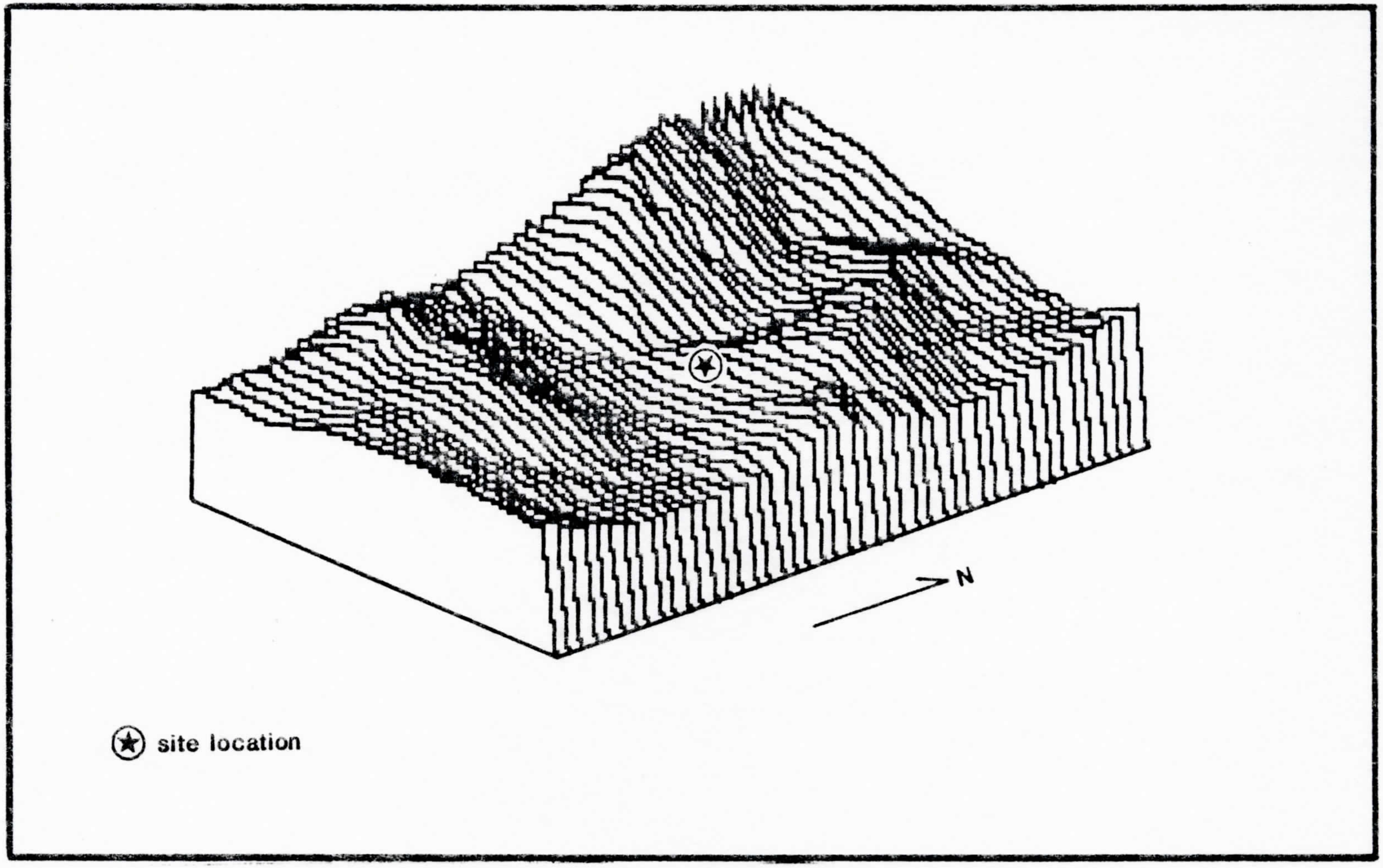

Figure 2.15. Digital Terrain Matrix of Site Four
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978, Terrain Matrix by Author.

Site Five

Site Five is located along Woodland Drive at an altitude of 3260 feet (see Figure 1.4). Chosen to represent a west aspect, the aspect of this site is 270 degrees or west. The slope where the thermometer was situated, and adjacent slopes to the north and east, have gradients of between 11 and 20 percent (see Figure 1.2). West and southwest of Site Five, on land adjacent to Boone Creek, the slopes have gradients of between 0 and 10 percent. The actual slope, shown as a profile in Figure 2.3, was found to be 20 percent. The position of the thermometer shelter at Site Five, in relation to the specific characteristics of the adjacent area, is shown in Figure 2.16.

Figures 2.17 and 2.18 show the nature of the topography surrounding Site Five. Of the five areas mapped, this area exhibited the smallest range of altitude (160 feet). The relatively gentle nature of this topography shows up quite clearly in Figure 2.18. The lack of adjacent hills or ridges to block the receipt of direct solar radiation was expected to be a primary factor in the temperature regime of this site. Although a west aspect is not optimum for maximizing the receipt of

Figure 2.16. Photograph of Site Five
Source: Photography by Author.

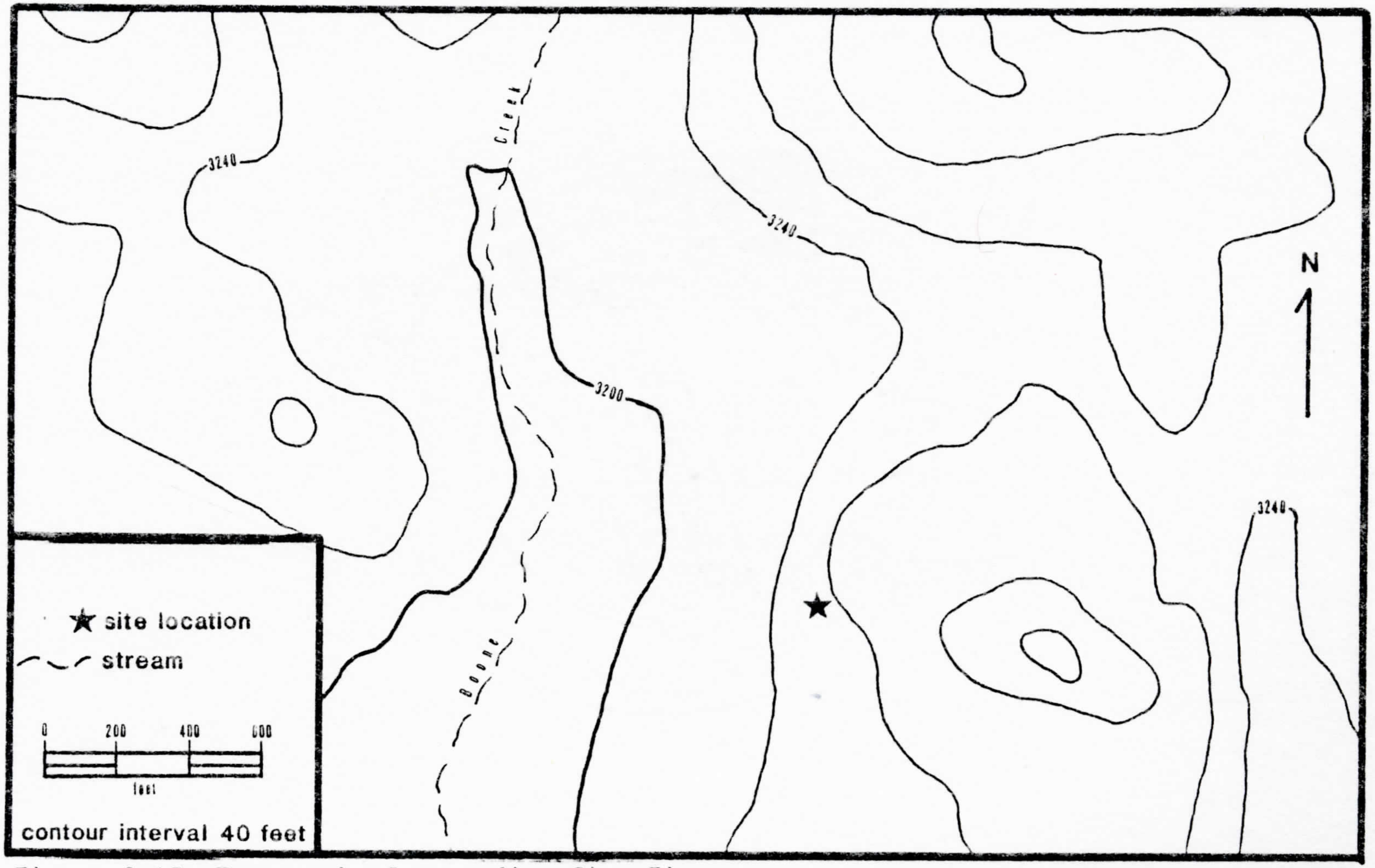

Figure 2.17. Topography Surrounding Site Five
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978.

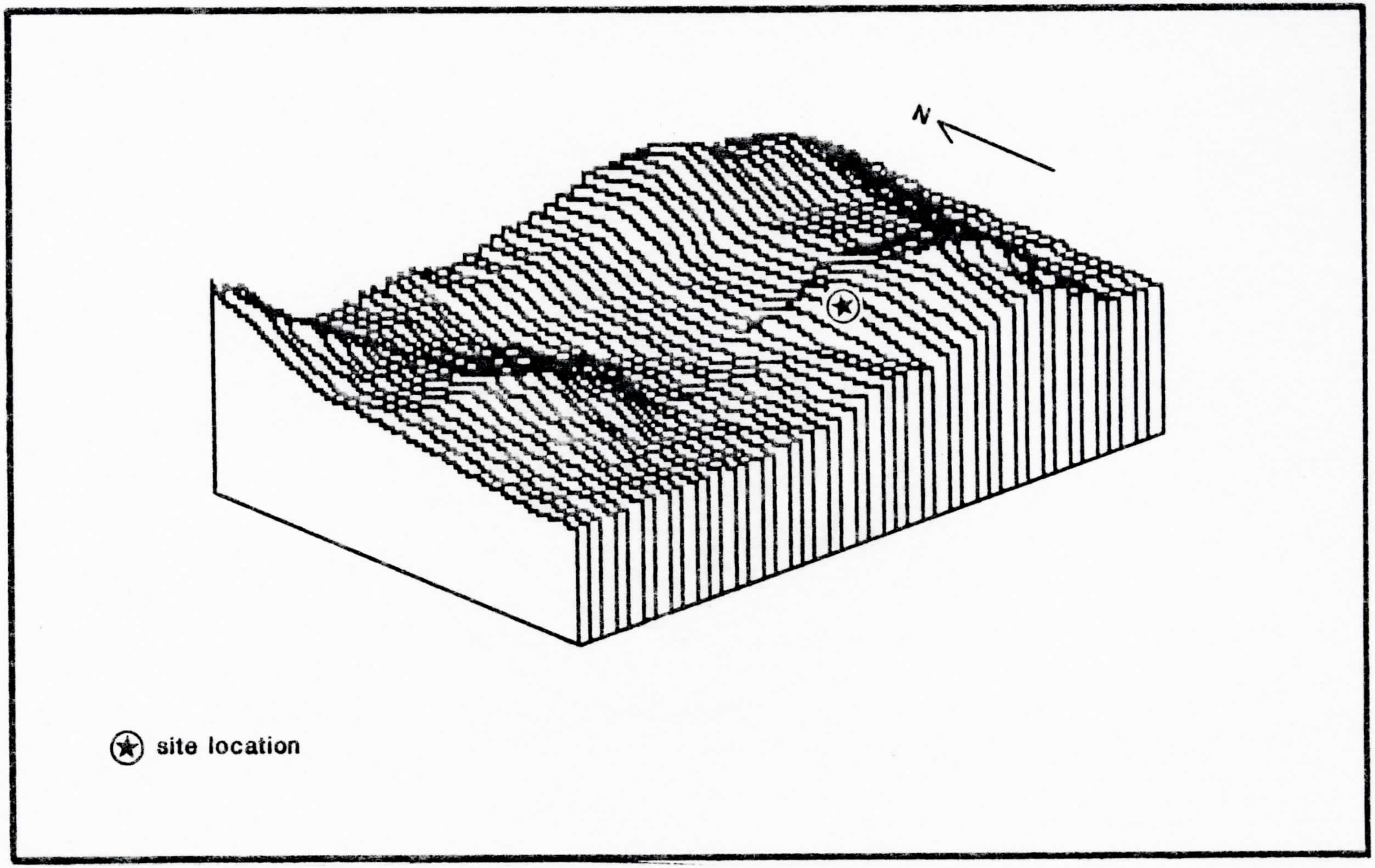

Figure 2.18. Digital Terrain Matrix of Site Five
Source: U.S.G.S. Topographic Map, Boone, N.C., 1978, Terrain Matrix by Author.

direct solar radiation, exposure to the late afternoon sun was expected to have a positive influence on average temperatures at this site.

Summary

In summary, the nature of the terrain within the study area is best described as complex. The sites chosen for use in this study represent only a small proportion of the possible combinations of physical elements which exist within this area. The influence of variations in slope, altitude, and aspect on recorded temperatures and heating degree days among the five study sites over the eighty day observation period is examined in the subsequent section, Chapter III.

NOTES

[1]The three-dimensional views of each site, also known as Digital Terrain Matrices, were generated with the aid of a microcomputer. A brief explanation of how these views were produced is given in Appendix II.

[2]Cold air drainage is a phenomenon that occurs on calm, clear nights when cold air from higher elevations flows downslope and settles in a valley bottom to create a localized temperature inversion. This produces colder air on the valley floor overlain by warmer air.

CHAPTER III

DATA ANALYSIS, HYPOTHESIS TEST, PRACTICAL APPLICATION

Data Analysis

Introduction

The focus of this study is on the variation of heating degree days among sites which was derived from an analysis of the distribution of mean minimum, maximum, and average temperatures among study sites. A complete list of the collected and computed data for the eighty day observation period is given in Appendix III.

Comparison of Mean Values

The mean minimum, maximum, and average temperatures and the mean number of heating degree days for each site based on the observation period are given in Table 3.1. The distribution of mean minimum temperatures among sites is shown in Figure 3.1. Sites One and Two had the lowest mean minimum temperatures of the group. Taking into account the dominant north aspect and slightly higher altitudes of these two sites (compared to the other three), this was an expected result.

Table 3.1.

MEAN VALUES FROM THE OBSERVATION PERIOD

Site	Mean Minimum Temps.	Mean Maximum Temps.	Mean Average Temps.	Mean Heating Degree Days
One	29.2	49.5	39.4	25.6
Two	29.2	49.2	39.2	25.8
Three	30.1	52.8	41.4	23.6
Four	31.1	53.8	42.4	22.6
Five	31.7	51.9	41.8	23.2

Source: Computed by Author.

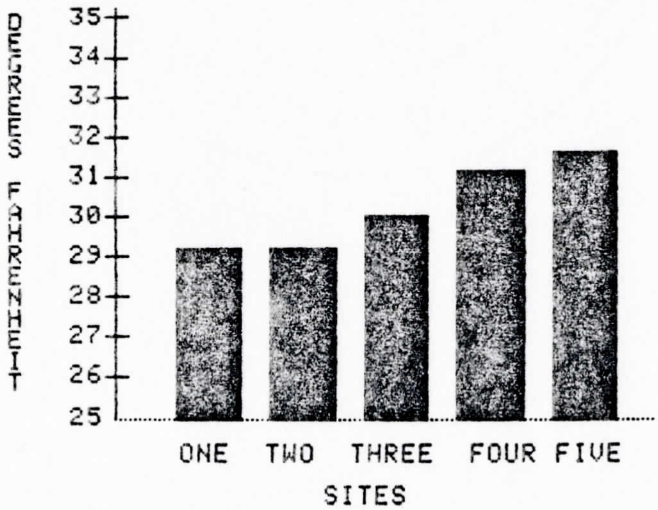

Figure 3.1. Mean Minimum Temperatures
Source: Collected by Author, Feb. 21 to May 11, 1983.

As can be seen in Figure 3.2, the distribution of mean maximum temperatures is closely related to aspect. Sites One and Two, which had nearly identical north-northeast aspects, exhibited the lowest maximum temperatures. Although the receipt of direct solar radiation was slightly greater at Site Two than at Site One due to the smaller slope gradient, the influence of altitude resulted in lower maximum temperatures at Site Two. The south-southwest aspect of Site Four was the most favorable for the receipt of direct solar radiation with this site sustaining the highest maximum temperatures throughout the observation period. Site

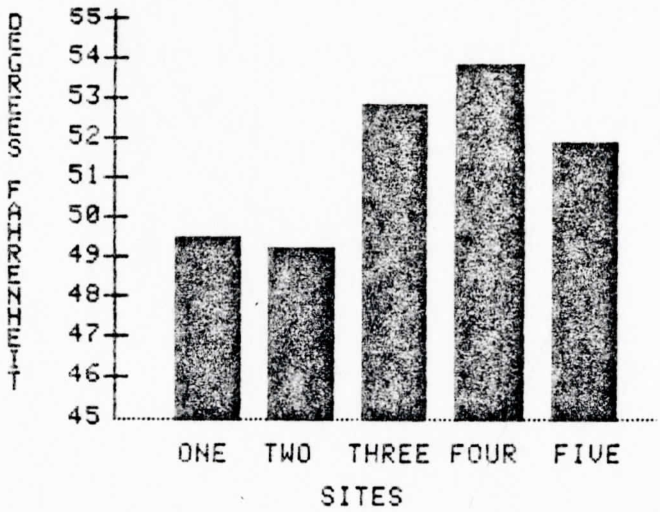

Figure 3.2. Mean Maximum Temperatures
Source: Collected by Author, Feb. 21 to May 11, 1983.

Three, with a southeast aspect, had the second highest mean maximum temperatures and Site Five, with a west aspect, had the third highest.

The distribution of average temperatures and heating degree days was greatly influenced by maximum temperatures. Mean average temperatures and mean number of heating degree days are shown in Figures 3.3 and 3.4. When analyzing heating degree days low values are indicative of relative warmth, high values are indicative of relative cold. Therefore, there is an inverse relationship between average temperatures and heating degree days. With the exception of Sites Three and Five, the general trend of mean average temperatures is similar and can be seen by comparing Figures 3.2 and 3.3. The strong influence of maximum temperatures on average temperatures can be attributed to the range. The range of mean maximum temperatures among sites was 4.5 degrees Fahrenheit while the range for mean minimum temperatures was only 2.5 degrees Fahrenheit. This greater range in maximum temperatures was expected and can be attributed to the varying amounts of direct solar radiation received at each site, a function of the aspect. The suspected

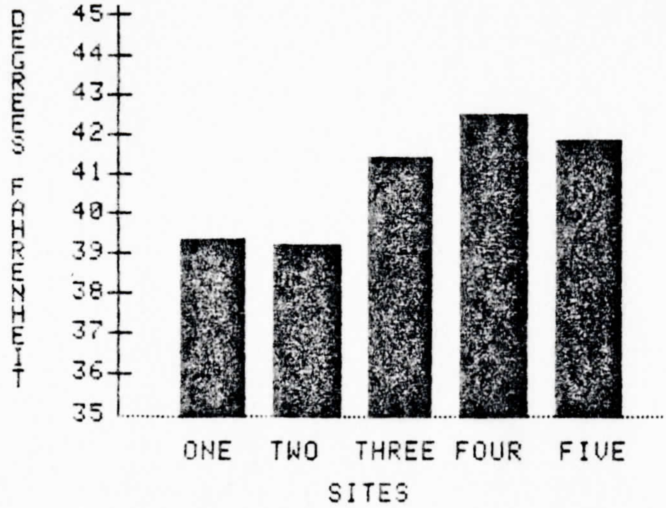

Figure 3.3. Mean Average Temperatures
Source: Collected by Author, Feb. 21 to May 11, 1983.

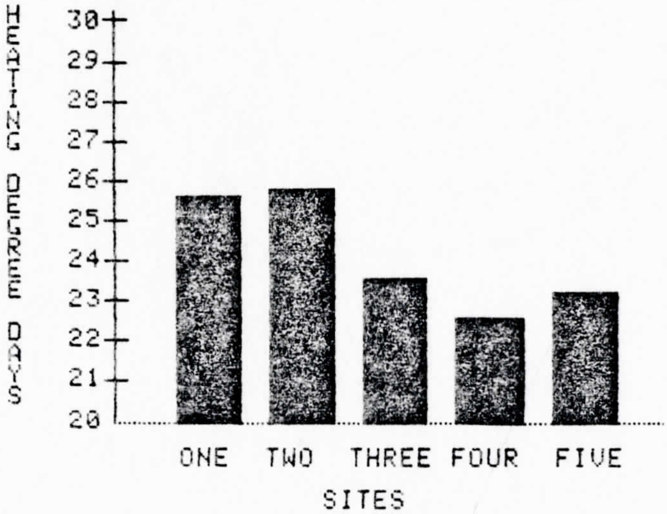

Figure 3.4. Mean Heating Degree Days
Source: Collected by Author, Feb. 21 to May 11, 1983.

influence of cold air drainage on minimum temperatures at Site Three was enough for this site to be slightly colder, on the average, than Site Five.

Comparison of 1983 with a Fifteen Year Average

Figure 3.5 compares the average heating degree days for the five sites with a fifteen year average for Boone, North Carolina, for the same time period (February 21 to May 11).[1] Both graphs show that the overall decline in the number of heating degree days during the observation period does not occur at a constant rate. As would be expected, the values obtained from one year are considerably more extreme than the values obtained from a fifteen year average. However, the general pattern of cold and warm trends is evident in both sets of data. The general conclusion drawn from this graph is that the distribution of heating degree days observed during this time period in 1983 is similar to what would be observed during any given year with respect to heating and cooling trends.

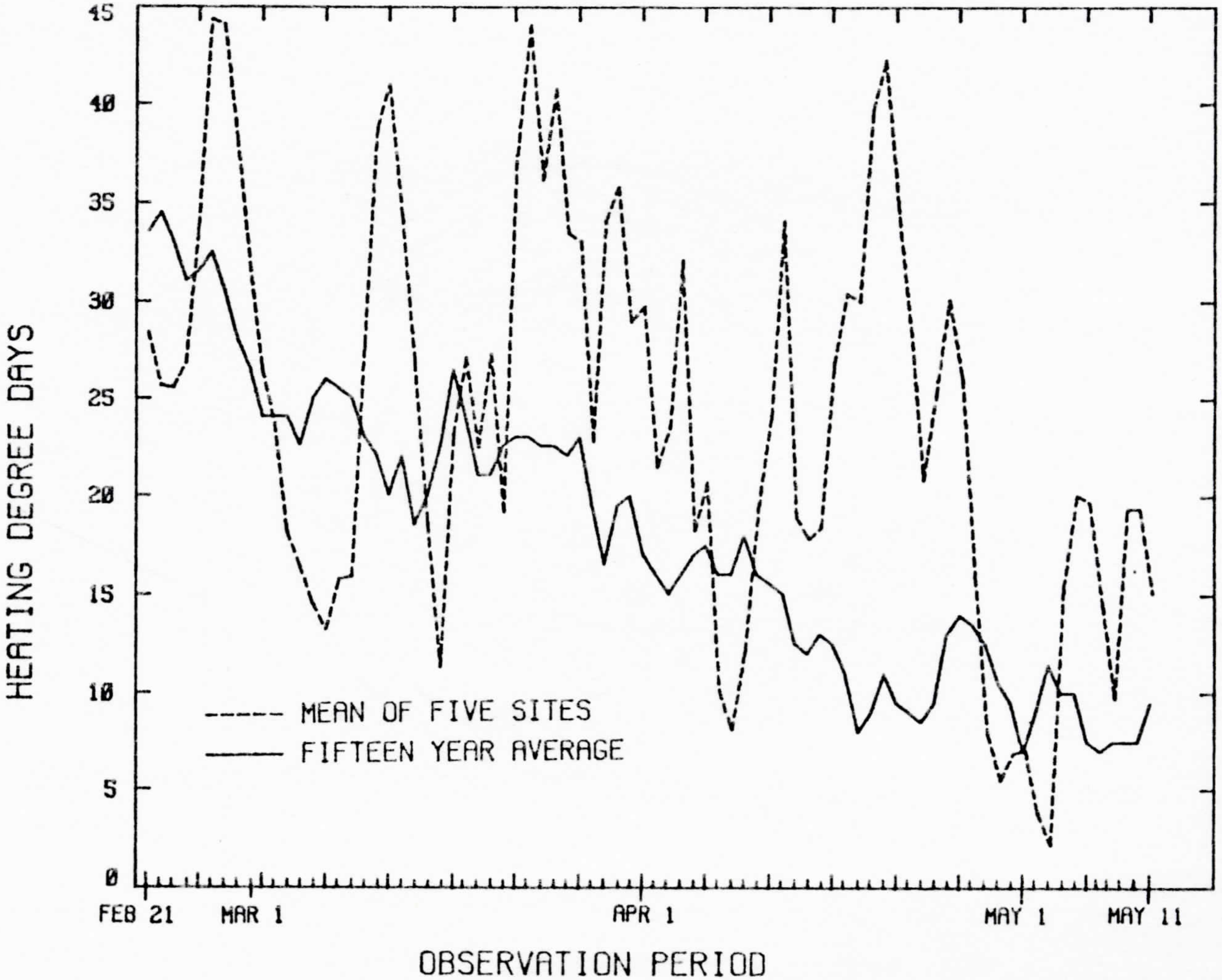

Figure 3.5. Heating Degree Day Comparison: Fifteen Year Average and Five Site Average

Source: United States Department of Commerce Annual Summary of Climatological Data for North Carolina, 1965-1979 and Collected by Author, Feb 21 to May 11, 1985.

Heating Degree Day Comparison

Several graphs were produced to aid in the comparison of heating degree day differences between sites. The first graph used is a box plot in which a number of observations taken from the data are plotted to form a "box" for each group. Comparing these boxes gives an indication of the amount of variation among study sites. The following heating degree day information from the eighty day observation period was plotted for each site: (1) the low value, (2) the high value, (3) the median value, (4) the mean value, (5) the first quarter value, and (6) the third quarter value.[2] The results can be seen in Figure 3.6.

Although slight differences do occur, an analysis of Figure 3.6 shows that the overall pattern of the data is quite uniform. It also indicates that the variation in heating degree days among sites was small. The greatest discrepancy within the group occurred between Sites Two and Four; the least between Sites Three and Five.

Computed heating degree days for Sites One through Five were plotted with the mean number of daily heating degree days from all five sites in Figures 3.7 to 3.11.

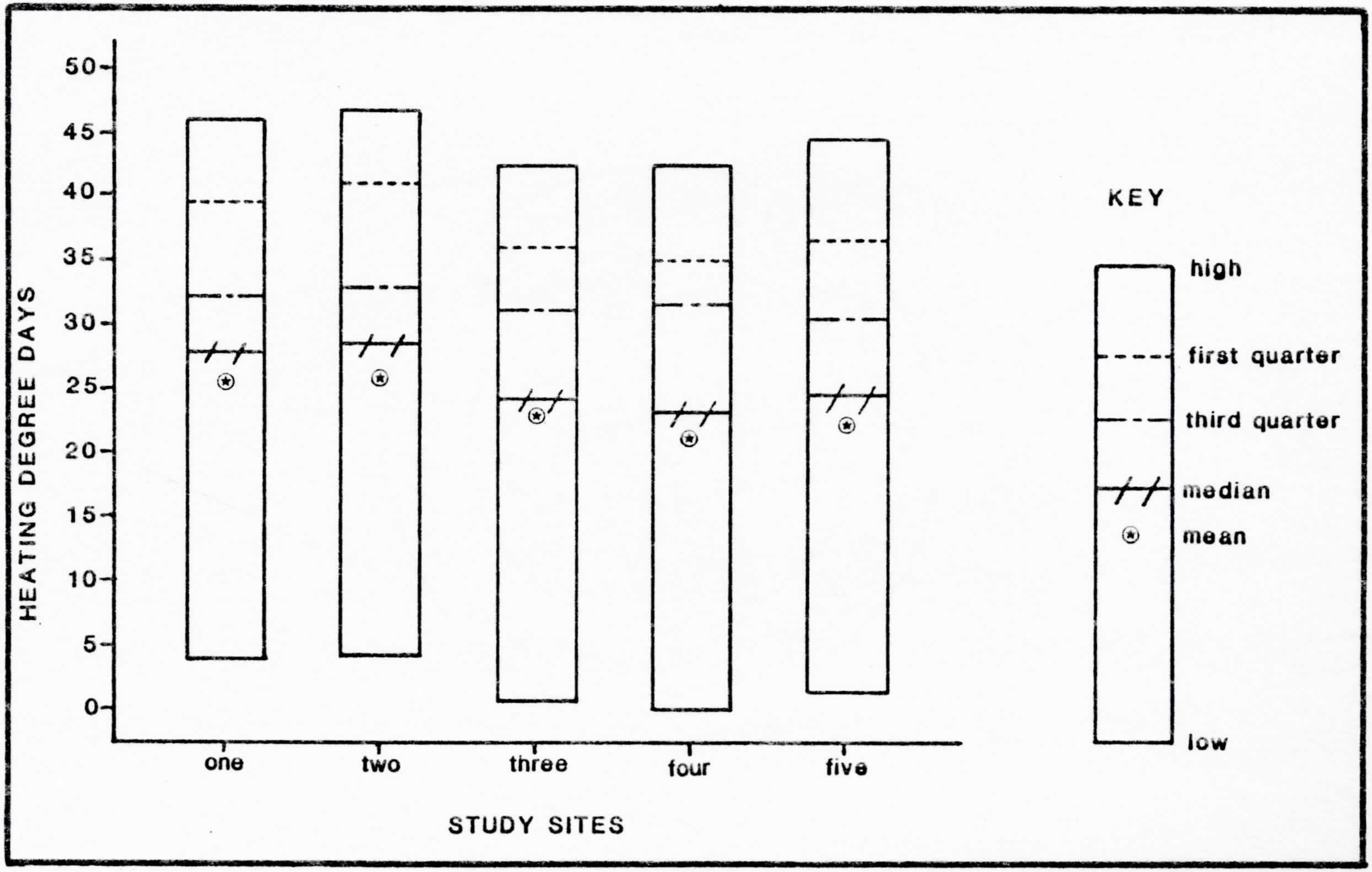

Figure 3.6. Box Plot Comparison of the Study Sites: Heating Degree Days
Source: Collected by Author, Feb. 21 to May 11, 1983.

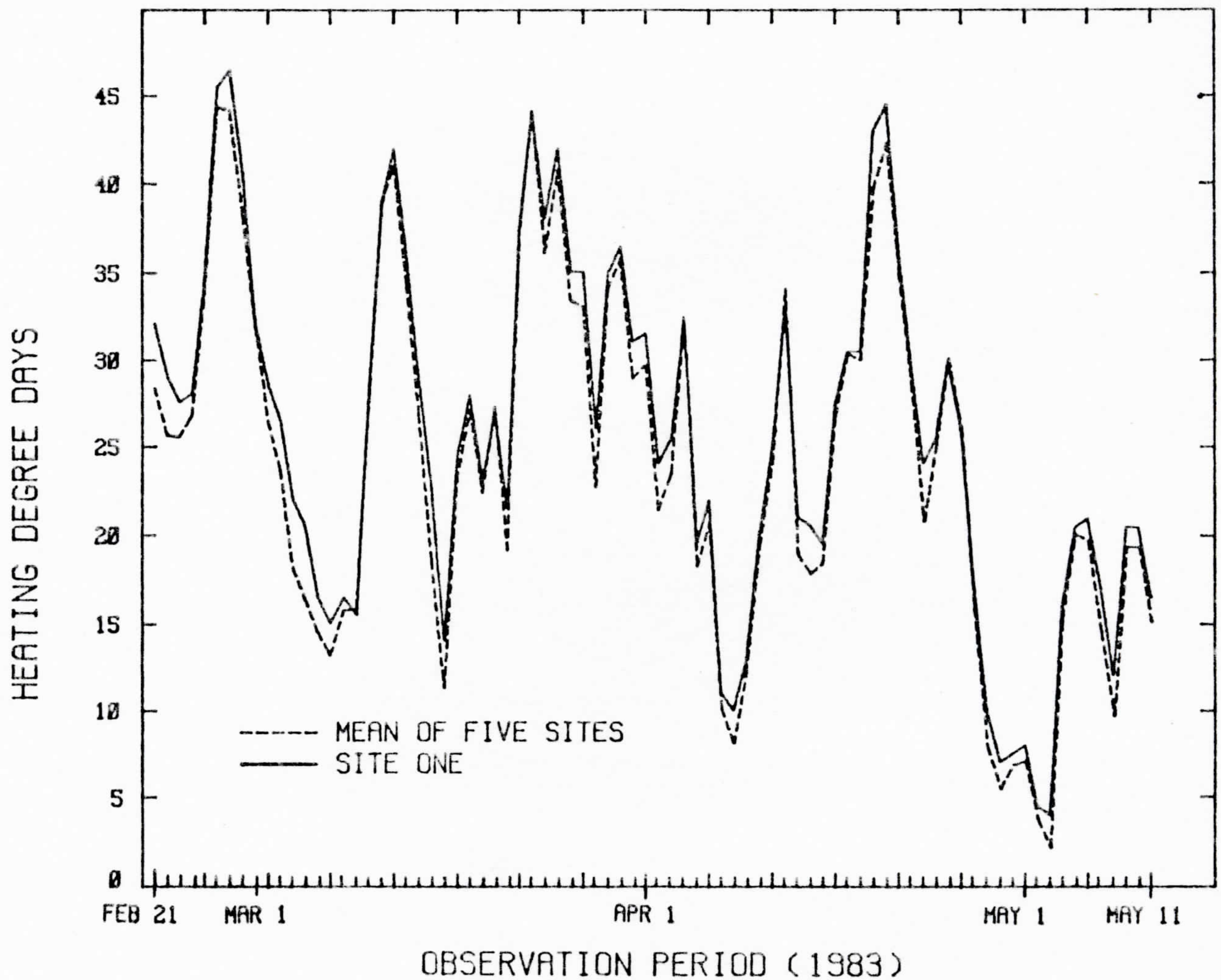

Figure 3.7. Heating Degree Day Comparison: Site One and Five Site Mean
Source: Collected by Author, Feb. 21 to May 11, 1983.

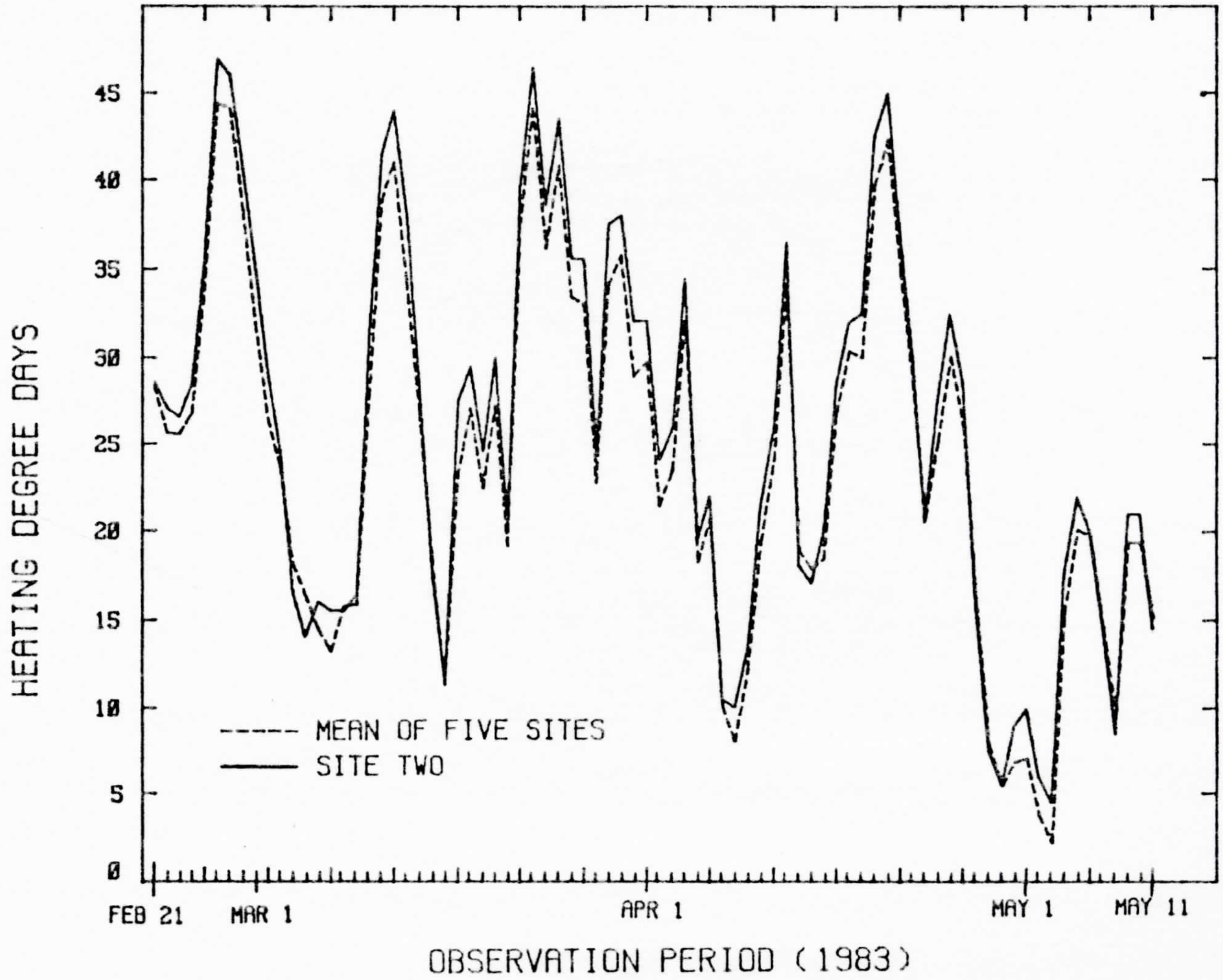

Figure 3.8. Heating Degree Day Comparison: Site Two and Five Site Mean
Source: Collected by Author, Feb. 21 to May 11, 1983.

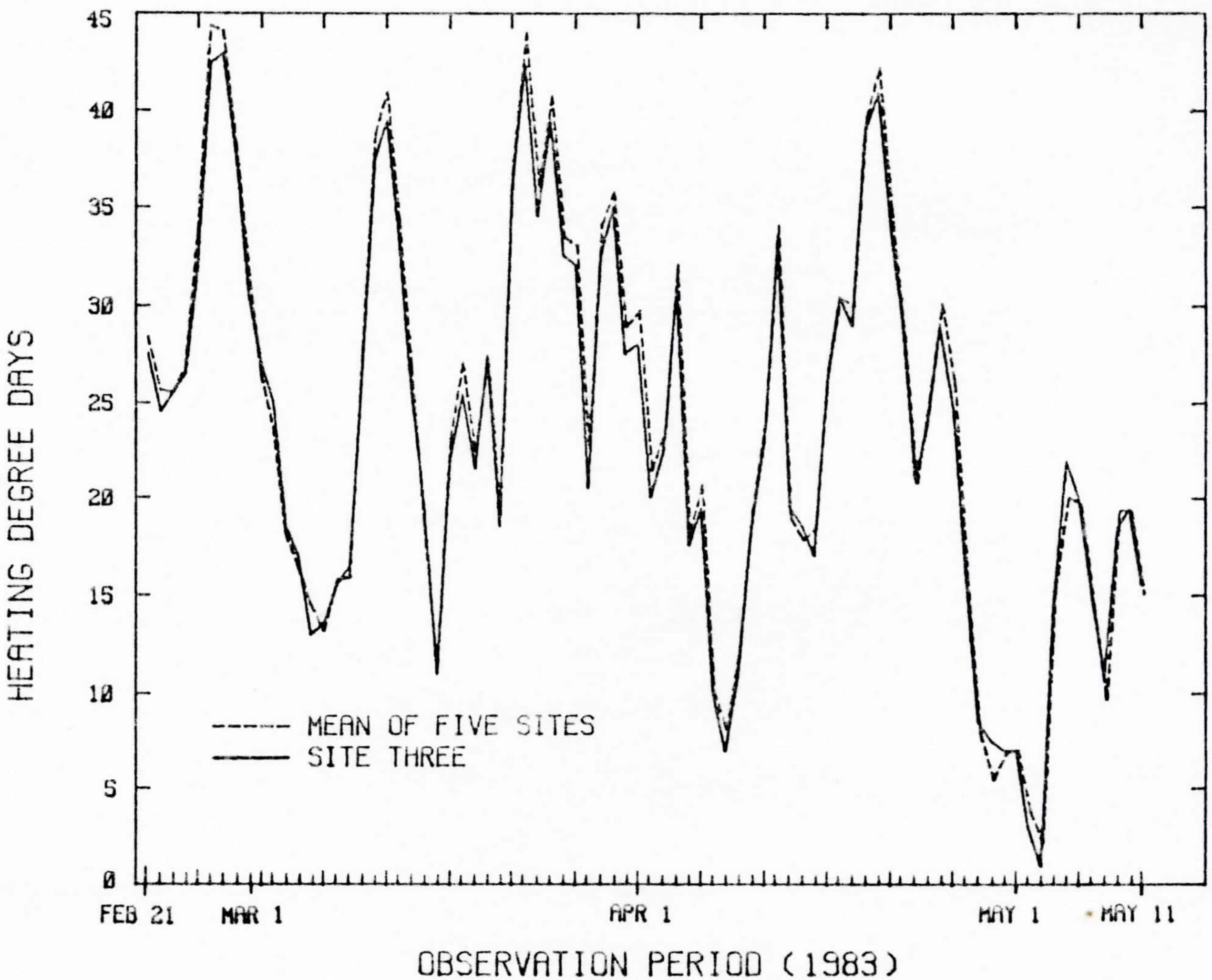

Figure 3.9. Heating Degree Day Comparison: Site Three and Five Site Mean
Source: Collected by Author, Feb. 21 to May 11, 1983.

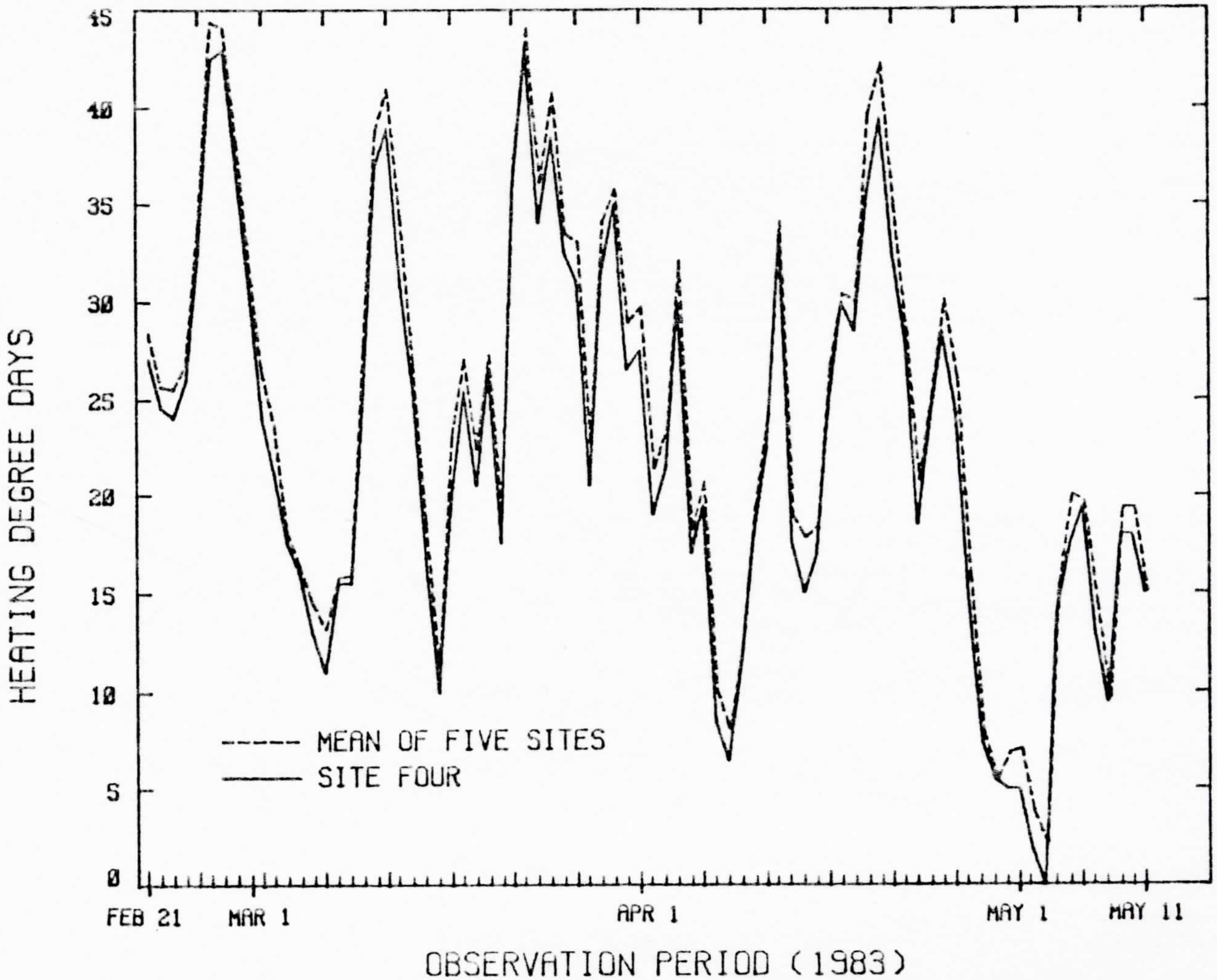

Figure 3.10. Heating Degree Day Comparison: Site Four and Five Site Mean
Source: Collected by Author, Feb. 21 to May 11, 1983.

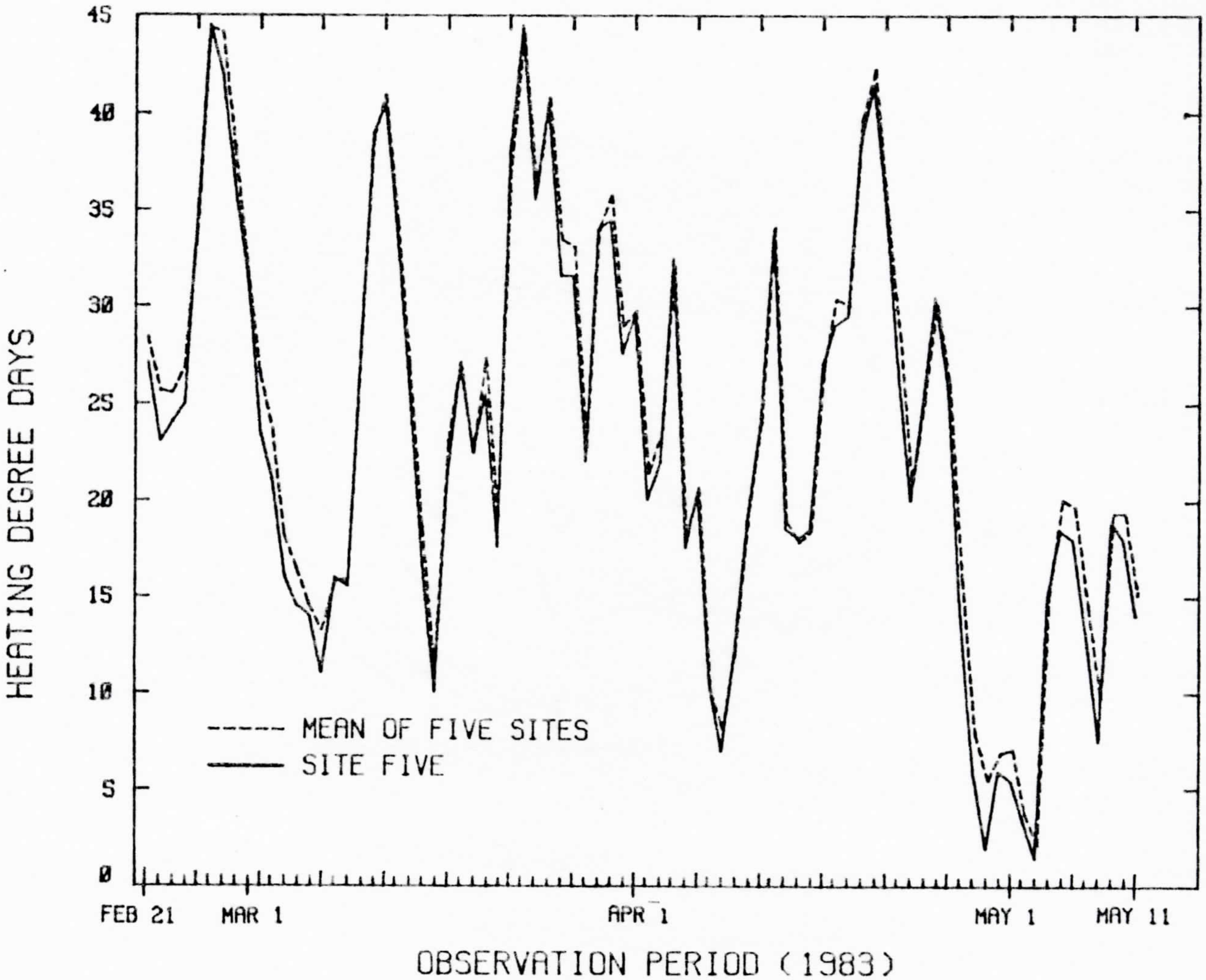

Figure 3.11. Heating Degree Day Comparison: Site Five and Five Site Mean
Source: Collected by Author, Feb. 21 to May 11, 1983.

An examination of these five Figures indicates that general warming and cooling trends were similar at each site. The intensity of heating degree day differences among sites was examined by comparing each site with the five site mean.

Sites One and Two were the coldest sites and their heating degree day profiles, as seen in Figures 3.7 and 3.8, were consistently higher than the five site mean. Site Two had a slightly higher percentage of days with visible deviations from the mean. The site which most closely approximated the mean was Site Three. This can be noted from the repeated convergence of the two graphs in Figure 3.9. As can be seen in Figure 3.11, the heating degree day graph of Site Five was also very close to the mean. A higher percentage of days with a negative departure from the mean indicates that Site Five was slightly warmer than Site Three. Site Four, which was the warmest of the study sites, maintained a consistently lower number of heating degree days than the five site mean. This can be seen by comparing the profiles in Figure 3.10.

Heating degree day profiles for Sites Two and Four, which represent the cold and warm extremes of the group, are shown in Figure 3.12. The maximum daily variation

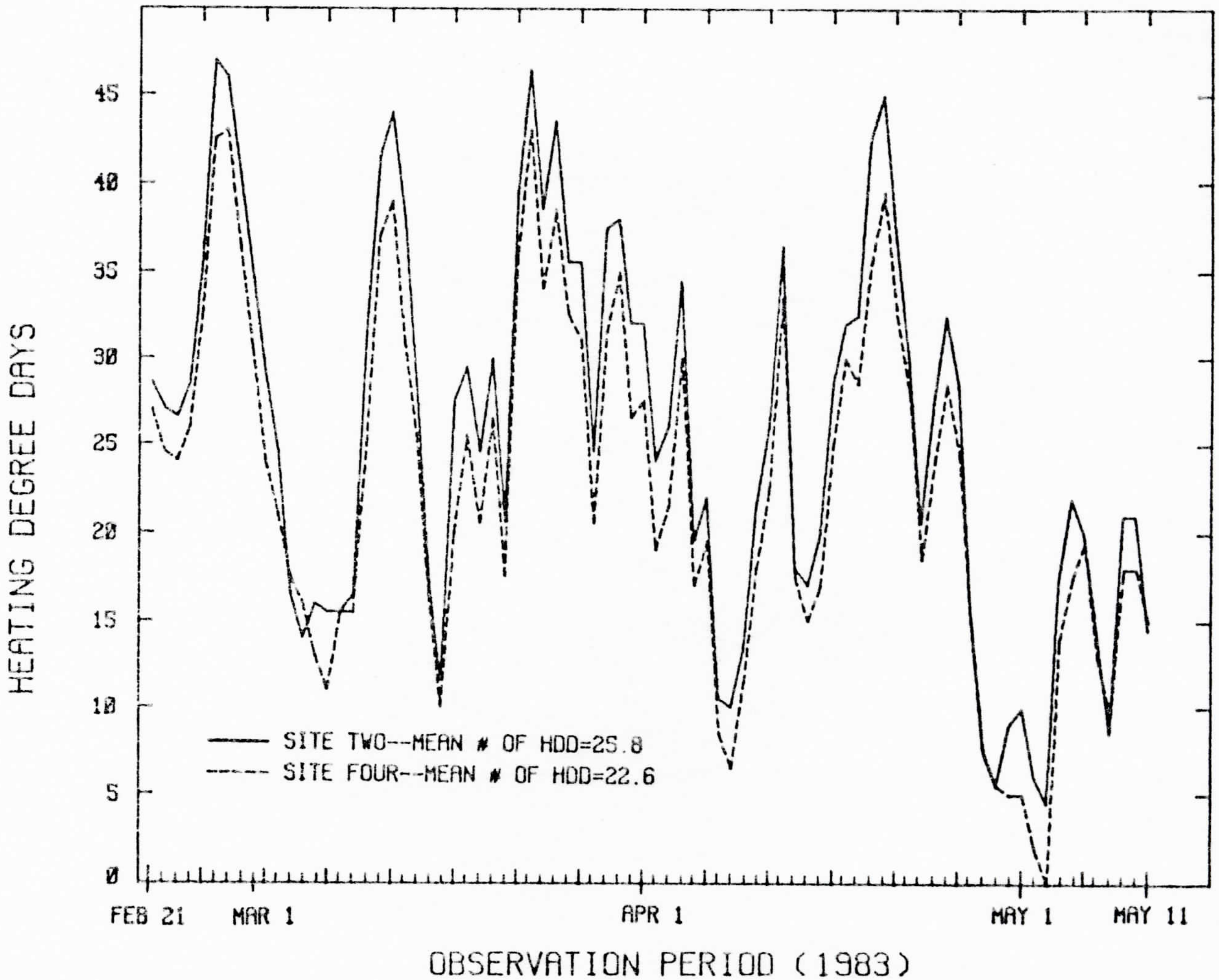

Figure 3.12. Heating Degree Day Comparison: Group Extremes
Source: Collected by Author, Feb. 21 to May 11, 1983.

in heating degree days between these sites was seven, the minimum was zero, and the average difference was slightly more than three. Although they rarely cross or converge, the two graphs are nearly identical in appearance.

Sites One and Two sustained a consistently higher number of heating degree days than the other sites due to the combination of northern exposure and altitude. Sites Three, Four, and Five had a consistently lower number of heating degree days. Although the aspect at Site Three is southeast, its average temperatures were moderated by the influence of cold air drainage and a hill which partially blocked the direct receipt of solar radiation during the observation period. The low number of recorded heating degree days at Site Four can be attributed to the positive effects of its southern exposure. The higher than expected temperatures at Site Five can be attributed to its direct receipt of solar radiation in the late afternoon.

In summary, the graphic analyses indicate that, in the aggregate, the influence of variations in slope, altitude, and aspect on the distribution of heating degree days among sites was small. The differences which did occur are best exemplified in Figure 3.12. Definite conclusions concerning the significance of heating degree day differences between sites could not be made solely on the basis of the graphic analyses. A statistical test was employed to determine the extent of these differences.

Hypothesis Test

To determine the statistical significance of recorded heating degree day differences among sites a one-way analysis of variance test was employed.[3] In an analysis of variance "all of the data are treated at once and a general null hypothesis of no difference among the means of the various groups is tested."[4] The tested null hypothesis for this study was: There are no significant differences in heating degree days within the study area due to variations in slope, altitude and aspect. The test was conducted at the 0.05 level of significance.

An analysis of variance tests the null hypothesis by comparing the amount of variation (of the variable being tested) among groups and within groups. The test is based on the fact that if the sample groups being tested are drawn from the same normal population: "the two variances, within and [among, will be] unbiased estimates of the same population variance. We can test for the significance of the difference of the two types by use of the F-test."[5]

The assumption that the groups are drawn from normal populations having the same variance is critical.[6] Bartlett's test for homogeneity of subgroup variance was utilized to test this assumption. The null hypothesis for Bartlett's test, there are no significant differences in variance among groups (Sites One through Five), was not rejected at the 95 percent confidence interval. In order to reject the null hypothesis of Barlett's test at this confidence interval the computed significance (P-value) needed to be between 0.0 and 0.05. The actual P-value was found to be 0.89 and this strongly supports the fact that the groups were drawn from populations having the same variance and, therefore, strongly supports the validity of the analysis of variance test.

Table 3.2 is a list of the computed values used in the F-test. The table can be analyzed as follows: (1) source: is the source of the variation, divided into among groups variance and within groups variance, (2) degrees of freedom, (3) sum of squares: is the sum of the squared deviations from the mean, (4) mean squares: is the sum of squares divided by the degrees of freedom, and

(5) F-ratio: is the observed F-statistic, obtained by dividing the mean squares among groups by the mean squares within groups.

Table 3.2

COMPUTED VALUES USED IN THE F-TEST

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-ratio
among groups	4	675.4285	168.8571	
within groups	395	42604.6523	107.8599	
total	399	43280.0780		1.566

Source: ONEWAY Subprogram of the Statistical Package for Social Sciences

The F-test is essentially a comparison of the computed F-ratio with a critical F-ratio (hereafter called critical-F) obtained from a Table of the F Statistic.[7] If the computed F-ratio is greater than the critical-F it can be assumed that the differences among groups are significant at the prescribed confidence interval and, therefore, that the null hypothesis be rejected in favor of the alternate, or research hypothesis. For degrees of freedom 4/395 the critical-F obtained from a Table of the F Statistic at the 0.05 level of significance was 2.39.[8] Since the computed F-ratio for the heating degree day variable was only 1.56, the null hypothesis could not be rejected in favor of the research hypothesis on the basis of this test. The computed F-ratio, critical-F, acceptance and rejection regions are depicted graphically in Figure 3.13.

Another method of analyzing the computed F-ratio is by the F-probability. The F-probability is a measure of the significance of the computed F-ratio. At the 0.05 level of significance the F-probability would have to be less than 0.05 in order to reject the null hypothesis. The smaller the F-probability, the greater the evidence in support of rejecting the null hypothesis. The computed F-probability for the heating degree day variable was 0.1827. Assuming the null hypothesis was true, an F-ratio of 1.56 or larger would have been observed 18.27 percent of the time. This was too high a percentage to conclude that the null hypothesis was not true. Therefore, the evidence was not strong for rejecting the null hypothesis.

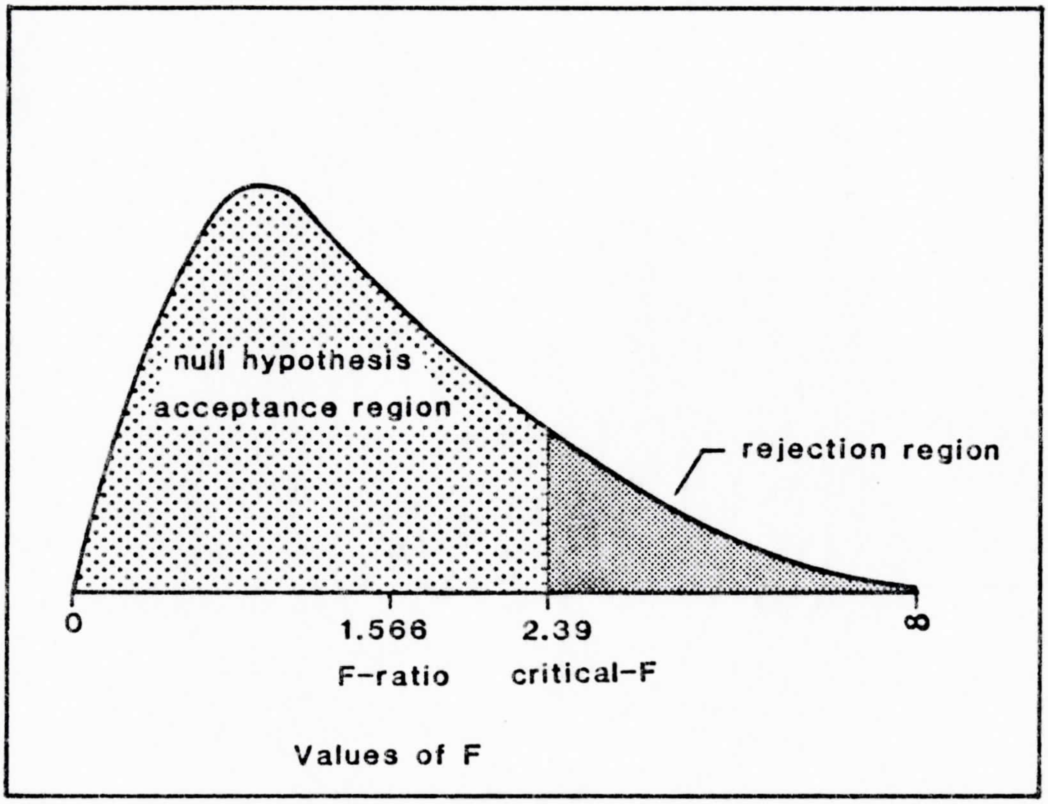

Figure 3.13. Graphic Illustration of the F Test
Source: By Author.

As noted in Chapter I, additional tests to determine the strength of differences between sites are only valid if the null hypothesis is rejected in favor of the research hypothesis. If this had been the case the Scheffe Procedure, a form of least significant difference test, would have been utilized. Since the null hypothesis was not rejected on the basis of the one-way analysis of variance test, no further statistical tests were used.

In summary, the research hypothesis of this thesis could not be supported on the basis of statistical testing. Conclusions of this study, based upon the graphic and statistical analyses of the data, are presented in Chapter IV. An economic method of analyzing the heating degree day variable was also utilized. Results of this financial method, which had no bearing on the final conclusions drawn, are presented in the next section.

Practical Application

The cost of heating a home is a critical consideration for many people. An understanding of local topographic and climatic elements can be important when deciding on a home location because these elements are directly related to energy consumption. The influence of the variation in topographic features on the distribution of heating degree days among the study sites was looked at from the perspective of the potential cost of heating a home at each site.

As discussed in Chapter I, the formula used to determine these costs was modified from one used by the Blue Ridge Electric Membership Corporation (BREMCO) as part of their Home Weatherization Audit Checklist. BREMCO uses the R-values (insulation ratings) and dimensions of the homes being audited and a standard heating degree day figure for Boone (5,400 a year) to determine what the average yearly energy costs should be. Since this section of the study was interested in the effects of heating degree day differences among sites, characteristics of the hypothetical homes assumed to exist at each site remained constant.[9] The total observed heating degree days from each site were used in place of the average figure, thus forming the basis of the comparison.

Dimensions and R-values for the hypothetical houses were as follows: (1) 2,000 square feet of ceiling with insulation rated at R-38 (twelve inches), (2) 2,000 square feet of floors with insulation rated at R-19 (six inches), (3) combined area of 153 square feet for the windows and doors, (4) windows rated at R-1.92

(thermal), (5) gross wall area of 1,440 square feet with insulation rated at R-19, and (6) net wall area of 1,287 square feet.

The formula used to determine the amount of energy required to heat the hypothetical houses is shown in Figure 3.14. The U-value is equal to 1/R (R=insulation rating). Degree days are the total number of observed heating degree days for each site. BTU's (British Thermal Units) per fuel unit are equal to the "amount of heat produced by burning a unit quantity of the fuel completely."[10] Home heating oil was used as the heating unit to calculate energy usage. One gallon of heating oil produces 100,000 BTU's and is equal to one heating unit. Total heating units were the total number of gallons of heating oil used during the eighty day observation period. This figure was multiplied by the current price of heating oil to determine the overall cost for heating each hypothetical house.[11]

The total number of observed heating degree days from each site and the results obtained from the formula is shown in Table 3.3. This table shows quite clearly the clustering of sites into "cold" and "warm" subgroups. Sites One and Two experienced a larger number of observed heating degree days and, subsequently, larger hypothetical energy costs than the other three sites.

CEILINGS:

$$\frac{\text{U-Value} \times \text{Sq. Feet} \times 24 \times \text{Degree Days}}{\text{BTU's Per Fuel Unit}} = \text{Heating Units}$$

FLOORS:

$$\frac{\text{U-Value} \times \text{Sq. Feet} \times 24 \times \text{Deg. Days} \times .5}{\text{BTU's Per Fuel Unit}} = \text{Heating Units}$$

WINDOWS AND DOORS:

$$\frac{\text{U-Value} \times \text{Sq. Feet} \times 24 \times \text{Degree Days}}{\text{BTU's Per Fuel Unit}} = \text{Heating Units}$$

WALLS:

$$\frac{\text{U-Value} \times \text{Net Wall* Sq. Feet} \times 24 \times \text{Degree Days}}{\text{BTU's Per Fuel Unit}} = \text{Heating Units}$$

*(Gross Wall Square Feet - Square Feet of Windows & Doors = Net Wall Square Feet)

Total Heating Units = Combined Heating Units of Ceilings, Floors, Windows and Doors, and Walls

Figure 3.14. Formula to Determine the Amount of Energy Used by the Hypothetical Houses

Source: Blue Ridge Electric Membership Corporation, 1982.

According to the formula used, a house located at Site Two would be the most expensive to heat, one located at Site Four the least expensive. The range in values between these group extremes was: (1) 256.5 for the total number of observed heating degree days, (2) \$23.40 for the total heating cost, and (3) \$0.23 for the average heating cost per day.

Table 3.3

ECONOMIC COMPARISON OF THE STUDY SITES

Site	Total Number of Observed Heating Degree Days	Total Gallons of Heating Oil Used	Total Cost	Cost Per Day
One	2049	150	\$160.50	\$2.01
Two	2062	153	\$163.71	\$2.05
Three	1886	138	\$147.66	\$1.85
Four	1806	133	\$142.31	\$1.78
Five	1849	136	\$145.52	\$1.82

Source: Computed by Author.

The difference in heating costs of twenty-three cents per day between Sites Two and Four does not appear to be significant. However, considering the average length of the heating season for the study area, the cumulative costs begin to add up.[12] On the basis of $0.23 per day, the average monthly difference in heating costs between Sites Two and Four would be approximately $7.00, the average difference for the entire heating season would be $63.00.

Because of the potential for bias on the basis of economic status, it was difficult to obtain a truly objective conclusion from these financial results. What may seem to be a small, insignificant cost to some may, for others, be perceived as being large and very significant. The results of this section, are therefore, only presented as a means of comparison. They are not used as a factor in the final conclusions of this study. These conclusions, along with a summary and suggestions for further research, are presented in Chapter IV.

NOTES

[1]The fifteen year average for Boone was computed from the United States Department of Commerce, National Oceanic and Atmospheric Administration, Annual Summary of Climatological Data for North Carolina, (Washington, D. C.: Government Printing Office, 1965 to 1969). The temperature data utilized was collected by Joe Minor, Boone's cooperative weather observer. The physical characteristics of this thermometer site are as follows: (1) altitude of 3360 feet, (2) west aspect, and (3) slope of 20 percent.

[2]The first quarter value was obtained by averaging the values for the twentieth and twenty-first observation days (March 12 and 13). The third quarter value was obtained by averaging the values for the fifty-ninth and sixtieth observation days (April 20 and 21).

[3]The test was conducted on Appalachian State University's mainframe Univac computer with the aid of the ONEWAY subprogram of the Statistical Package for Social Sciences (SPSS). The SPSS series of computer programs are commonly used in the social sciences as a means of manipulating large amounts of data.

[4]N. M. Downie and R. W. Heath, Basic Statistical Methods (New York: Harper & Row, 1970), p. 215.

[5]Ibid, p. 216.

[6]Ibid.

[7]Paul Games and George Klare, Elementary Statistics (New York: McGraw Hill, 1967), p. 495.

[8]2.39 is the critical-F for degrees of freedom 4/400. The actual critical-F value for degrees of freedom 4/395 could not be attained from a table but would only differ from 2.39 by less than one-hundredth of a percent.

[9]The R-values and dimensions of the hypothetical houses were felt to be representative of energy efficient homes in the Boone area and were chosen on the basis of information obtained from an interview with Doug Johnson, BREMCO's Energy Specialist.

[10]James A. Moyer, Oil Fuels and Burners, (New York: McGraw-Hill, Inc., 1937), p. 21.: British Thermal Units are defined as: "The quantity of heat required to raise the temperature of one avoirdupos pound of water one degree Fahrenheit at or near 39.2 degrees Fahrenheit, its temperature of maximum density."; Webster's Third New International Dictionary, (1965), s.v. "British Thermal Units."

[11]The price of heating oil used was \$1.07 per gallon. This price was quoted by Hayes Oil Company, Boone, North Carolina, on March 15, 1984.

[12]On the average, heating degree days are recorded in Boone during all months except June, July, and August. Boone's typical heating season is, therefore, nine months or 273 days long.

CHAPTER IV

SUMMARY, CONCLUSIONS, SUGGESTIONS FOR FURTHER RESEARCH

Summary

Research Objectives

The primary objective of this thesis was to examine how variations in altitude, aspect, and slope among sites located in a small area of complex terrain influenced recorded temperatures during an eighty day observation period. This was achieved through graphic and statistical analyses. To set the stage for the graphic analyses and statistical tests a detailed analysis of the physical characteristics of each site, based on: (1) field observations, (2) photography, (3) topographic mapping, and (4) three dimensional mapping, was presented. Minimum and maximum temperatures were recorded and used to compute average temperatures and heating degree days for each site. The distribution of minimum, maximum, and average temperatures among sites was analyzed graphically. Because the primary focus of the thesis was on the difference in heating degree days among sites, the graphic analysis of this variable was extensive. A one-way analysis of variance was used to test the statistical significance of computed heating degree day differences among sites.

The secondary objective of this thesis was to demonstrate how a topoclimatic analysis can be practically applied and was achieved by incorporating the total number of heating degree days from each site into a formula used to determine the amount of energy required for home heating purposes. All the elements of the formula were held constant except the total number of heating degree days. The results of this formula provided a means for comparing the study sites from an economic perspective. The advantages or disadvantages of the physical characteristics of each study site are thus placed in a context which is comprehensible to home energy consumers.

Findings

Graphic Analyses

The general physical characteristics of the study sites and part of the data presented in the graphic analyses can be seen in Table 4.1. In the aggregate, the graphic analyses indicate that the differences in heating

Table 4.1

COMPARISON OF THE STUDY SITES

Site	Altitude (feet)	Average Slope (percent)	Azimuth (degrees)	Aspect Bearing	Mean Minimum Temperature	Mean Maximum Temperature	Mean Average Temperature	Mean Heating Degree Days	Total Number of Heating Degree Days
One	3360	54	26	NNE	29.2	49.5	39.4	25.6	2049
Two	3620	14	18	NNE	29.2	49.2	39.2	25.8	2062
Three	3220	24	137	SE	30.1	52.8	41.4	23.6	1886
Four	3240	12	210	SSW	31.1	53.8	42.4	22.6	1806
Five	3260	20	270	W	31.7	51.9	41.8	23.2	1849

Source: Collected by Author, February 21 to May 11, 1983.

degree days among sites was small. The differences which did occur are, however, worthy of discussion. A brief synopsis of the study sites is presented next.

Based on the mean number of heating degree days, Site One was the second coldest of the five sites. As shown in Figure 3.7, Site One experienced a consistently higher number of heating degree days than the five site mean. Site Two was the coldest of the five sites in all categories. Like Site One, this site maintained a consistently higher number of heating degree days than the five site mean throughout the observation period (see Figure 3.8). Site Three was the third coldest of the five study sites. As shown in Figure 3.9, the distribution of heating degree days for this site was nearly identical to that of the five site mean. Site Four was the warmest of the five study sites. As shown in Figure 3.10, Site Four maintained a consistently lower number of heating degree days than the five site mean throughout the observation period. Site Five was the second warmest of the five study sites. As shown in Figure 3.11, the heating degree day distribution for Site Five was very similar but consistently lower than that of the five site mean.

Hypothesis Test

The research hypothesis of this thesis was tested by means of a one-way analysis of variance. The observed F-ratio of 1.566 was well below the critical-F value of 2.39 needed to reject the null hypothesis at the 0.05 level of significance. The research hypothesis could, therefore, not be accepted on the basis of statistical inference.

Practical Application

Results of the economic comparison were not used to determine the conclusions of this study due to the potential for bias. The greatest discrepancy within the group occurred between Sites Two and Four, the least between Sites Three and Five. The range in values between the group extremes (Sites Two and Four) was $23.40 for the total heating cost or $0.23 per day for the average heating cost per day. Between Sites Three and Five the range was $2.14 for the total heating cost or $0.03 per day.

The Influence of Altitude, Aspect, and Slope

As noted earlier, the differences in recorded temperatures and heating degree days for the eighty day observation period among sites was small and not statistically significant. The differences which did occur can, however, be partially attributed to the influence of variations in altitude, aspect, and slope. A summary of the influences of these three physical elements follows.

Altitude

The influence of altitude on recorded temperatures and heating degree days was most evident at Site Two. Site Two is located at an altitude at least 250 feet greater than the other sites and this, in combination with its north-northeast aspect, made this the coldest site of the group. Although it is suspected that the dominant factor which controlled the temperature regime at Site One during the observation period was its north-northeast aspect, this site is located at an altitude at least 100 feet greater than Sites Three, Four, and Five, and this can partially account for this site being the second coldest of the group.

In general, the influence of altitude on temperature shows up best at night because other factors, principally receipt of direct solar radiation and turbulent mixing of the air, are not present. Under normal conditions the minimum temperature readings occur at night and follow an environmental temperature lapse rate of 3.5 degrees Fahrenheit per 1000 feet of altitude. The mean minimum temperatures of the five sites used in this study did not tend to follow this lapse rate. If minimum temperatures had reflected this normal lapse rate the distribution, from highest to lowest minimum temperature, would have been Sites Three, Four, Five, One, and Two. The actual distribution was Sites Five, Four, Three, Two, and One (see Figure 3.1). The fact that minimum temperatures did not follow normal lapse rates supports the findings of both Harding and Brazel.[1] A general conclusion which can be drawn is that factors other than altitude, such as longwave emission of stored radiation and cold air drainage, exerted some influence on recorded minimum temperatures.

According to research conducted by Brazel, maximum temperatures closely followed normal lapse rates. Although not conclusively, the fact that maximum temperatures at Site One were slightly higher than those of Site Two tends to support Brazel's findings because Site Two has a nearly identical aspect with Site One but is located 260 feet higher in altitude.[2]

Aspect

The influence of aspect on temperatures and heating degree days was best exemplified by Sites Two and Four. The north-northeast aspect of Site Two is the least favorable for the receipt of direct solar radiation, while the south-southwest aspect of Site Four is the most favorable. Consequently, Site Two experienced the greatest number of heating degree days, Site Four the least. The north-northeast aspect of Site One, nearly identical to that of Site Two, was a major factor influencing the temperature regime with this site experiencing the second highest number of heating degree days. The heating degree day distributions of Sites Three and Five were very similar (see Figure 3.9 and 3.11). Both sites were more favorably located for the receipt of direct solar radiation than Sites One and Two and less favorably located than Site Four. A combination of factors caused Sites Three and Five to experience similar heating degree day distributions. Because a southeast aspect is more favorable than a west aspect for the receipt of direct solar radiation, Site Three experienced greater mean maximum temperatures than Site Five. Site Five experienced the highest mean minimum temperatures of the group. This would appear to be due to the fact that with a west aspect this site receives direct solar radiation later in the day than the other four sites. Therefore, the longwave emission of this stored radiation occurs later in the evening at this site and, consequently, prevents minimum temperatures from reaching the values obtained at the other four sites. Finally, it is suspected that the influence of cold air drainage at Site Three caused this site to experience lower minimum temperatures than would be expected under normal lapse rate conditions. This moderating effect of cold air drainage was similar to that reported by Harding. He found that valley sites often had lower minimum temperatures than summit sites due to the influence of cold air drainage.[3]

As noted in Chapter I, one of the main conclusions reached by Olson and Gill, Brazel and Outcalt, Brazel, and Marcus was that aspect is one of the major factors controlling surface temperatures.[4] The findings of this thesis, as evidenced by the differences in computed heating degree days between Sites One and Four, also support this conclusion.

Slope

Because of the limited number of observation sites, conclusions concerning the influence of slope on recorded temperatures and heating degree days could not be made. In studies that deal with the influence of slope and aspect on air temperature, such as those done by Barry and Van Wie, and Garnier and Ohmura, conclusions concerning the influence of slope are only made from observations conducted at sites which maintain the same aspect but have varying slopes.[5] Of the five study sites, only Sites One and Two have the same aspect. The temperature regimes of these two sites were so similar that it must be concluded that the large difference in average slope (40 percent) between the two had little influence on these recorded temperatures.

Conclusions

In view of the results presented from the statistical and graphic analyses, the research hypothesis of this thesis can not be supported. The computed F-probability of 18.27 percent is considerably larger than the 5 percent or less needed to reject the null hypothesis. That there are no significant differences in heating degree days among the five study sites is also supported by the graphic analyses. They show that while differences in heating degree days do occur among sites, in no case are these differences particularly well defined. Figures 3.7 to 3.11 show clearly that the deviations from the mean are consistently small or non-existent. As shown in Figure 4.1, when the distribution of heating degree days over the eighty day observation period from each site is presented on one graph the individual graphs are so similar that individual sites become indiscernable. The main conclusion of this thesis is, therefore: there are no significant differences in heating degree days within the study area due to variations in slope, altitude, and aspect.

There are several possible reasons as to why there were no significant differences in heating degree days among sites. The first possible reason is related to instrumentation. The minimum/maximum thermometers which were utilized only permitted the recording of extreme daily values. Without continuous recording thermometers (thermographs) there is no effective way to determine exactly how the temperature regime at a particular site behaved. For example, on a given day the maximum temperature at Site Two may have been sixty degrees Fahrenheit, the maximum temperature at Site Four sixty-three degrees Fahrenheit. Although these values are very close, the temperature at Site Four may have remained at sixty-three degrees for two hours

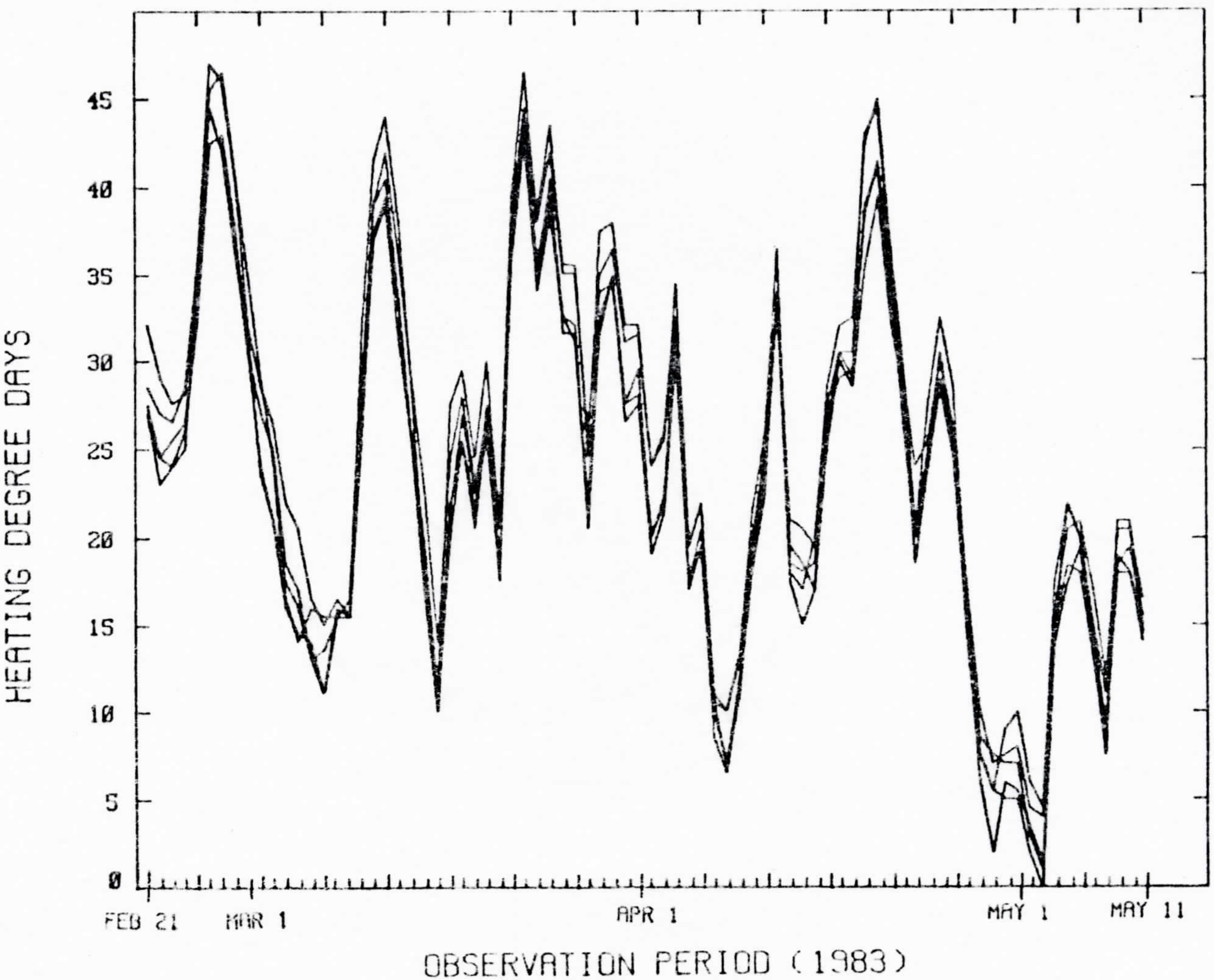

Figure 4.1. Heating Degree Day Comparison: All Study Sites
Source: Collected by Author, Feb. 21 to May 11, 1983.

while the temperature at Site Two may have remained at sixty degrees for only ten minutes. The exclusive use of minimum/maximum thermometers, therefore, may not provide the observer a true representation of the daily pattern of temperature at a particular site. A second possible reason is that although the sites chosen for this study were felt to be a representative sample, there are sites within the study area which are topographically more extreme and may have produced a greater variance in temperatures. The research design called for sites with aspects representing all the cardinal directions and one at a slightly higher altitude. The research design was limited to five sites because this was all the instrumentation that was available. A minimum of two more sites would have allowed the testing of a valley bottom and ridgetop location. The third possible reason is that the study area was simply too small. Of the literature surveyed, there were no studies undertaken at a scale as large (small area) as that utilized in this study.

Suggestions for Further Research

The suggestions presented in this section are closely related to the limitations discussed in Chapter I. It is the author's contention that further research should include one or more of the following: (1) a larger number of study sites monitoring a greater array of altitudes, aspects, and slopes, (2) more diversified and accurate instrumentation, or (3) a longer observation period.

If more study sites were incorporated into a study of this nature a wider range of the possible combinations of physical elements could be tested. If two of the main physical elements (altitude, aspect, and slope) could be held constant over a series of sites the influence of the third element could be accurately tested. Even if this could not be accomplished a larger, diversified sample would yield more meaningful results.

As noted in Chapter I, a number of meteorological instruments could be utilized to undertake a more comprehensive topoclimatic study. Two instruments, a thermograph and recording wind instrument, would be essential equipment for any one pursuing a similar study. A thermograph is a thermometer which records temperature data continuously onto a rotating sheet of ruled paper. Continuous temperature data would give a more accurate accounting of the true temperature regime at any site. A continuous recording wind instrument, which would monitor both wind speed and direction, would be extremely useful for studies dealing with the influence of topoclimates on energy use because factors such as wind stress could then be considered.

A longer observation period would be helpful because seasonal variations and long term trends of climatic elements could then be analyzed. However, due to financial and manpower limitations, most microclimatic studies are both time and area intensive. The use of continuous recording meteorological instruments generally alleviates the need for an extended observation period. As noted in Chapter I, meaningful results have been obtained by researchers in as little as two weeks.

The primary and secondary research objectives of this thesis have been met. An assessment of the influences of variations in altitude, aspect, and slope on the distribution of heating degree days among the study sites has been made and the research hypothesis has been conclusively proven not to be true. Additional, more in-depth analyses are needed to expand the knowledge concerning the influences of topographic variations on the distribution of climatic elements in areas of complex terrain.

NOTES

[1] R. J. Harding, "Altitudinal Gradients of Temperature in the Northern Pennines," Weather 34 (May, 1979): 190-202; Anthony Brazel, "A Note on Topoclimatic Variation of Air Temperature, Chitistone Pass Region, Alaska," in Icefield Ranges Research Project, Scientific Results: Volume 4, eds. Vivian Bushnell and Melvin Marcus (New York: American Geographical Society, 1974), pp. 81-88.

[2] Brazel, "A Note on Topoclimatic Variation," p. 83.

[3] Harding, "Altitudinal Gradients of Temperature," p. 194.

[4] P. R. Olson and D. Gill, "A Preliminary Analysis of Microclimatic Variations in a Small Mountain Valley of Western Alberta during Warm and Cool Weeks in Summer," in Contemperary Geography in Western Canada: The Calgary Papers, ed. Nigel M. Waters (Vancouver: Tantalus Research Limited, 1980), pp. 37-51; Anthony Brazel and Samuel Outcalt, "The Observation and Simulation of Diurnal Surface Thermal Contrasts in an Alaskan Alpine Pass," Archives for Meteorology, Geophysics, and Bioclimatology, Series B 21 (Spring, 1973): 156-174; Brazel, "A Note on Topoclimatic Variation," pp. 81-88; and Melvin Marcus, "Summer Temperature Relationships Along a Transect in the St. Elias Mountains," in Icefield Ranges Research Project, Scientific Results: Volume 1, eds. Vivian Bushnell and Richard Ragle (New York: American Geographical Society, 1969), pp. 23-32.

[5] Roger Barry and Claudia Van Wie, "Topo- and Microclimatology in Alpine Areas," in Arctic and Alpine Environments, eds. Jack Ives and Roger Barry (London: Methuen and Co., 1984) pp. 76-81; B. J. Garnier and Atsumu Ohmura, "The Evaluation of Surface Variations in Solar Radiation Income," Solar Energy 13 (1970): 21-34.

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APPENDIX I

English to Metric Conversion Table

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English to Metric Conversion Table

Multiply English Unit	by	To Obtain Metric Unit
feet	0.3048	meters
miles	1.609	kilometers
square feet	0.0929	square meters
square miles	2.590	square kilometers
pounds	0.4536	kilograms
BTU's	252.0	gram calories
Degrees - 32 Fahrenheit	5/9	Degrees Celsius

Source: Adapted from Edward R. Mack, "Conversion Tables," Publisher and Publication Date Unknown, (mimeographed.)

APPENDIX II

Creation of Digital Terrain Matrices

APPENDIX II

Creation of Digital Terrain Matrices

The three-dimensional views (Digital Terrain Matrices) of the topography surrounding each study site were created on a microcomputer with the aid of the "Micro-Map II" computer program.* A brief listing of the procedures used to create each view follows:

1. A grid system was placed on top of each large-scale topographic map presented in Chapter II (see Figures 2.5, 2.8, 2.11, 2.14, and 2.17) and 100 data points were selected.

2. The elevation for each data point was entered into the program.

3. The viewpoint was then selected. The program allows for a viewpoint from any azimuth and angle above the horizon. The angle above the horizon (23 degrees) was kept constant for each view. The azimuth was rotated until the nature of the topography surrounding the site was most accurately represented.

4. The generated view was then printed by means of a dot matrix printer.

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*Carl Youngman, "Micro-Map II: Computer Assisted Cartography," (Seattle: Morgan-Fairfield Graphics, 1982).

APPENDIX III

Collected and Computed Data for the

Eighty Day Observation Period

APPENDIX III

Collected and Computed Data for the Eighty Day Observation Period

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	19	47	33	32
	Two	21	52	36.5	28.5
2-21	Three	20	55	37.5	27.5
	Four	20	56	38	27
	Five	22	54	38	27
	One	20	52	36	29
	Two	21	55	38	27
2-22	Three	22	59	40.5	24.5
	Four	21	60	40.5	24.5
	Five	24	60	42	23
	One	25	50	37.5	27.5
	Two	25	52	38.5	26.5
2-23	Three	25	54	39.5	25.5
	Four	25	57	41	24
	Five	28	54	41	24
	One	30	44	37	28
	Two	29	44	36.5	28.5
2-24	Three	29	48	38.5	26.5
	Four	30	48	39	26
	Five	32	48	40	25
	One	24	37	30.5	34.5
	Two	22	37	29.5	35.5
2-25	Three	24	42	33	32
	Four	25	40	32.5	32.5
	Five	23	38	30.5	34.5
	One	12	27	19.5	45.5
	Two	8	28	18	47
2-26	Three	13	32	22.5	42.5
	Four	13	32	22.5	42.5
	Five	12	29	20.5	44.5

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	10	27	18.5	46.5
	Two	9	29	19	46
2-27	Three	12	32	22	43
	Four	11	33	22	43
	Five	13	33	23	42
	One	12	37	24.5	40.5
	Two	14	35	24.5	40.5
2-28	Three	15	40	27.5	37.5
	Four	13	44	28.5	36.5
	Five	16	42	29	36
	One	26	38	33	32
	Two	24	36	30	35
3-1	Three	28	41	34.5	30.5
	Four	29	30	34.5	30.5
	Five	29	38	33.5	31.5
	One	28	45	36.5	28.5
	Two	28	44	36	39
3-2	Three	28	48	38	27
	Four	32	50	41	24
	Five	35	48	41.5	23.5
	One	27	50	38.5	26.5
	Two	28	53	40.5	24.5
3-3	Three	24	56	40	25
	Four	30	58	44	21
	Five	32	56	44	21
	One	26	60	43	22
	Two	32	65	48.5	16.5
3-4	Three	26	67	46.5	18.5
	Four	27	68	47.5	17.5
	Five	30	68	49	16
	One	27	62	44.5	20.5
	Two	35	67	51	14
3-5	Three	28	68	48	17
	Four	29	69	49	16
	Five	32	69	50.5	14.5

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps	Maximum Temps.	Average Temps.	Heating Degree Days
	One	44	53	48.5	16.5
	Two	46	52	49	16
3-6	Three	47	57	52	13
	Four	48	56	52	13
	Five	47	55	51	14
	One	40	60	50	15
	Two	39	60	49.5	15.5
3-7	Three	38	65	51.5	13.5
	Four	39	69	54	11
	Five	41	67	54	11
	One	41	56	48.5	16.5
	Two	42	57	49.5	15.5
3-8	Three	40	59	49.5	15.5
	Four	40	59	49.5	15.5
	Five	41	57	49	16
	One	36	59	57.5	15.5
	Two	36	61	48.5	16.5
3-9	Three	35	62	48.5	16.5
	Four	35	64	49.5	15.5
	Five	37	62	49.5	15.5
	One	29	44	36.5	28.5
	Two	26	41	33.5	31.5
3-10	Three	31	46	38.5	26.5
	Four	31	49	40	25
	Five	30	45	37.5	27.5
	One	21	31	26	39
	Two	18	29	23.5	41.5
3-11	Three	23	33	27.5	37.5
	Four	23	33	28	37
	Five	22	30	26	39
	One	21	25	23	42
	Two	18	24	21	44
3-12	Three	23	28	25.5	39.5
	Four	23	39	26	39
	Five	23	26	24.5	40.5

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	23	35	29	36
	Two	20	34	27	38
3-13	Three	25	39	32	33
	Four	25	43	34	31
	Five	24	39	31.5	33.5
	One	24	48	36	29
	Two	21	52	36.5	28.5
3-14	Three	24	55	39.5	25.5
	Four	24	55	39.5	25.5
	Five	24	55	39.5	25.5
	One	28	57	42.5	22.5
	Two	35	60	47.5	17.5
3-15	Three	28	63	45.5	19.5
	Four	34	63	48.5	16.5
	Five	36	61	48.5	16.5
	One	35	67	51	14
	Two	38	69	53.5	11.5
3-16	Three	36	72	54	11
	Four	37	73	55	10
	Five	39	71	55	10
	One	30	51	40.5	24.5
	Two	28	47	37.5	27.5
3-17	Three	32	54	43	22
	Four	33	57	45	20
	Five	32	55	43.5	21.5
	One	34	40	37	28
	Two	33	38	35.5	29.5
3-18	Three	36	42	39.5	25.5
	Four	37	42	39.5	25.5
	Five	36	40	38	27
	One	38	46	42	23
	Two	36	45	40.5	24.5
3-19	Three	39	48	43.4	21.5
	Four	39	50	44.5	20.5
	Five	38	47	42.5	22.5

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	30	46	38	27
	Two	28	42	35	30
3-20	Three	29	46	37.5	27.5
	Four	30	47	38.5	26.5
	Five	34	45	39.5	25.5
	One	30	57	43.5	21.5
	Two	30	59	44.5	20.5
3-21	Three	32	61	46.5	18.5
	Four	33	62	47.5	17.5
	Five	35	60	47.5	17.5
	One	16	39	27.5	37.5
	Two	14	37	25.5	39.5
3-22	Three	18	40	29	36
	Four	18	40	29	36
	Five	17	37	27	38
	One	17	25	21	44
	Two	14	23	18.5	46.5
3-23	Three	18	27	22.5	42.5
	Four	17	27	22	43
	Five	17	24	20.5	44.5
	One	17	37	27	38
	Two	15	38	26.5	38.5
3-24	Three	19	42	30.5	34.5
	Four	19	43	31	34
	Five	19	40	29.5	35.5
	One	17	29	23	42
	Two	15	28	21.5	43.5
3-25	Three	19	32	25.5	39.5
	Four	19	34	26.5	38.5
	Five	18	31	24.5	40.5
	One	16	44	30	35
	Two	15	44	29.5	35.5
3-26	Three	17	48	32.5	32.5
	Four	16	49	32.5	32.5
	Five	19	48	33.5	31.5

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	18	42	30	35
	Two	18	41	29.5	35.5
3-27	Three	21	45	33	32
	Four	21	47	34	31
	Five	23	44	33.5	31.5
	One	29	49	39	26
	Two	29	52	40.5	24.5
3-28	Three	31	58	44.5	20.5
	Four	31	58	44.5	20.5
	Five	30	56	43	22
	One	26	34	30	35
	Two	23	32	27.5	37.5
3-29	Three	27	38	32.5	32.5
	Four	28	39	33.5	31.5
	Five	26	36	31	34
	One	20	37	28.5	36.5
	Two	17	37	27	38
3-30	Three	21	39	30	35
	Four	19	41	30	35
	Five	21	40	30.5	34.5
	One	23	45	34	31
	Two	22	44	33	32
3-31	Three	24	51	37.5	27.5
	Four	25	52	38.5	26.5
	Five	25	50	37.5	27.5
	One	29	38	33.5	31.5
	Two	29	37	33	32
4-1	Three	31	43	37	28
	Four	32	43	37.5	27.5
	Five	31	40	35.5	29.5
	One	31	51	41	24
	Two	32	50	41	24
4-2	Three	35	55	45	20
	Four	35	57	46	19
	Five	35	55	45	20

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	32	47	39.5	25.5
	Two	31	47	39	26
4-3	Three	34	51	42.5	22.5
	Four	34	53	43.5	21.5
	Five	33	53	43	22
	One	28	37	32.5	32.5
	Two	26	35	30.5	34.5
4-4	Three	30	38	34	31
	Four	30	40	35	30
	Five	29	36	32.5	32.5
	One	30	61	45.5	19.5
	Two	30	61	45.5	19.5
4-5	Three	32	63	47.5	17.5
	Four	34	62	48	17
	Five	32	63	47.5	17.5
	One	39	47	43	22
	Two	39	47	43	22
4-6	Three	41	50	45.5	19.5
	Four	42	49	45.5	19.5
	Five	41	48	44.5	20.5
	One	46	62	54	11
	Two	44	65	54.5	10.5
4-7	Three	45	65	55	10
	Four	47	66	56.5	8.5
	Five	46	63	54.5	10.5
	One	51	59	55	10
	Two	50	60	55	10
4-8	Three	52	64	58	7
	Four	53	64	58.5	6.5
	Five	53	63	58	7
	One	50	54	52	13
	Two	49	54	51.5	13.5
4-9	Three	51	57	54	11
	Four	51	56	53.5	11.5
	Five	51	55	53	12

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	35	55	45	20
	Two	33	54	43.5	21.5
4-10	Three	36	57	46.5	18.5
	Four	37	57	47	18
	Five	36	56	46	19
	One	28	52	40	25
	Two	26	52	39	26
4-11	Three	30	54	42	23
	Four	30	55	42.5	22.5
	Five	29	53	41	24
	One	26	38	32	33
	Two	22	35	28.5	36.5
4-12	Three	24	39	31.5	33.5
	Four	25	38	31.5	33.5
	Five	26	36	31	34
	One	27	61	44	21
	Two	33	61	47	18
4-13	Three	28	63	45.5	19.5
	Four	31	64	47.5	17.5
	Five	30	63	46.5	18.5
	One	33	56	44.5	20.5
	Two	41	55	48	17
4-14	Three	35	58	46.5	18.5
	Four	40	60	50	15
	Five	37	57	47	18
	One	40	51	45.5	19.5
	Two	39	51	45	20
4-15	Three	42	54	48	17
	Four	43	53	48	17
	Five	41	52	46.5	18.5
	One	23	52	37.5	27.5
	Two	20	53	36.5	28.5
4-16	Three	24	54	39	26
	Four	25	55	40	25
	Five	24	52	38	27

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	24	45	34.5	30.5
	Two	22	44	33	32
4-17	Three	22	47	34.5	30.5
	Four	23	47	35	30
	Five	25	47	36	29
	One	23	46	34.5	30.5
	Two	20	45	32.5	32.5
4-18	Three	24	48	36	29
	Four	25	48	36.5	28.5
	Five	24	47	35.5	29.5
	One	14	30	22	43
	Two	11	34	22.5	42.5
4-19	Three	15	37	26	39
	Four	16	43	29.5	35.5
	Five	15	38	26.5	38.5
	One	14	27	20.5	44.5
	Two	12	28	20	45
4-20	Three	16	32	24	41
	Four	19	32	25.5	39.5
	Five	16	31	23.5	41.5
	One	21	37	29	36
	Two	20	36	28	37
4-21	Three	22	40	31	34
	Four	24	41	32.5	32.5
	Five	22	38	30	35
	One	24	47	35.5	29.5
	Two	25	45	35	30
4-22	Three	22	50	36	29
	Four	25	49	37	28
	Five	28	49	38.5	26.5
	One	32	50	41	24
	Two	36	53	44.5	20.5
4-23	Three	34	54	44	21
	Four	37	56	46.5	18.5
	Five	38	52	45	20

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	36	43	39.5	25.5
	Two	34	41	37.5	27.5
4-24	Three	38	44	41	24
	Four	39	43	41	24
	Five	38	42	40	25
	One	28	42	35	30
	Two	25	40	32.5	32.5
4-25	Three	29	43	36	29
	Four	29	44	36.5	28.5
	Five	28	41	34.5	30.5
	One	28	50	39	26
	Two	26	47	36.5	28.5
4-26	Three	29	51	40	25
	Four	30	51	40.5	24.5
	Five	28	50	39	26
	One	32	63	47.5	17.5
	Two	37	61	49	16
4-27	Three	33	64	48.5	16.5
	Four	36	64	50	15
	Five	38	63	50.5	14.5
	One	36	74	55	10
	Two	43	72	57.5	7.5
4-28	Three	36	77	56.5	8.5
	Four	38	77	57.5	7.5
	Five	42	76	59	6
	One	42	74	58	7
	Two	46	73	59.5	5.5
4-29	Three	39	76	57.5	7.5
	Four	42	77	59.5	5.5
	Five	50	76	63	2
	One	44	71	57.5	7.5
	Two	42	70	56	9
4-30	Three	44	72	58	7
	Four	46	74	60	5
	Five	47	71	59	6

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	47	67	57	8
	Two	46	64	55	10
5-1	Three	46	70	58	7
	Four	50	70	60	5
	Five	50	69	59.5	5.5
	One	51	70	60.5	4.5
	Two	50	68	59	6
5-2	Three	53	71	62	3
	Four	53	73	63	2
	Five	52	71	61.5	3.5
	One	51	71	61	4
	Two	51	70	60.5	4.5
5-3	Three	54	74	64	1
	Four	55	75	65	0
	Five	54	73	63.5	1.5
	One	39	59	49	16
	Two	37	58	47.5	17.5
5-4	Three	40	61	50.5	14.5
	Four	40	62	51	14
	Five	40	60	50	15
	One	37	52	44.5	20.5
	Two	36	50	43	22
5-5	Three	32	54	43	22
	Four	39	56	47.5	17.5
	Five	39	54	46.5	18.5
	One	28	60	44	21
	Two	32	58	45	20
5-6	Three	28	62	45	20
	Four	30	61	45.5	19.5
	Five	34	60	47	18
	One	30	66	48	17
	Two	37	64	50.5	14.5
5-7	Three	31	69	50	15
	Four	32	72	52	13
	Five	35	69	52	13

APPENDIX III (continued)

Day (1983)	Site	Minimum Temps.	Maximum Temps.	Average Temps.	Heating Degree Days
	One	36	70	53	12
	Two	46	67	56.5	8.5
5-8	Three	37	71	54	11
	Four	38	73	55.5	9.5
	Five	43	72	57.5	7.5
	One	29	60	44.5	20.5
	Two	27	61	44	21
5-9	Three	30	63	46.5	18.5
	Four	30	64	47	18
	Five	30	62	46	19
	One	26	63	44.5	20.5
	Two	28	60	44	21
5-10	Three	26	65	45.5	19.5
	Four	26	68	47	18
	Five	29	65	47	18
	One	27	70	48.5	16.5
	Two	33	68	50.5	14.5
5-11	Three	28	71	49.5	15.5
	Four	28	72	50	15
	Five	31	71	51	14

VITA

Peter Thomas Soule' was born on November 11, 1958 in Rockville, Maryland. He was awarded a B. A. in Geography from Florida Atlantic University in March 1980. Prior to entering the graduate program in Geography at Appalachian State University he worked in the hang gliding industry in both North Carolina and California. While attending Appalachian State University he held a teaching assistantship in Geography and was awarded the Julian Yoder Scholarship, Zigli Family Endowment for Research Award, and an Alumni Scholarship.

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