To the Graduate Council:

I am submitting herewith a thesis written by Thomas Brock Maertens, Jr. entitled "The Relationship of Maintenance Costs to Terrain and Climate on Interstate 40 in Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Edwin H. Hammond

Edwin H. Hammond, Major Professor

We have read this thesis
and recommend its acceptance:

Theodore H. Schmeeckle

Thomas L. Bell

Accepted for the Council:

L. Evans Peel

Vice Chancellor
Graduate Studies and Research

B

Thesis
80
.M343
cop.2

THE RELATIONSHIP OF MAINTENANCE COSTS TO TERRAIN AND CLIMATE ON INTERSTATE 40 IN TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Thomas Brock Maertens, Jr.

June 1980

0041770

ACKNOWLEDGMENTS

I am grateful for the assistance and guidance of Professor Edwin H. Hammond who directed this project. The subject of my research was, in part, developed from his suggestion that I investigate an aspect of environmental costs. I also appreciate the critical suggestions and encouragement offered by Professors Theodore H. Schmudde and Thomas L. Bell.

I appreciate the cooperation and assistance of the Tennessee Department of Transportation's offices in Nashville and Knoxville. Mr. Alan Pinson of the Maintenance Management Division and Mr. Fred Corum, Chief Highway Maintenance Engineer for Region I, were particularly helpful. Other highway maintenance personnel that I contacted across the state were also very helpful in providing insight into highway maintenance operations.

I also wish to thank the United States Army and the Department of Geography of The University of Tennessee, Knoxville, for granting me the opportunity to further my graduate education. In the department, I appreciate the support and suggestions of my fellow graduate students, particularly those of Carolyn Jenks and Vincent Ambrosia.

Finally, I wish to thank my wife, Karen, for her understanding and encouragement during the period of research and writing of this project. For her dedication in typing the numerous drafts and final copy of this thesis, I am most grateful.

ABSTRACT

Terrain and climate are discussed as environmental factors affecting the maintenance costs of selected sections of Tennessee's Interstate Highway System. Among the environmental factors discussed are precipitation (distribution, frequency, and intensity), temperature (annual means, norms, and extremes), slope, local relief, soils, roadway gradient, geologic stability (landslide stability), and drainage. Precipitation, more than temperature, acts in conjunction with terrain to contribute to the spatial variability of maintenance costs. Heavy truck traffic is also discussed as a factor for high maintenance costs in Tennessee.

High maintenance cost segments of Interstate 40 are identified along the eastern escarpment of the Cumberland Plateau, in the hilly terrain of the western Highland Rim near the Tennessee River, and in the steep and geologically complex terrain along the Pigeon River in the Great Smoky Mountains.

While generalized relationships between maintenance costs and environmental factors are difficult to establish on a statewide basis, detailed analysis of specific high-cost segments of Interstate 40 suggests clear relationships between microenvironmental factors and costs.

This study suggests that maintenance costs are influenced by environmental factors related to the highway's location in areas of varying terrain and climate. Highway planners should consider environmental factors, not only as they affect the initial construction and operating costs, but also as they may contribute to long-term maintenance costs.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION.	1
	The Problem	1
	Outline of the Study.	4
II.	CONCEPTS OF HIGHWAY MAINTENANCE	13
	Highway Design.	13
	Maintenance Activities.	16
III.	TERRAIN AND CLIMATE OF TENNESSEE.	19
	Overview of Terrain	19
	Overview of Climatic Patterns	23
	Climatological Data	25
IV.	ANALYSIS OF MAINTENANCE COSTS	30
	Roadway Costs	30
	Traffic Loading	30
	Pavement Materials.	33
	Environmental Factors	34
	Distribution of Costs	37
	Analysis of High-Cost Areas	40
	Drainage Costs.	51
	Drainage Systems.	51
	Distribution of Costs	55
	Analysis of Costs	55

CHAPTER PAGE

IV. (Continued)

Snow and Ice Removal Costs. 59

Distribution of Costs 61

Analysis of Costs 63

Extraordinary Costs 71

Distribution of Costs 71

Analysis of Costs 73

Roadside Costs. 89

Distribution of Costs 91

Analysis of Costs 91

Total Costs 100

Distribution of Costs 100

Analysis of Costs 102

V. CONCLUSIONS AND RECOMMENDATIONS 104

BIBLIOGRAPHY. 108

VITA. 119

LIST OF TABLES

TABLE		PAGE
1.	Roadway Inventory	6
2.	Climate Reporting Stations	9
3.	Vehicle Classification Counts for I-40	32
4.	Ranking of Counties by Five-Year Average (1974-1979) Maintenance Costs per Mile for Selected Activities	38
5.	Summary of Roadside Costs	92

LIST OF FIGURES

FIGURE		PAGE
1.	Climate Reporting Stations	10
2.	Profile of the I-40 Roadway in Tennessee	20
3.	Distribution of Roadway Costs	39
4.	I-40 Roadway on the Eastern Escarpment of the Cumberland Plateau in the Vicinity of Rockwood	41
5.	Embankment along I-40 in Roane County as Viewed Before and After Failure	44
6.	Cut Slope along I-40 in Roane County as Viewed Before and After Failure	45
7.	I-40 Roadway in the Hills of Benton County	48
8.	Distribution of Drainage Costs	56
9.	Distribution of Snow and Ice Costs	62
10.	I-40 Roadway in the Harpeth River Valley in Cheatham County	67
11.	Extensive Cuts on the Eastbound Lane of I-40 in the Vicinity of Crab Orchard Mountain in Cumberland County	69
12.	Distribution of Extraordinary Costs	72
13.	Cut and Fill Areas of the I-40 Roadway in the Vicinity of Rockwood in Roane County	76
14.	Slide on the Eastbound Lane of I-40 in Roane County, February 1974, with View to the West	79
15.	Slide on the Eastbound Lane of I-40 in Roane County, February 1974, with View to the Northwest	80
16.	Slide on the Eastbound Lane of I-40 in Roane County, July 1971	81

FIGURE PAGE

17. Gabion Walls on the I-40 Roadway in Roane County 82

18. Gabion Walls above the Westbound Lane of the I-40 Roadway in Roane County. 83

19. I-40 Roadway along the Pigeon River in Cocke County. 85

20. I-40 Roadway along the Sugar Creek Valley in Hickman County 90

21. Distribution of Roadside Costs 93

22. Pine Trees along the I-40 Roadway in Benton County. 95

23. Distribution of Total Maintenance Costs. . . . 101

CHAPTER I

INTRODUCTION

The Problem

The highways of the National System of Interstate and Defense Highways (commonly known as the Interstate System) carry more traffic per mile than any other comparable national system. They include the highways of greatest significance to the economic welfare and defense of the nation. At present the 42,500-mile system is 93 percent complete at a total cost of $104 billion. Many of the highways, however, are deteriorating from years of neglect and heavy use.[1] The result has been a change in emphasis from highway design and construction to highway maintenance. Questions are being asked as to why the Interstates are in such poor condition and whether or not highway maintenance has been adequate.

One factor affecting the condition of the Interstate System is inadequate funds. In 1956 the Highway Trust Fund was established by Congress to support construction of the system, with the Federal government bearing 90 percent of the costs. Once the

---

[1] Fred W. Frailey, "America's Highways: Going to Pot," U.S. News & World Report, 24 July 1978, p. 36.

Interstates were constructed, the various states would bear the costs of maintaining the highways. Unfortunately, the states did not provide adequate funds to maintain the Interstates, and the system is deteriorating 50 percent faster than expected. To help offset this lack of funds, Congress, in 1976, enacted legislation that allows the Highway Trust Fund to be used for maintenance as well as for construction of the Interstate System. The Department of Transportation estimates, however, that to maintain the level of highway quality that existed in 1975 would cost an average of $21.8 billion annually until 1990. This estimate does not take into account inflation since 1975. Ironically, the Highway Trust Fund, which is derived from gasoline taxes, is suffering from fuel conservation measures enacted to cope with the energy crisis.

Another factor contributing to deterioration has been the effect of raising the permissible truck weights--both gross and per axle--by 10 percent above the maximum design weight of the Interstates.[2] The interstate network was designed to the high weight specification of 73,280 pounds (single axle limit of 18,000 pounds) to withstand the possible heavy military

---

[2]Robert Sherrill, "Truckers Blitz the Interstate," Nation, 29 April 1978, p. 501.

traffic in a national emergency. In 1974, however, the Congress, as a reaction to the Arab oil embargo, allowed states to permit 80,000-pound vehicle loads on federally aided highways. This action is very significant, because pavement damage increases exponentially as axle weights are raised. For example, an 80,000-pound truck does 10,000 times as much damage to a highway as a 2000-pound automobile.[3]

Other external factors contribute to the maintenance problem of the nation's Interstates. In addition to the effects of traffic, other factors include the highway construction materials used, the quality of the initial construction (surface evenness and compaction, for example), the effectiveness of drainage, and environmental conditions such as the terrain, climate, and soils. Attention of the public and the media has generally focused on the impact of heavy trucks and fiscal constraints as the major causes of the poor condition of the Interstate Highway System. This study, however, will focus on the maintenance costs of an interstate highway system as they relate to environmental factors. Specifically, the purpose of this thesis is to describe and analyze the effects of terrain and climate on maintenance costs of selected sections of

---

[3]Frailey, op. cit., footnote 1, p. 37.

Tennessee's Interstate Highway System. The cost factors generated by climate and terrain are considered as environmental costs and represent an aspect of the man-land relationship. If the effects of these external components can be analyzed, perhaps from a geographical standpoint, better planning for highway location and design may reduce long-term maintenance costs. Currently the geographical aspects of highway maintenance receive little attention.

Outline of the Study

With emphasis on variability of climate, soils, and terrain, this study focuses on the geography of maintenance costs along Interstate 40 (hereafter known as I-40) in Tennessee. Interstates are more suitable than other highway systems for an investigation of this kind because of their higher design standards and uniformity of maintenance standards. Information used in this study is based on the county, because in Tennessee the Department of Transportation's Bureau of Highways records maintenance costs only to the county level. Maintenance costs for different routes of the Interstate System are not kept separately in counties with more than one interstate (e.g., Davidson County, with segments of I-40, I-24, and I-65). Consequently, to insure the specificity of data, counties with only an I-40 segment were selected

for study. The sole exception is Cheatham County, with 7.35 miles of I-40 and 3.64 miles of I-24. It is included in the study because the I-24 segment was not completed until fiscal year 1979 (July 1978 to June 1979), the final year of this study. To insure that maintenance costs for only I-40 were analyzed, cost data for Cheatham County are based on a four-year average (July 1974 to June 1978) rather than the five-year averages used for the remaining counties in the study. Carroll County, with only 1.65 miles of I-40, is rejected because of insufficient mileage for analysis. Counties selected and their associated mileage are presented in Table 1. Maintenance costs obtained from the Tennessee Maintenance Management Office in Nashville were for the five-year period (representing five fiscal years) between 1 July 1974 and 30 June 1979. The Maintenance Management Office maintains cost histories on seventy specified highway maintenance activities, but only certain activities were selected for study. These include roadway surface, shoulder, and drainage system repair; snow and ice removal; landslide removal; mowing and landscaping; and roadway settlement repair. Some maintenance activities were omitted because, intuitively, they appear to possess little or no relationship to terrain and climate. Examples are litter removal, fence repair, roadway sweeping, sign repairs, and centerline painting. Bridge

TABLE 1

ROADWAY INVENTORY

County	Miles of I-40[1]	Number of Bridges	Feet of Bridge
Cocke	22.74	29	5718
Sevier	4.56	10	1383
Roane	23.22	25	7375
Cumberland	34.20	35	8236
Putnam	37.29	32	6217
Smith	17.09	29	6799
Wilson	27.37	31	5313
Cheatham	7.35	11	4229
Dickson	17.98	11	2602
Hickman	15.11	23	7406
Humphreys	14.52	12	5001
Benton	8.78	5	3413
Decatur	5.63	3	467
Henderson	23.88	19	4854
Madison	28.03	35	7538
Haywood	23.84	29	6945
Fayette	16.17	23	4848

[1]All mileage is four lane with the exception of the 4.56 miles in Sevier County which is six lane.

maintenance was initially investigated, but because bridge maintenance consists chiefly of routine, periodic inspection and repair, the activity did not lend itself to meaningful analysis. The maintenance cost data were reduced to a five-year average cost per centerline mile for each activity in each county.

The key step in this investigation was the analysis of the spatial variability of the maintenance costs along I-40 in terms of the environmental factors of climate and terrain. Specific environmental factors considered were precipitation, temperature, ground water table, soil types, topography, subsurface drainage, frost penetration, and frequency of steep grades with large volumes of heavy truck traffic.[4] It was recognized that the sources for this information provided some data of a general nature. For example, although distances were minimized, climate reporting stations were located some distance from the I-40 roadway and reflected only general conditions in the surrounding area. Data on subsurface drainage, ground water tables, and soil types were often based on surveys and maps made ten or twenty years prior to this study. The most significant and

---

[4] U.S. Army Engineer Waterways Experiment Station, Climatic Effects on Airport Pavement Systems; State of the Art, by Barry J. Dempsey, Contract Report S-76-12 (Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, 1976), pp. 9-1--9-2.

meaningful analysis, therefore, resulted from data and information concerning specific locations and situations along the I-40 roadway. Highway maintenance personnel from various districts along I-40 provided much of this local information.

Climatological information was obtained from the National Oceanic and Atmospheric Administration's (NOAA) annual and monthly summaries of climatological data for fifteen reporting stations along I-40. To insure that the data for the highways are representative, all reporting stations chosen lie within a radius of twenty-five miles of the associated I-40 segment. In two instances, a single reporting station is associated with I-40 segments in two counties (see Table 2 and Figure 1). Data on temperature and precipitation (to include snowfall) were obtained in the form of monthly and yearly averages, extremes, and distribution for the five-year period from July 1974 to June 1979. The climatological data were to be integrated with the cost data, utilizing the statistical methods of correlation and multiple regression analysis.

Terrain information was obtained by analyzing topographic, geologic, and soils maps and aviation Visual Flight Rules (VFR) sectionals of the I-40 segments in Tennessee. A corridor of influence was utilized as a means of integrating the terrain data with the associated

TABLE 2

CLIMATE REPORTING STATIONS

County	Station	Latitude	Longitude	Elevation	Years of Record	
					Temp.	Precip.
Cocke	Newport	35 59	83 12	1035	89	89
Sevier	Sevierville	35 52	83 33	930	25	25
Roane	Rockwood	25 51	84 42	860	18	18
Cumberland	Crossville (airport)	35 57	85 05	1881	26	26
Putnam	Cookeville	36 09	85 30	1060	25	29
Smith	Cordell Hull Lock and Dam	36 17	85 56	510	16	16
Wilson	Lebanon	36 12	86 19	525	19	35
Cheatham	Kingston Springs	36 07	87 06	448	18	37
Dickson	Dickson	36 04	87 23	780	83	87
Hickman	Centerville Water Plant	35 45	87 27	660	34	40
Humphreys	Linden (Perry County)	35 37	87 50	498	17	17
Benton	Linden (Perry County)	35 37	87 50	498	17	17
Decatur	Lexington (Henderson County)	35 40	88 25	540	17	17
Henderson	Lexington	35 40	88 25	540	17	17
Madison	Jackson Experiment Station	35 37	88 50	400	87	90
Haywood	Brownsville	35 35	89 15	330	74	97
Fayette	Moscow	35 04	89 24	340	60	59

CLIMATE REPORTING STATIONS

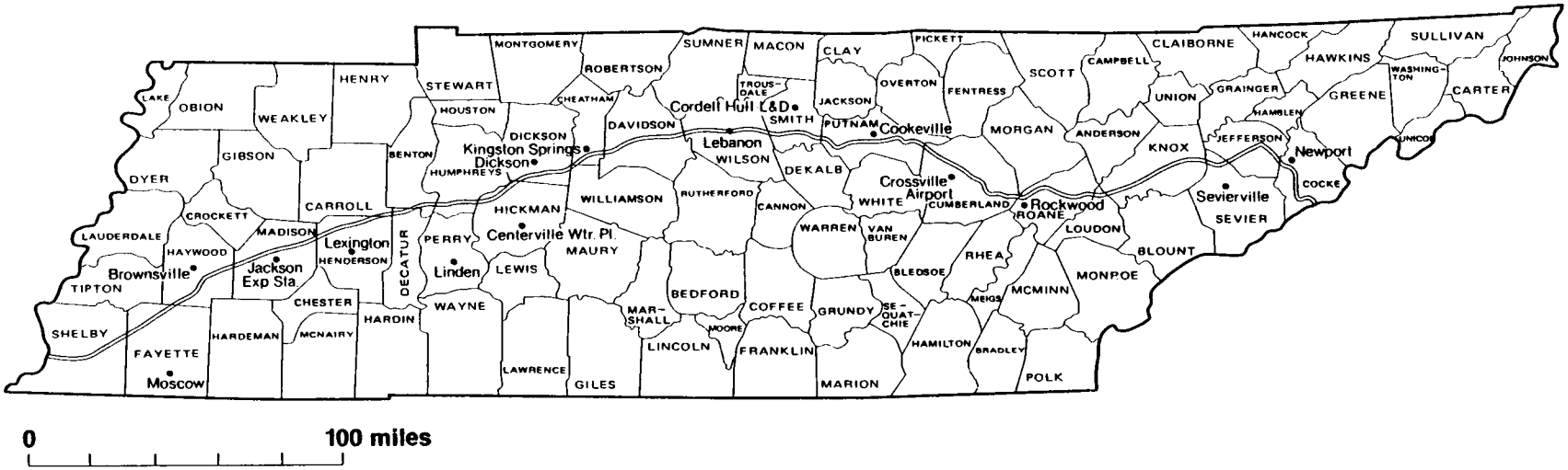


Figure 1. Climate Reporting Stations.

highway segment. This corridor generally extends one mile on either side of the highway. Within this corridor of influence, data concerning roadway elevations (gradient), local relief from the roadway, ratio of stream crossings to highway miles, surface texture, drainage densities, annual peak and mean runoff (for selected basins), maximum and average slopes, soil types, and geologic stability were obtained.

As previously mentioned, many factors affect highway maintenance costs, including traffic count or volume. It is difficult to specify accurately what share of pavement deterioration is attributable to traffic volume, since all factors act in conjunction. A recent study by Oregon highway engineers credits heavy trucks with 80 percent of road surface wear, climate with 19 percent, and automobiles with 1 percent.[5] This is only an estimate, and figures vary widely. In any case, average daily traffic counts and vehicle classifications were obtained for this study from the Tennessee Department of Transportation and are used to amplify the analysis of certain costs.

As in any study, certain assumptions must be made to facilitate the obtaining and analysis of data.

---

[5] "Deaths, Road-Wear Up with Truck Weight," The Knoxville News-Sentinel, 24 July 1979, sec. 1, p. 1.

For example, this study assumes equal maintenance efforts on I-40 throughout the state. In other words, the maintenance management system provides equal highway maintenance standards and priorities on I-40 over the long run. Another basic assumption is that the maintenance cost data, which are based on individual and crew labor hour inputs for specific activities, are reasonably accurate. A third assumption concerns the ages of the various sections of pavement on I-40. Completion dates of sections of I-40 range from 1960 to 1976. Certainly, older segments of the highway should reflect increased wear and deterioration. Pavements, however, are continually rejuvenated by patching or resurfacing. It is beyond the scope of this investigation to document and delimit each occurrence of pavement resurfacing along the I-40 roadway. Therefore, the various ages of sections of I-40 are not considered as factors in this investigation.

CHAPTER II

CONCEPTS OF HIGHWAY MAINTENANCE

Highway Design

In order to understand the basic concepts of highway maintenance, a brief discussion of some of the key terms is needed. Generally speaking, all pavements may be divided into two broad types, rigid and flexible. The term "rigid pavement" is used when the pavement surface is constructed of Portland cement concrete. A pavement constructed with concrete possesses considerable flexural strength which permits it to act as a beam and allows it to bridge over minor irregularities which may occur in the support surfaces (base and subgrade) beneath the pavement. Rigid pavements deflect slightly under design loads and distribute the loading over a large area, thus bridging weak spots. Only 5 percent of Tennessee's highways are constructed with Portland cement concrete.[6] Of the 450 miles of I-40 in Tennessee, only 68 miles, or 15 percent, of the road surface is rigid concrete, chiefly in Madison, Haywood, and Fayette counties. All other types of

---

[6] The Road Information Program, The Effect of Substandard Roads on Tennessee Drivers' Costs (Nashville: Tennesseans for Better Transportation, 1979), p. 8.

pavements (chiefly asphalt in the Interstate System) are classified as flexible. In a flexible pavement, any distortion or displacement occurring in the support layers underneath the paved surface is transmitted upward into the surface. The design of flexible pavements is based on the principle that the magnitude of stress induced by wheel loading decreases with depth below the surface. Thus, with increasing depth, wheel loads are spread over larger areas, reducing the intensity of loading.

The material placed in embankments (fills) or unmoved from cuts in the normal grading of the roadway is the subgrade. The subgrade serves as the foundation of the pavement structure or the "basement soil." The base course is the support layer just beneath the paved surface. The purpose of the base course is to distribute the induced stresses from wheel loads so they will not exceed the strength of the subgrade. For example, when the subgrade strength is known to be low because of the infringement of moisture from a high water table, the stress must be reduced to a low value, and a substantial thickness of base is required. A wide variety of materials can be used as a base course, including gravels, sands, limerock, coral, shells, and caliche. In flexible pavement construction, a layer known as the subbase is employed between the subgrade

and base to help distribute the applied loads to the subgrade. This layer usually consists of coarse-grained soils (if available) or other materials, such as lime-rock, ashes, coral, shell, caliche, or cinders.

Other terms to consider refer to the components of a highway system. The roadway or traveled way is that portion of the road surface upon which all vehicles move. The shoulder is the additional width provided beyond the traveled way, usually extending some twelve feet in the Interstate System. Together, the traveled way and shoulders form the roadbed. The term "right-of-way" refers to the entire area occupied by the highway between boundary lines with private property. This width varies from section to section depending on the terrain and property lines; an average right-of-way for an interstate highway is 400 feet. Basically, all interstate highways are required to meet the minimum standards established by the Policy on Design Standards adopted on 12 July 1956 by the American Association of State Highway Officials (AASHO) and later revised on 15 May 1965. This policy includes design standards concerning traffic volume, access, gradients, medians, shoulders, side slopes, intersections, design speed,

curvature, superelevation, sight distance, right-of-way, and bridges and other structures.[7]

Maintenance Activities

Highway maintenance is defined as the routine prevention and correction of normal damage and deterioration from use and the elements as necessary to keep road surfaces and facilities in usable condition. Another definition states that maintenance is the routine work performed to keep a pavement, under normal conditions of traffic and normal forces of nature, as nearly as possible in its "as constructed" condition.[8] There is some disagreement as to whether repairs made necessary by unusual events such as landslides, earthquakes, windstorms, forest fires, or severe accidents should be classified as maintenance. In this study, however, the procedures outlined in the Tennessee Department of Highway's Maintenance Field Operations Manual are used.[9]

---

[7]Radnor J. Paquette, Norman Ashford, and Paul H. Wright, Transportation Engineering (New York: Ronald Press Co., 1972), pp. 404-417.

[8]The Asphalt Institute, Asphalt in Pavement Maintenance (College Park, MD: The Asphalt Institute, 1967), p. 5.

[9]Tennessee Department of Highways, Maintenance Field Operations Manual (Nashville: Tennessee Department of Highways, 1971), pp. 2-3--2-13.

In accordance with the manual, roadway maintenance includes activities such as spot and continuous premix patching of bituminous (asphalt) and concrete surfaces to correct surface irregularities, edge failures, leveling of depressed wheel areas and other potential surface hazards on roadways and shoulders, crack pouring and joint repair to prevent the entry of moisture and debris into the base and subgrade, resurfacing of the roadway with bituminous overlay to restore smooth riding surface and skid resistance properties to the surface, seal coating with hot liquid asphalt and cover aggregate to protect the existing surface and to seal open cracks on roadways and shoulders, and patching of gravel shoulders by replacing lost material and grading. Drainage maintenance includes cleaning and reshaping of roadside ditches to restore original grade and cleaning of culverts, pipes, and catch basins by removing accumulated dirt and debris. Roadside maintenance activities include machine mowing of roadside vegetation within the designated mowing limits of the right-of-way, chemical control of vegetation to eliminate noxious weeds and vegetation and to retard their growth along guardrails and in other areas, brush and tree cutting to restore sight distances and eliminate traffic hazards, and maintenance of landscaped areas, including trees, shrubs, and plants, by replanting or replacing,

cultivating, pruning, thinning, and watering, and reseeding, mulching, resodding, and fertilizing of backslopes, medians, and other areas to restore vegetation cover for erosion controls and beautification. Snow and ice removal activities include plowing of snow and ice from roadways and shoulders, including ramps and interchanges, spreading of chemicals for snow and ice removal to maintain safe driving conditions, and stockpiling and loading of chemicals, sand, and other abrasive materials to be used for snow and ice control. Finally, extraordinary maintenance includes removing rocks and other slide debris as well as any excavating necessary to control or preclude recurrence, repairing major roadway settlements, including the loading, hauling, and placement of suitable material to restore and maintain the roadway in a safe condition, and the removal of debris due to accidents, severe storms, or other natural disasters. These are the selected activities for which the cost data were obtained from the Department of Transportation Maintenance Management Office in Nashville.

CHAPTER III

TERRAIN AND CLIMATE OF TENNESSEE

Because the 450 miles of I-40 run almost the entire length of Tennessee, the ensuing discussions of terrain and climate are general and statewide. Consideration of the surface characteristics of Tennessee is supported by a profile of I-40 as it traverses the state (see Figure 2). The general pattern of Tennessee's climate is discussed in terms of temperature, precipitation, and snowfall with some emphasis on the associated influences of terrain.

Overview of Terrain

The terrain of Tennessee is quite varied, and the 450 miles of I-40 traverse the entire spectrum. The western part of the state, between the loessial bluffs overlooking the Mississippi River and the western valley of the Tennessee River, includes the three physiographic sections of the Coastal Plain Province known as the Mississippi Alluvial Plain, the Mississippi Loessial Upland, and the East Gulf Coastal Plain. This is a region of relatively flat to gently rolling terrain sloping gradually from 200 to 250 feet in the west to 600 feet in the hills overlooking the Tennessee River

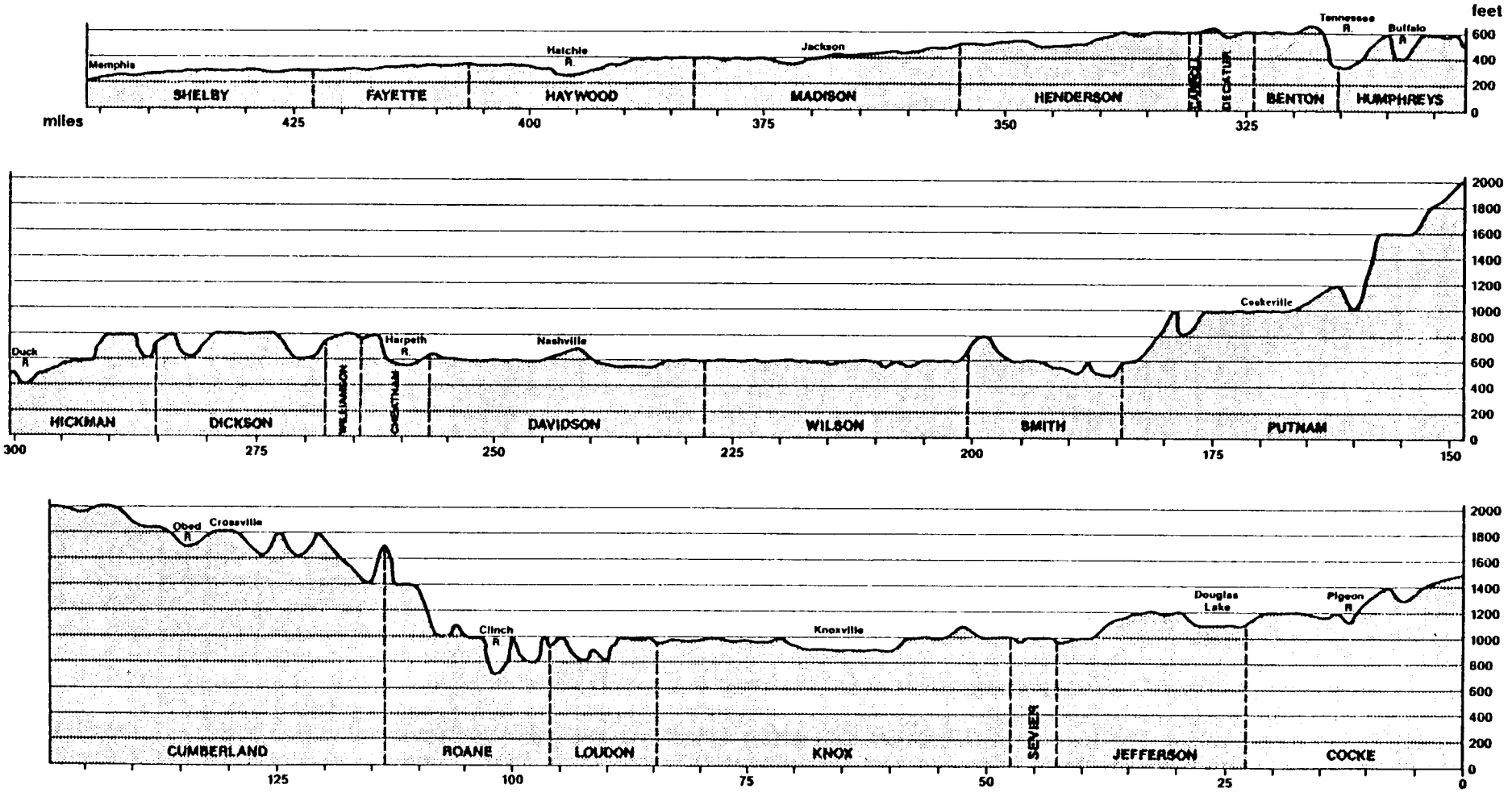


Figure 2. Profile of the I-40 Roadway in Tennessee.

Valley.[10] The hilly Highland Rim section stretches from the Tennessee River Valley to the Cumberland Plateau in the east and encircles the area known as the Central or Nashville Basin. Elevations in the Highland Rim range from 600 feet along the Tennessee River to 1000 feet in the eastern section. The Highland Rim rises 300 to 400 feet above the Central Basin, which is generally a rolling plain at about 600 feet elevation except for a band of hills reaching 1000 feet south of Nashville. The Cumberland Plateau, thirty to fifty miles wide, extends northeast to southwest with an average elevation of 2000 feet. The Plateau is bounded on the east by the Great Valley of East Tennessee of the Appalachian Valley and Ridge Province. The Great Valley of East Tennessee, paralleling the Cumberland Plateau to the west and the Great Smoky Mountains to the east, is a valley varying in width from thirty miles in the south to ninety miles in the north. Within the valley is a series of generally parallel linear ridges, rising, as a rule, less than 1000 feet above the rolling lands of the valley. The Smoky Mountains, part of the Southern Blue Ridge Province, lie along the Tennessee-North Carolina border

---

[10] All values for elevation in this study are measured from Mean Sea Level (MSL). Values for local relief are absolute values measured from the local ground level.

and represent the highest and most rugged terrain of Tennessee, with numerous peaks reaching 4000 to 6000 feet elevation. Specifics of the terrain along the I-40 roadway are covered in the analysis sections.

The drainage systems of Tennessee (except for a small area east of Chattanooga) all flow into the Mississippi River system. The extreme western section of the state is drained by small rivers, such as the Natchie and the South Fork of the Forked Deer, which flow directly into the Mississippi River. Otherwise, drainage is into either the Cumberland or Tennessee rivers. The Cumberland River, which drains the north-central portions of Tennessee, rises in the Cumberland Mountains in Kentucky, flows southwest and south into Tennessee, runs through Nashville, and then turns north to reenter Kentucky. The Tennessee River, formed by the Holston and French Broad rivers as they join at Knoxville, flows southwest along the Great Valley of East Tennessee to Chattanooga, cuts southwest and through the Cumberland Plateau into Alabama, reenters Tennessee at the Alabama-Mississippi state line, and then flows north through Tennessee into Kentucky. Important tributaries of the Tennessee include the Clinch, Little Tennessee, Hiwassee, Buffalo, Elk, and Duck rivers.

Overview of Climatic Patterns

Tennessee's climate is generally characterized as a humid subtropical type, with warm, humid summers and mild winters. Statewide average annual temperatures vary from 60°F in the southwest to 45°F in the higher elevations of the Great Smoky Mountains. Because of the standard decrease of temperature with increase in elevation, the average summer and winter temperatures are lower on the Cumberland Plateau and in the Smoky Mountains than in the Great Valley of East Tennessee. January temperatures average 35°F in East Tennessee and 45°F in West Tennessee, while July temperatures average 75°F in East Tennessee and 80°F in West Tennessee.[11]

Average precipitation in Tennessee decreases slightly from south to north. This trend is modified somewhat by the influence of terrain, for average precipitation is generally higher at the higher elevations. For example, the average annual precipitation in West Tennessee increases from 46 inches in the Mississippi Bottomlands (elevations of 200 to 300 feet) to 54 inches in the hills along the Tennessee River (elevations of 600 feet). In Middle Tennessee,

---

[11] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Heating and Cooling Degree Days for Tennessee, Technical Memorandum 24 (1978), p. 2.

precipitation varies from a maximum of 45 inches in the Nashville Basin (average elevation of 600 feet) to 50 to 55 inches in the surrounding Highland Rim (average elevation of 1000 feet). Fifty to 55 inches fall annually on the Cumberland Plateau (elevation of 2000 feet). In the Great Valley of East Tennessee, precipitation decreases from more than 50 inches in the south to 40 inches in the north. The mountains of the eastern Tennessee border have the highest average annual precipitation, with amounts up to 80 inches on the higher peaks.[12]

The seasonal distribution of precipitation is similar throughout the state. The highest amounts occur during the winter and early spring because of more frequent passage of large-scale cyclonic storms over and near the state during those months. A secondary maximum of precipitation occurs in midsummer because of frequent thunderstorms. The lowest precipitation amounts occur in the fall, when slow-moving high pressure cells dominate the synoptic pattern.[13]

---

[12] Robert R. Dickson, "The Climate of Tennessee," in Climates of the States, vol 1: Eastern States (Port Washington, NY: Water Information Center, 1974), p. 371.

[13] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Climatology of the United States No. 60, Climate of Tennessee (1977), p. 4.

Average annual snowfall varies from 4 to 6 inches in the southern and western parts of the state and in the Great Valley of East Tennessee to more than 10 inches on the Cumberland Plateau and the eastern mountains. Because of the relatively mild winters, a snow cover rarely persists for more than a few days.[14]

Climatological Data

Thus far the climatological information discussed has dealt with statewide trends and patterns. Attention is now directed to the climatological information taken from the fifteen reporting stations along and within twenty-five miles of the I-40 roadway (see Table 2, page 9, and Figure 1, page 10). The data as presented in the NOAA summaries were transposed to correlate with the fiscal year format (July to June) of the maintenance cost data. As an initial investigation, temperature and precipitation data were to be correlated with the different maintenance costs to identify significant statistical relationships. Before such an investigation was made, however, discussions with various highway maintenance personnel and subsequent research eliminated the statistical approach.

---

[14]Dickson, op. cit., footnote 12, p. 371.

The climatological data for the study area along I-40 present few anomalies. The distribution of precipitation follows the statewide pattern, with the highest amounts during the winter and early spring (March) and a secondary maximum in late summer because of thunderstorm activity. The lowest amounts occur in October. The average annual precipitation for the five-year period was 55.5 inches with a standard deviation of 5.6 inches; average annual snowfall was 11.3 inches with a standard deviation of 3.65 inches. The standard deviations indicate some variability in the precipitation regime along I-40. The highest precipitation average was for Benton and Humphreys counties with 63.7 inches, and the highest snowfall total was 17.3 inches in Cumberland County. Five-year, thirty-minute rainfall intensity amounts ranged only from 1.5 to 1.6 inches across the study area.

The temperature regime presents less variation than the precipitation regime. Since the I-40 study is based on an east-west linear feature with little latitudinal amplitude (57 minutes), most variations in temperature are due to the influence of terrain. Since the elevation of the I-40 roadway varies only from 200 feet in the extreme western end to 2000 feet on the Cumberland Plateau, such temperature differences are minimal. The standard deviation for the mean annual

temperature of all the reporting stations was only 1.48°F. The standard deviation for the annual range of temperature (difference between extreme high and low temperatures) was 2.42°F. The average monthly maximum temperatures varied only 4.3°F, and the average monthly minimum temperatures varied 8.4°F among the stations. Hence there is little spatial variability in the temperature data reported by the fifteen climatic stations along I-40. Pavement systems throughout the study area, thus, experience similar temperature regimes.

Temperature is also not seen as a significant factor in maintenance costs along I-40, because Tennessee lies just south of the area where frost may be expected to penetrate pavement and base to a depth of 12 inches (minimum significant depth for frost heaving) on the average of one year in ten.[15] The effect of frost action on pavement systems is discussed further in Roadway Costs. Temperatures in Tennessee do go below freezing during the winter, but not for a significant length or to a significant degree to penetrate the pavement, base, and subgrade. Mr. Fred Corum, Region I Chief Highway Maintenance Engineer,

---

[15] Highway Research Board, National Cooperative Highway Research Program Report 132, Relationships Between Physiographic Units and Highway Design Factors (Washington, D.C.: Highway Research Board, National Academy of Sciences, 1972), p. 18.

stated that low temperatures occasionally generated contraction and reflection cracks (cracks in asphalt overlays which reflect the crack pattern in the pavement structure underneath) in asphaltic pavements that have been placed over old concrete surfaces. Moisture that becomes trapped between the old concrete layer and the newer bituminous surface readily freezes when the temperature goes below freezing. It is difficult to pinpoint every location of this type of pavement, but Mr. Corum suggested they occur throughout the state. He also noted that extremely high temperatures can cause pavements to lose strength and "buckle" under traffic loading. Mr. Corum emphasized that, in his opinion, precipitation is a more significant factor than temperature in affecting highway maintenance costs.[16] The aforementioned comments, plus the uniform temperature regime along the study area, suggest that temperature (and especially mean values) not be considered as a significant factor in any statistical investigation. Additionally, it was determined that precipitation data, in any form, are not necessarily indicative of the soil moisture conditions beneath the pavement surface. Properly constructed highways are designed to prevent

---

[16] Fred Corum, Region I Chief Highway Maintenance Engineer, Tennessee Department of Transportation, Knoxville, personal interview, 12 October 1979.

the infiltration of surface water; therefore, the variation in soil moisture content in the pavement system is more dependent on the type of soil and the existing drainage conditions than upon the quantity and frequency of precipitation. Basically, an investigation of climatological factors did not indicate a significant relationship between climate (as an isolated environmental factor) and maintenance costs on I-40 in Tennessee.

CHAPTER IV

ANALYSIS OF MAINTENANCE COSTS

This chapter looks at each maintenance cost category and discusses the environmental factors that affect that maintenance activity. The distribution of the maintenance cost data along I-40 is shown on maps. Selected high and low-cost areas are identified and the spatial variability explained through an analysis of the combined effects of climate and terrain.

I. ROADWAY COSTS

Roadway maintenance costs are largely concerned with the deterioration of pavement surfaces. Three contributing factors that act in conjunction to cause pavement deterioration are traffic loading conditions, inadequate pavement materials, and environmental factors, specifically temperature and moisture. Each factor will be discussed followed by the identification and analysis of selected high-cost areas.

Traffic Loading

As discussed in the Introduction, traffic loading, particularly from heavy trucks, causes significant damage to pavement surfaces. The design loads for interstate highways are 73,280 pounds (maximum gross

weight), single-axle limit of 18,000 pounds, and tandem-axle limit of 32,000 pounds. In Tennessee, however, only the gross weight limit is enforced (the degree of enforcement is questionable), and the rationale for this policy, established in 1963, is to allow "natural resource" trucks, such as coal, gravel, and dirt trucks, unlimited access to the Interstate System, a boost to the coal and trucking industries. Theoretically, if a truck were loaded with a million pounds, it could move without damaging the roadway as long as the million pounds were spread over enough axles. By exceeding the per-axle weight limit, Tennessee's heavy trucks are contributing significantly to the deterioration of the Interstate System. Highway engineers estimate that an additional 2000 pounds per axle, permitted on a regular bases, would shorten the life of the highway by 25 to 40 percent.[17] Table 3 shows the highway traffic volume and vehicle classification counts for I-40. Emphasis should be on the column representing tractor-trailer traffic. From the vehicle classification count at the Tennessee River Bridge in Humphreys County, it can be seen that the volume of heavy truck traffic, both as a percentage of total traffic and in absolute numbers, is higher on the I-40

---

[17]Sherrill, op. cit., footnote 2, p. 499.

TABLE 3

VEHICLE CLASSIFICATION COUNTS FOR I-40[1]

Location	Passenger Car	Motorcycle	Bus[2]	Single-Unit Truck[3]	Tractor-Trailer Truck[4]
Weight Station in West Knox County	73.0 (25493)	0.42 (147)	0.20 (70)	16.3 (5692)	10.03 (3503)
West of SR 109 in Wilson County	70.9 (16462)	0.54 (125)	0.28 (65)	19.8 (4597)	8.39 (1948)
East Nashville in Davidson County	74.5 (19254)	0.43 (111)	0.16 (41)	20.2 (5226)	4.71 (1217)
Tenn. River Bridge in Humphreys County	58.8 (10019)	0.09 (15)	0.47 (80)	12.5 (2130)	28.10 (4788)

[1]In terms of percent of average daily traffic. Figures in parentheses represent number of vehicles.

[2]Buses include school and commercial.

[3]Single-unit trucks include pickup, panel van, dual rear tire, and three and four-axle vehicles.

[4]Tractor-trailer trucks include all axle combinations.

Source: Tennessee Department of Transportation.

segment between Nashville and Memphis than between Nashville and Knoxville. The segment of Interstate 75 originating in Loudon County (just west of Knoxville) and Interstates 24 and 65 in Nashville siphon truck traffic from I-40 towards key transportation centers in Atlanta, Birmingham, Louisville, and St. Louis. Trucks using I-40 between Memphis and Nashville generally remain on I-40 for the entire segment.

Pavement Materials

Inadequate pavement materials contribute to pavement deterioration through underdesigning and poor construction techniques. Underdesigning occurs when the actual pavement thickness is less than the design critical thickness based on anticipated traffic. Poor construction techniques cause the quality of pavements to suffer from inadequate mixing or compaction of materials or the use of weak binders and poor aggregates.[18] It is difficult, if not impossible, in a study of this type, to ascertain the quality of workmanship or the correct use of materials on I-40 in Tennessee; therefore, for convenience, it is assumed that the quality of workmanship and the use of materials were in

---

[18]Organization for Economic Cooperation and Development, Maintenance Techniques for Road Surfacings: Assessment, Choice of Treatment, Planning, Implementation (Paris: Organization for Economic Cooperation and Development, 1978), pp. 35-36.

accordance with the standards established by the Tennessee Department of Transportation, the Federal Highway Administration, and the American Association of State Highway and Transportation Officials.

Environmental Factors

Changes in environmental factors such as temperature and moisture result in changes in strength (bearing capacity), resiliency or stiffness, durability, and volume (shrink and swell) of pavement and subgrade materials. Usually, these changes result in significantly detrimental effects on pavement performance. The most significant effect is the change in subgrade support for flexible and rigid pavements as a result of moisture changes or frost action. In Tennessee, however, frost action is not a significant factor. Frost penetration into soil depends not only on the intensity and duration of subfreezing temperatures, but also on the frost susceptibility and the moisture content of the soil. Frost penetration is considerably greater on roadways underlain by granular soils with low moisture content than on fine-grained soils with high moisture content. High moisture content retards frost penetration because of the high latent heat content released upon freezing. The U.S. Army Corps of Engineers utilizes a frost design classification system based on the

susceptibility of soils to frost penetration as a major function of soil texture. Frost-susceptible soils are classified as F-1, F-2, F-3, and F-4, in order of increasing susceptibility to frost heaving or to subgrade weakening as a result of frost melting.[19] Interestingly enough, no Tennessee soils fall into any of these categories; all are considered relatively safe from freezing and outside the freezing zone.[20] When surveyed by the Transportation Research Board in 1974 as part of a national research effort on highway design in seasonal frost areas, Tennessee highway officials responded that the effects of frost were not considered in highway design but that some low-temperature contraction cracks did affect pavement maintenance.[21]

More important to roadway maintenance on I-40 in Tennessee are the volume changes in swelling clays and shales related to changes in moisture content. When the clays dry, the soils are pulled together under

---

[19]U.S. Army Engineer School, Engineer Subcourse 360-1, Soils Engineering (Fort Belvoir, VA: U.S. Army Engineer School, 1975), p. 6-3.

[20]Highway Research Board, op. cit., footnote 15, pp. 47-48.

[21]Transportation Research Board, National Cooperative Highway Research Program Synthesis of Highway Practice 26, Roadway Design in Seasonal Frost Areas (Washington, D.C.: Transportation Research Board, National Research Council, 1974), pp. 88, 95.

tension, and on wetting, the tension decreases and the soils expand. Volume changes cause pavement cracking, distortion, and disintegration and generally disrupt the pavement surface. Soils of high volume change are very widespread in areas of West Tennessee traversed by I-40. Coarse-grained soils are much less affected by moisture than the fine-grained clays and silts. The larger void openings allow gravity water to drain more easily through the soil. The capillary potential for coarse-grained soils is also less than for fine-textured soils. Coarse-grained soils are more prevalent on the Cumberland Plateau and in the Great Valley of East Tennessee than in West Tennessee.

How does moisture enter the pavement systems to create the loss of bearing capacity in the subgrade and base layers? Moisture may permeate the sides, particularly where coarse-grained layers are used or where surface drainage systems on the roadway are inadequate. Surface water may enter joints and cracks in the pavement, penetrate at the edges of the surfacing, or percolate through the surfacing and shoulders. Moisture can enter the subgrade and base layers as water tables rise in periods of high precipitation (winter and spring

in Tennessee). Finally, water may move vertically in capillaries or interconnected water films.[22]

In order to combine information on soils with highway design criteria, highway engineers use a soil classification system approved by the American Association of State Highway Officials (AASHO).[23] This system is based on grain size and distribution, liquid limit, and plasticity index. The soils are classified into seven principal groups, ranging from A-1, consisting of gravelly soils of high bearing capacity, to A-7, consisting of clay soils having low strength when wet. In short, the A-1 through A-3 soils are suitable for well-drained and compacted subgrades under pavements of moderate thickness. Groups A-4 through A-7, the silt-clay materials, are regarded as fair to poor as subgrades and require a subbase layer or an increased base course thickness.[24]

Distribution of Costs

The distribution of roadway maintenance costs is enumerated in Table 4 and depicted in Figure 3.

---

[22]U.S. Army Engineer Waterways Experiment Station, op. cit., footnote 4, p. 4-2.

[23]The organization is currently known as the American Association of State Highway and Transportation Officials (AASHTO).

[24]W. L. Schroeder, Soils in Construction (New York: John Wiley & Sons, 1975), pp. 44-48.

TABLE 4

RANKING OF COUNTIES BY FIVE-YEAR AVERAGE (1974-1979) MAINTENANCE COSTS PER MILE FOR SELECTED ACTIVITIES

	Roadway Costs		Drainage Costs		Snow & Ice Removal Costs		Extraordinary Costs		Roadside Costs		Total Costs	
1.	Roane	5580	Roane	356	Decatur	1681	Cocke	1497	Sevier	1466	Roane	8191
2.	Humphreys	2731	Henderson	318	Cheatham	1400	Roane	791	Benton	1454	Benton	5572
3.	Benton	2730	Benton	298	Cumberland	1280	Cumberland	581	Henderson	1432	Humphreys	5310
4.	Decatur	2443	Humphreys	286	Putnam	992	Putnam	275	Madison	1391	Decatur	5057
5.	Madison	1512	Madison	268	Benton	969	Smith	272	Cheatham	1309	Cocke	4948
6.	Cocke	1473	Haywood	226	Humphreys	869	Fayette	220	Cocke	1280	Madison	3460
7.	Haywood	1244	Hickman	193	Roane	712	Humphreys	198	Humphreys	1226	Cheatham	3294
8.	Sevier	895	Fayette	180	Hickman	666	Hickman	171	Fayette	1142	Putnam	3078
9.	Putnam	822	Cocke	134	Henderson	623	Benton	121	Hickman	1082	Sevier	3054
10.	Fayette	712	Decatur	131	Cocke	564	Cheatham	115	Haywood	1015	Cumberland	3024
11.	Hickman	500	Putnam	130	Sevier	554	Sevier	76	Wilson	904	Haywood	2905
12.	Cumberland	467	Cumberland	78	Dickson	480	Decatur	66	Putnam	859	Henderson	2832
13.	Cheatham	445	Sevier	63	Smith	418	Haywood	38	Smith	837	Hickman	2612
14.	Henderson	430	Wilson	41	Wilson	415	Dickson	29	Roane	752	Fayette	2299
15.	Wilson	280	Smith	38	Haywood	382	Henderson	29	Decatur	736	Smith	1708
16.	Smith	143	Cheatham	25	Madison	273	Madison	16	Cumberland	618	Wilson	1655
17.	Dickson	78	Dickson	24	Fayette	45	Wilson	15	Dickson	603	Dickson	1214

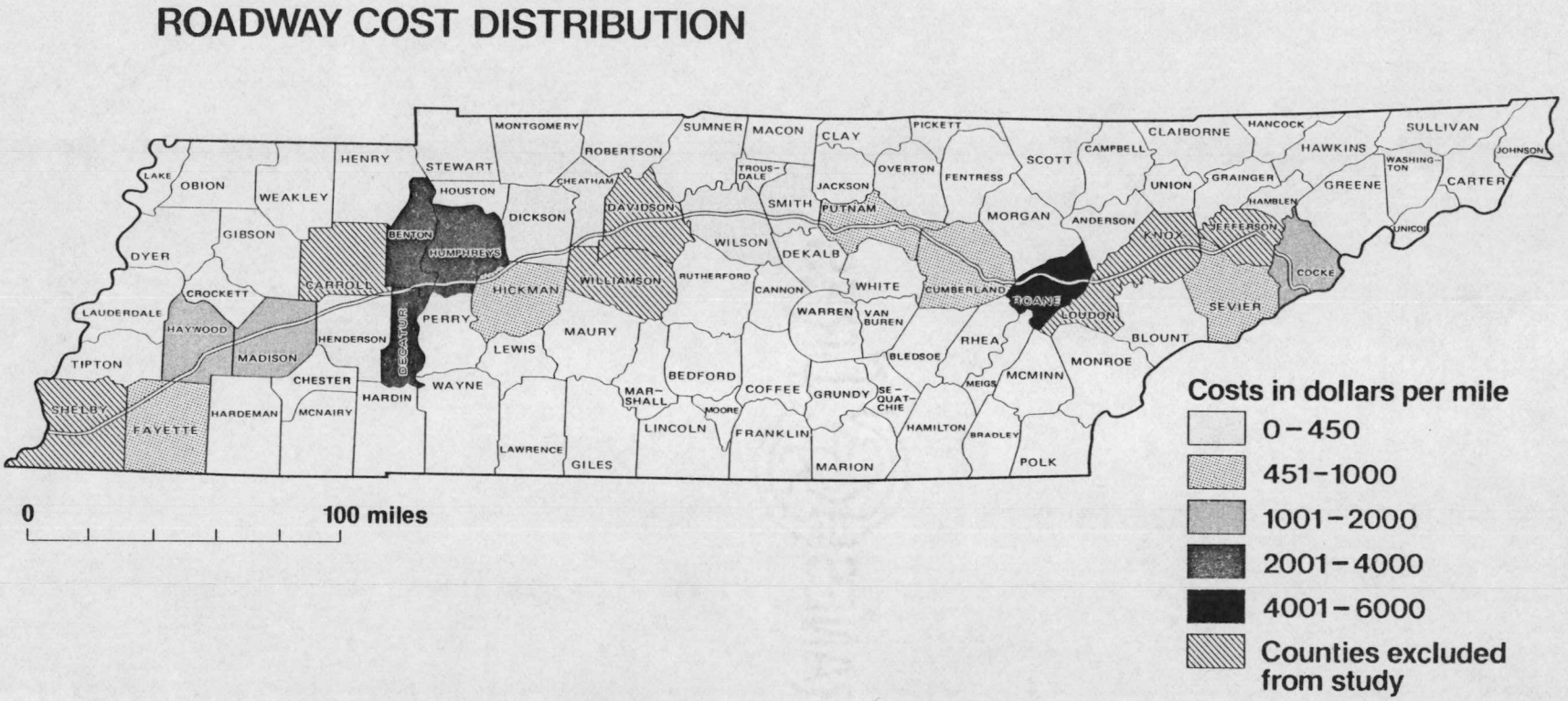


Figure 3. Distribution of Roadway Costs.

Roane County averaged the highest roadway maintenance costs per mile, $5580. This figure is almost $3000 per mile greater than the second-ranked county, Humphreys, with $2731 per mile. Roane County's major expenditures were for continuous premix patching of roadway shoulders and for complete resurfacing with bituminous overlay. Roane County expended seventy times the roadway maintenance costs of Dickson County (the lowest-ranked county in the study, with only $78 per mile). The map of roadway costs also shows a cluster of three high-cost counties along the Tennessee River Valley in West Tennessee--Humphreys, Benton, and Decatur.

Analysis of High-Cost Areas

What factors contributed to Roane County's significant margin as the highest-ranked county in roadway maintenance costs? For one, I-40 crosses the eastern Cumberland Escarpment in the west side of the county (see Figure 4). This segment of I-40 has the steepest grade in the study. The nearly 2000 tractor-trailer trucks that move through Roane County on I-40 daily generate additional wear on the pavement surface as they slowly ascend the escarpment going westbound and continually decelerate and brake as they descend the escarpment heading east on I-40. Grade, in this

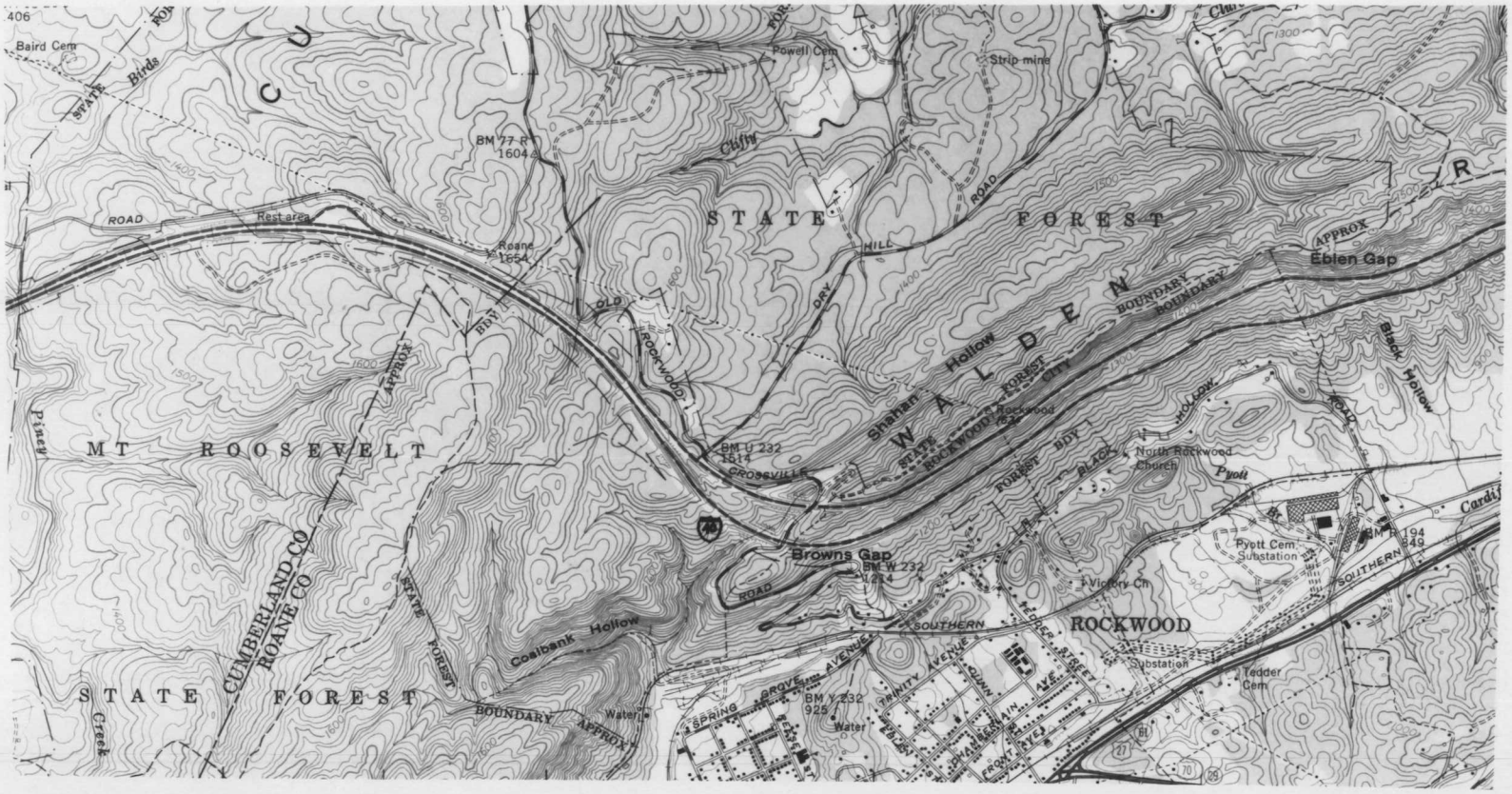


Figure 4. I-40 Roadway on the Eastern Escarpment of the Cumberland Plateau in the Vicinity of Rockwood.

Scale: 1:24,000.

study, is a mean value, used as a comparative index among counties, and is found by taking the difference in elevation between the highest and lowest points on the roadway and dividing by the centerline mileage in the county. Values ranged from 41.0 feet per mile for Roane County to 4.2 feet per mile for Henderson County.

Second, the I-40 segment in Roane County passes over the Wallen-Talbott soil association (stoney and clayey soils from sandstone, shale, and limestone) and the Fullerton-Bodine association (cherty and clay soils from dolomitic limestone). The Wallen-Talbott soils have AASHO soil classifications of A-6 or A-7, with high shrink-swell potential and poor suitability as a subgrade or fill. The Fullerton-Bodine soils are somewhat better, as they are classified A-2 or A-4 and are considered fair soils for subgrade or fill.

Also basic to the discussion of roadways in Roane County are the geologic foundations of the area. In the Valley and Ridge, the ridges are either underlain by cherty dolomite (Chestnut Ridge) or interbedded sandstone and shale (Dug and Pine ridges). The Pennington shale is found along the escarpment at Rockwood. This shale weathers and breaks down rapidly to a relatively weak, impervious clay. Colluvium and slope debris wash down from the higher elevations and accumulate over the shale along the base and lower

slopes of the escarpment. Percolating water passes through the colluvium to the impervious clays or shales and forms a saturated zone. When embankments (fills) are placed on this material, particularly on hillsides or when the toe support of the slope is removed by cuts, the potential for roadway instability is high (see Figures 5 and 6). Subsurface moisture in the saturated zone easily penetrates the subgrade and base layers causing instability. In the worst case, the roadway completely fails as the slope material slides downslope (see further discussion of landslides under Extraordinary Costs in Roane County). High annual precipitation amounts (61.8 inches, second highest in the study) contribute further to the problem. The steep side slopes in the area (as steep as 45 percent on the escarpment) carry high amounts of runoff to the I-40 roadway, necessitating extensive drainage systems to cope with the surface as well as subsurface water (see further discussion under Drainage Costs).

What factors cause the high roadway maintenance costs in the three counties along the Tennessee River? Humphreys County is on the Highland Rim, while Benton and Decatur counties are transition areas between the East Gulf Coastal Plain and the Highland Rim. In Humphreys County, the upland has been thoroughly dissected by a dendritic drainage system, with the

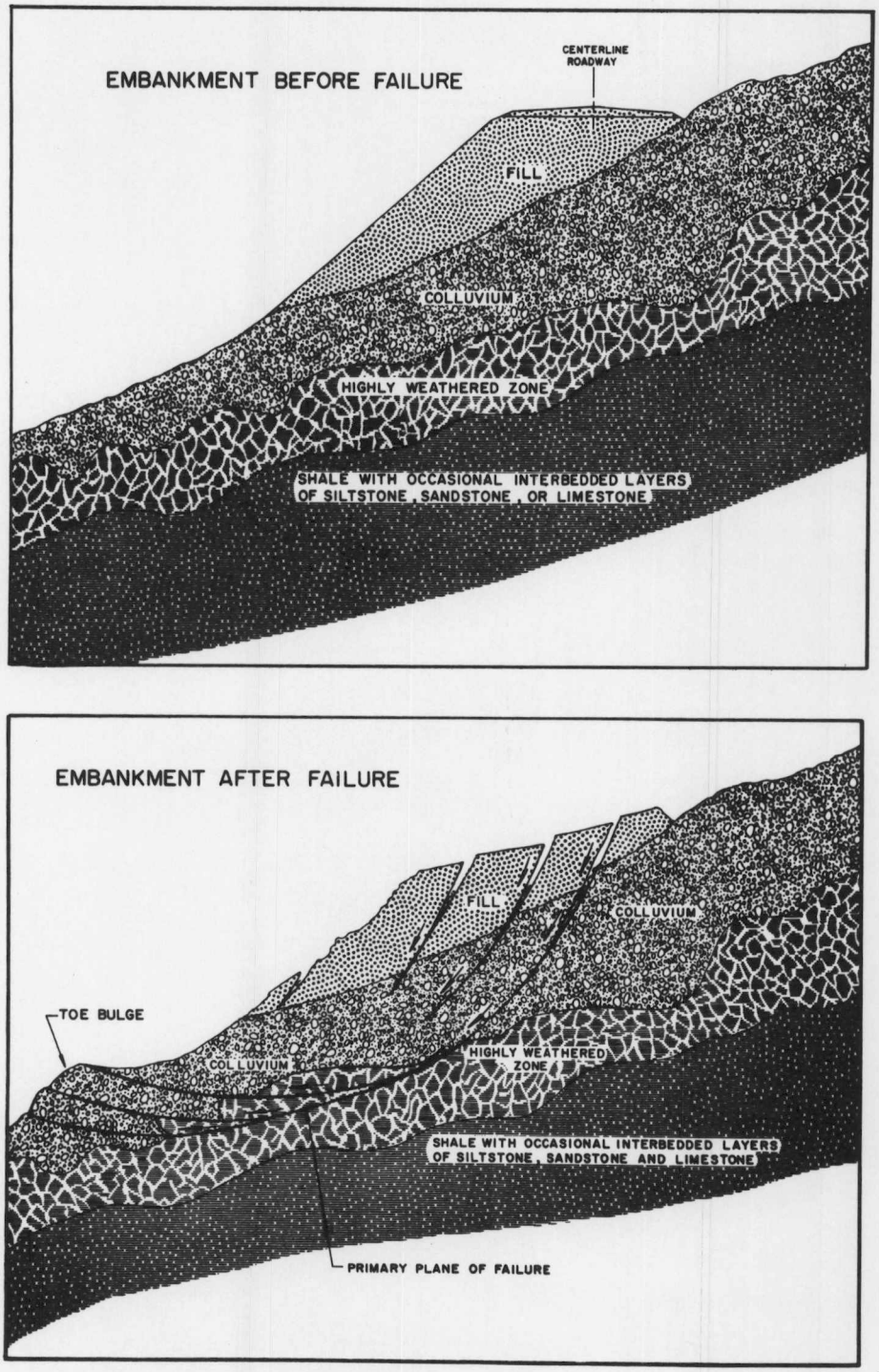


Figure 5. Embankment along I-40 in Roane County as Viewed Before and After Failure.

Source: David L. Royster, "Some Observations on the Use of Horizontal Drains in the Correction and Prevention of Landslides," paper presented at the 28th Annual Highway Geology Symposium, Rapid City, SD, August 1977.

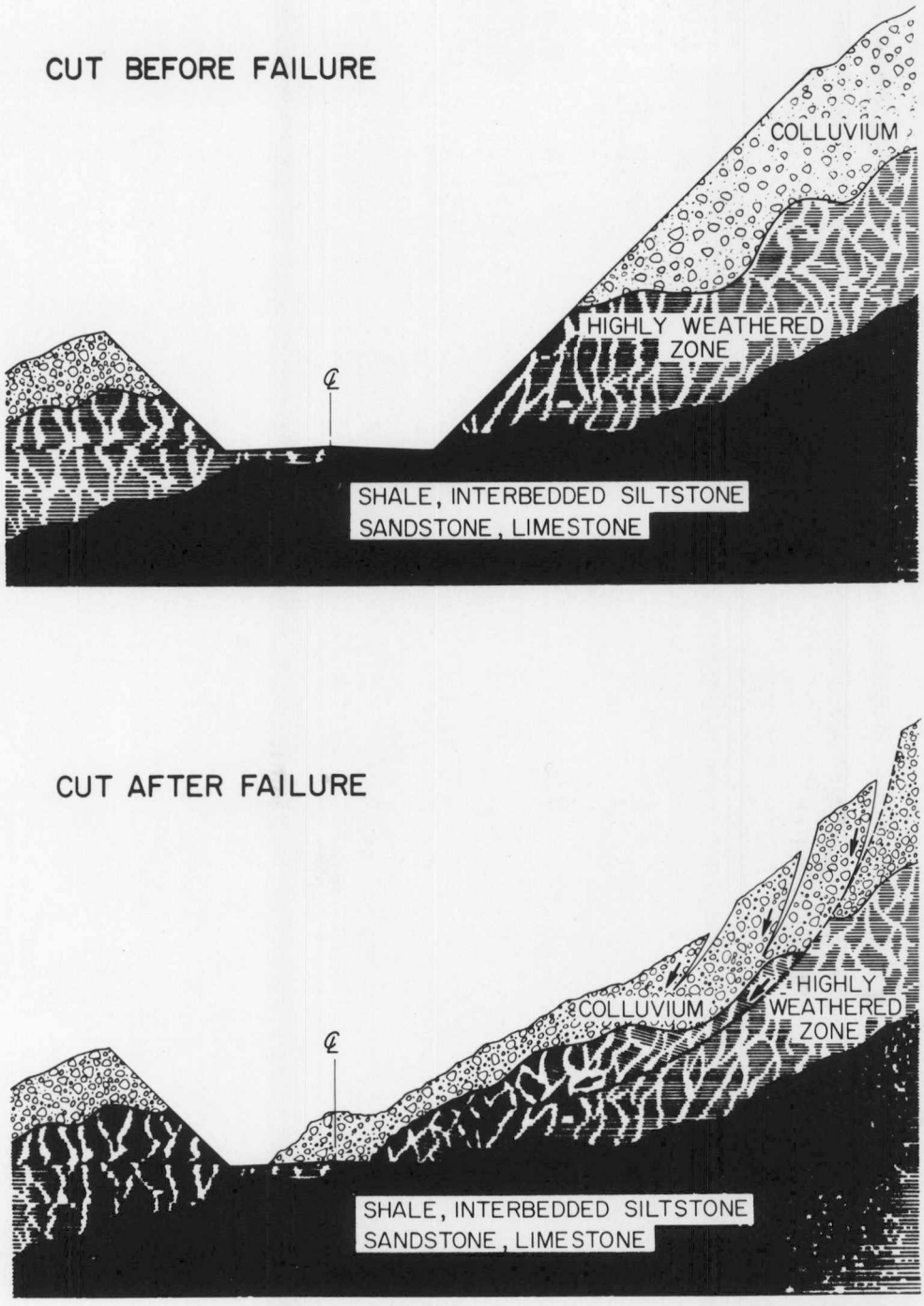


Figure 6. Cut Slope along I-40 in Roane County as Viewed Before and After Failure.

Source: David L. Royster, "Some Observations on the Use of Horizontal Drains in the Correction and Prevention of Landslides," paper presented at the 28th Annual Highway Geology Symposium, Rapid City, SD, August 1977.

principal streams being the Duck, Buffalo, and Tennessee rivers. As a result, much of the I-40 roadway is on lowland and riverbed soils, such as the Ennis series, and on the Bodine-Dickson soils on the interfluves. The closely spaced valley system has necessitated an almost continuous use of fills across the lowlands and bottom areas. During a recent winter field trip, after a period of heavy rainfall, I saw moderate flooding on the north side of the roadway for several miles. Because of a fragipan or claypan formed at depths of 28 to 36 inches in the thin loess mantle of the area, a perched water table exists during the winter months. The roadway soils are rated A-4 to A-7, with moderate shrink-swell potential and poor suitability for subgrade and fill. The problem of excessive moisture in the subgrade and base is compounded by the high amount of annual precipitation (63.7 inches, the highest amount in the study). Precipitation during the late winter and early spring months of January, February, and March, averaging 6.4 inches per month (also the highest amount in the study for those months), contributes to the perched water table. High precipitation amounts in these months are significant because low potential evapotranspiration and melting snow result in a saturated soil condition.

Benton County, which borders Humphreys County on the Tennessee River, averaged only one dollar per mile less than Humphreys in roadway maintenance costs. The I-40 roadway in Benton County passes over the flood plain of the Tennessee River and then continues westward into the cherty, limestone hill section, which is highly dissected and characterized by narrow ridges, steep slopes, and narrow flood plains (see Figure 7). Numerous springs are found in this area. As in Humphreys County, the I-40 roadway lies on many areas of fill in the bottomlands. The same soils are found in Benton as in Humphreys County, with the Bodine and Dickson series on the interfluves, the Humphreys series on the terraces, and the Ennis series on the bottomlands. Except for the Bodine series, the soils along I-40 here are considered only poor to fair as subgrade and fill material, and the combination of thin loess and cherty limestone residuum yields siltpans at 24 to 40 inches. Precipitation in Benton County is also high.

In the third high-cost county, Decatur, the I-40 segment passes over three physiographic sections--the Coastal Plain, the Loess Plain, and a small section of the Limestone Hills. The Coastal Plain section is underlain by unconsolidated material ranging from loose gravel and sand to heavy clay. The Loess Plain is an area of mild relief with a loess mantle as deep as four



Figure 7. I-40 Roadway in the Hills of Benton County.

Scale: 1:24,000.

feet. Needless to say, the soils in these areas are not conducive to well-drained, trouble-free roadbeds. In fact, the Savannah soil on the Loess Plain has a hardpan at a depth of two feet, and the Dulac soils on the ridge crests are classified A-7, with a perched water table from December to April.

In general, the three counties of Humphreys, Benton, and Decatur, are high in roadway maintenance costs because of poor subgrade and fill soils and the presence of high water tables attributable to the underlying loess mantle and abundant precipitation. In addition, all three counties have relatively high roadway gradients (an average of 23.5 feet per mile compared with 7.0 feet per mile for the other four western counties). The effect of steep gradients is significant because of the heavy volume of tractor-trailer trucks on I-40 between Nashville and Memphis (see Table 3, page 32). While the grade in these counties is not as great as in Roane County, the daily heavy truck traffic is approximately 2.5 times as great. Again, the interaction of abundant precipitation with existing soil and moisture conditions greatly affects the continued stability of the subgrade and fill materials and thus contributes to high roadway maintenance costs.

Highway maintenance engineers recognize these problem areas and attempt to mitigate the adverse

effects. For example, Portland cement concrete pavement is used in the three most western counties of the study--Fayette, Haywood, and Madison. Concrete pavement used with a stabilized, sandy base helps to offset weak areas in the subgrade (see Concepts of Highway Maintenance). Calcium chloride and "pug-mill" (a moistened mixture of sand and gravel) are also added to the subgrade to stabilize and strengthen the soil. Compaction is used to rearrange the soil particles to form a denser mass, with a resulting change in engineering properties such as strength, permeability, and compressibility.[25] Perhaps the most important measure used by maintenance engineers is the employment of both surface and subsurface drainage systems. Inadequate drainage systems will significantly affect the performance of roadways. A more detailed discussion of the relationship between roadways and drainage systems is found in the next section on Drainage Costs. In spite of these measures, however, the counties in the western part of Tennessee continue to rank high in roadway maintenance costs.

---

[25] B. G. Dedmon, Highway Maintenance Engineer, Tennessee Department of Transportation, Jackson, telephone interview, 28 March 1980.

II. DRAINAGE COSTS

The maintenance of highway surface and subsurface drainage systems is critical in preserving a pavement's ability to withstand the effects of precipitation and traffic over long periods of time. This section begins by discussing basic drainage systems and the maintenance of these systems. Next the distribution of drainage costs is shown with an analysis of selected high and low-cost areas.

Drainage Systems

The accumulation of excess water in the base or subgrade underlying any pavement structure can cause damage in several ways. In soils that are partially or completely saturated, the application of dynamic loads causes pore pressures that reduce the internal friction and lower the resistance to shearing. The same principle applies to saturated roadbeds, in that the buoyant effect of the water reduces the weight on the base or subgrade particles and the friction between the particles is reduced. The result is a weakening of the pavement structure. Also, some underlying soils experience high volume change when water is added, resulting in differential heaving and weakening of the pavement. Many of the subgrade and fill soils used with I-40 consist of silt and clay materials which

weaken when wet. Consequently, when the subgrade is not properly shaped and sloped for drainage, water will collect on its surface, beneath the pavement layers, causing the subgrade to lose stability and support. Under traffic loading, the wet subgrade soil will be churned into a mud slurry which can push up into the voids of the aggregate base courses and destroy grain-to-grain interlock. Water may flow underneath the pavement as throughflow from surrounding higher ground and if not drained at a sufficient rate will produce a hydrostatic head (see discussion of hydrostatic heads under Extraordinary Costs in Cocke County). This force causes upheaval and failure in adjacent roadways. Water table levels vary from location to location and from season to season and usually rise after heavy rains, occasionally rising into the subgrade layers. Drainage systems are needed to prevent the water table from reaching the pavement subsurface levels.[26]

All drainage systems can be classified as surface or subsurface, depending on whether the water is above or below the surface when it is first intercepted or collected for removal. Surface drainage systems provide for the interception, collection, and

---

[26]The Asphalt Institute, Drainage of Asphalt Pavement Structures (College Park, MD: The Asphalt Institute, 1966), pp. 1-2.

removal of water from the surfaces of roadways. The removal of surface water is important, because water on roadways interferes with traffic, causes erosion, and if allowed to infiltrate will damage the subgrade. Subsurface drainage systems are designed to intercept, collect, and remove any ground water flow into the subgrade, to lower high water tables, and to drain water pockets or perched water tables. Drainage systems generally include gutters, dikes, ditches (both diversion and interception), culverts, storm drains, subdrains, and vertical wells.[27]

With this basic discussion of drainage systems, emphasis will turn to the maintenance of these systems. This study has assumed that highway engineers designed adequate drainage systems for I-40 on the basis of their analysis of precipitation, terrain, infiltration and runoff, temperature, soils, and ground water information.

With regard to surface drainage, ditches, culverts, and drains must be kept clear of weeds, brush, sediment, and other accumulations of debris that obstruct the flow of water. Ditches are also maintained in line and grade. All of these maintenance activities keep the

---

[27] U.S. Army Engineer School, Engineer Subcourse 359-3, Drainage (Fort Belvoir, VA: U.S. Army Engineer School, 1973), pp. 1-1--1-5.

capacity of the channel at design level. If the channel cross section contains sediment and debris, the geometry of the channel is modified, and the channel cannot carry the flow for which it is designed. In addition, the sediment and debris may kill the grass lining the ditch and thus contribute to subsequent erosion during periods of heavy rainfall. Erosion may be prevented by lining the ditch with gravel or compacted, pre-mixed asphalt. Checkdams are occasionally used to control erosion in side ditches. These dams must be inspected and cleaned regularly to prevent the water from building up and cutting into the banks at the edges of the dam. Clogged culverts are also susceptible to undermining by the build-up of water. During the winter, side ditches, culverts, and drains should be kept free of ice and snow to permit meltwater to escape and prevent ponding.[28] The major problem of subsurface drainage systems is the clogging or "silting up" of pipes and gravel layers caused by percolating water. In areas of soils with high silt and clay contents, the soil particles in suspension are deposited as the water moves through the granular material of the subdrains.[29]

---

[28]U.S. Army Engineer School, Engineer Subcourse 365-2, Roads and Airfields II (Fort Belvoir, VA: U.S. Army Engineer School, 1975), p. 6-3.

[29]The Asphalt Institute, op. cit., footnote 26, p. 4.

Distribution of Costs

The distribution of drainage maintenance costs is shown in Table 4, page 38, and Figure 8. An interesting relationship appears to exist between the maintenance costs for roadways and the maintenance costs for drainage. With a few exceptions (Sevier and Henderson), those counties that ranked high in roadway maintenance costs also ranked high in drainage maintenance costs. In fact, several counties ranked the same for both activities. Roane County ranked first in both activities, Benton County third, Madison County fifth, Cumberland County twelfth, and Dickson County last. As discussed in the analysis of roadway costs, the interaction of abundant precipitation with existing soil conditions is one of the major factors affecting the continued stability of the subgrade and fill materials, which in turn affects the condition of the pavement surface and shoulders. The surface and subsurface drainage systems control the interaction of water with the roadway, so that those areas possessing drainage systems difficult to maintain will also incur high roadway maintenance costs.

Analysis of Costs

Out of the ten highest-ranked counties in drainage maintenance costs, eight (the exceptions are Roane and Cocke) are from West Tennessee--the East

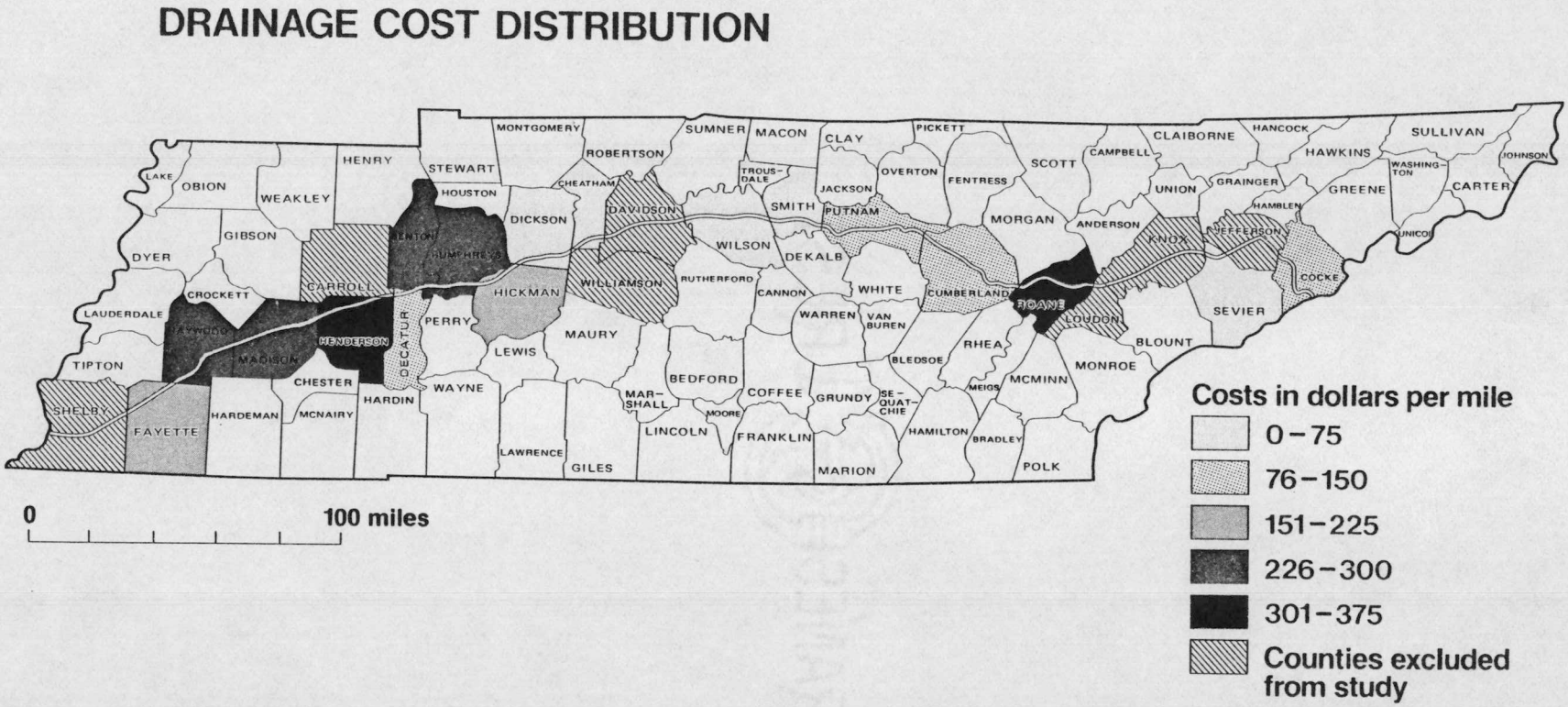


Figure 8. Distribution of Drainage Costs.

Gulf Coastal Plain, the Mississippi Loessial Upland, and the western Highland Rim physiographic sections (see Figure 2, page 20). In these western counties, I-40 passes through areas underlain by soils formed from loess deposits, high in clay and silt content, low in permeability, and generally rated low in terms of soil engineering qualities. For example, the predominant soils along I-40 in Henderson County, ranked second in drainage maintenance costs, are the Cuthbert-Shubuta-Dulac association. These soils have an AASHO rating of A-4 to A-7 and are rated not suitable as a base course, poor to fair as a fill material, and poor to fair as a subgrade, with moderate shrink-swell potentials. Depth to water table for Cuthbert and Dulac soils is 24 inches. Drainage systems are extremely important in controlling the detrimental effects of moisture in these low-strength soils. Ironically, these same soils compound the problem, for as they are transported by runoff and throughflow from surrounding hills and cultivated fields, they clog and "silt up" the protective drainage system.

Areas with inherent geological instability problems and areas with low roadway grades require especially extensive drainage systems to control and remove the water. In addition to what one might consider a normal drainage system for an area of high precipitation, high local relief, steep side slopes, and a steep

roadway grade, Roane County has added an additional 50,000 feet (9.5 miles) of horizontal, subsurface drainage to prevent landslides (see discussion of Roane County in Extraordinary Costs). As a result, Roane County's drainage system is the most extensive per road-mile in the study, offering the potential for unusually high required maintenance. Cocke County has a similar circumstance but to a lesser extent.

The areas of high drainage maintenance costs along I-40 in West Tennessee are characterized by irregular plains, with 50 to 80 percent of the land surface gently sloping and local relief varying from 0 to 300 feet.[30] The average roadway grade for these western counties is 14.6 feet per mile, compared to 23.4 feet per mile for the seven counties ranked lowest in drainage maintenance costs. Average annual precipitation in these western counties was 56.4 inches, 0.1 inch less than the median value for the study. The average maximum rainfall in a 24-hour period was 3.9 inches, compared to the mean of 3.6 inches for all counties. Another intensity factor is the maximum amount of rainfall in one hour that can be expected in any five-year period. For the eight western counties along

---

[30] Edwin H. Hammond, "Classes of Land-Surface Form in the Forty-Eight States, U.S.A." Map supplement no. 4, Annals of the Association of American Geographers 54 (March 1964).

I-40 this amount is 2.1 inches, compared to 1.9 inches for the study as a whole.[31]

If one excludes Roane and Cocke counties' high drainage maintenance costs as largely related to the inordinate system requirements to control landslides, the remaining high-cost counties represent areas of similar terrain and climate. A combination of factors such as mild relief, low grades, poor soils in terms of drainage and engineering stability, and ample precipitation account for the high drainage maintenance costs found along I-40 in West Tennessee.

III. SNOW AND ICE REMOVAL COSTS

Snow and ice removal costs involve chiefly the plowing of snow and ice from roadways and shoulders and the spreading of chemicals on roadways to remove ice and snow and to maintain safe driving conditions. The Tennessee Department of Transportation provides guidelines for the employment of chemicals and snowplows. When icy conditions (sleet, frozen rain, or frozen drizzle) or snowfall begin, road crews are to apply chemicals at a rate of 500 pounds per two-lane mile and

---

[31] U.S. Department of the Interior, Geological Survey, A Proposed Streamflow-Data Program for Tennessee, by V. Jeff May, George H. Wood, and Donald R. Rima (Nashville: U.S. Department of the Interior, 1970), pp. A-16--A-22.

at a maximum frequency of once every three hours. Chemicals require some forty-five minutes to one hour to become effective and lose their effectiveness in approximately three hours after application. If only bridge surfaces are icy, spot applications may be used; otherwise, the entire roadway should be covered. When accumulations exceed one inch, roadways must be initially plowed before applying the chemicals.[32] This procedure enables the chemicals to work more quickly and effectively on the road surface. Snowplowing operations do not commence until the snow has accumulated to a depth of one inch or greater. Since hazardous, icy road conditions can occur without a significant snowfall, chemical applications occur more frequently than snowplowing. Thus maintenance costs for the application of chemicals far exceed those for plowing. For the counties in this study, an average of only 12 percent of their total snow and ice removal costs were for snowplowing. In fact, twelve counties had one or more years in which they had no expenditures for plowing. The remainder of this section discusses the distribution of snow and ice removal costs along I-40 and the factors affecting the high and low-cost areas.

---

[32]Tennessee Department of Highways, op. cit., footnote 9, pp. 3-50--3-52.

Distribution of Costs

The distribution of snow and ice removal costs is shown in Table 4, page 38, and Figure 9. One might expect that snow and ice removal costs are largely dependent on annual snowfall amounts. The highest average annual snowfall amounts during the five-year period were recorded in Cumberland County with 17.3 inches, Cheatham County with 16.5 inches, Wilson County with 16.0 inches, and Putnam County with 15.7 inches. The lowest amount was in Fayette County with 5.7 inches. The high snowfall amounts for the Plateau counties of Cumberland and Putnam, with maximum roadway elevations of 2000 feet, might be expected. The high snowfall amounts in Cheatham and Wilson counties, with maximum roadway elevations of only 820 feet and 700 feet, respectively, appear unusual. In any case, Cumberland County, with the highest snowfall amount, ranked third in snow and ice removal costs. The county with the second highest snowfall amount, Cheatham, ranked second in maintenance costs. Wilson, the county with the third highest amount of snowfall, ranked fourteenth in maintenance costs. Surprisingly, Decatur County, which ranked eleventh in snowfall, with 8.7 inches, ranked first in snow and ice removal costs. The three lowest-ranked counties--Haywood, Madison, and Fayette--together averaged an annual snowfall of 8.4 inches.

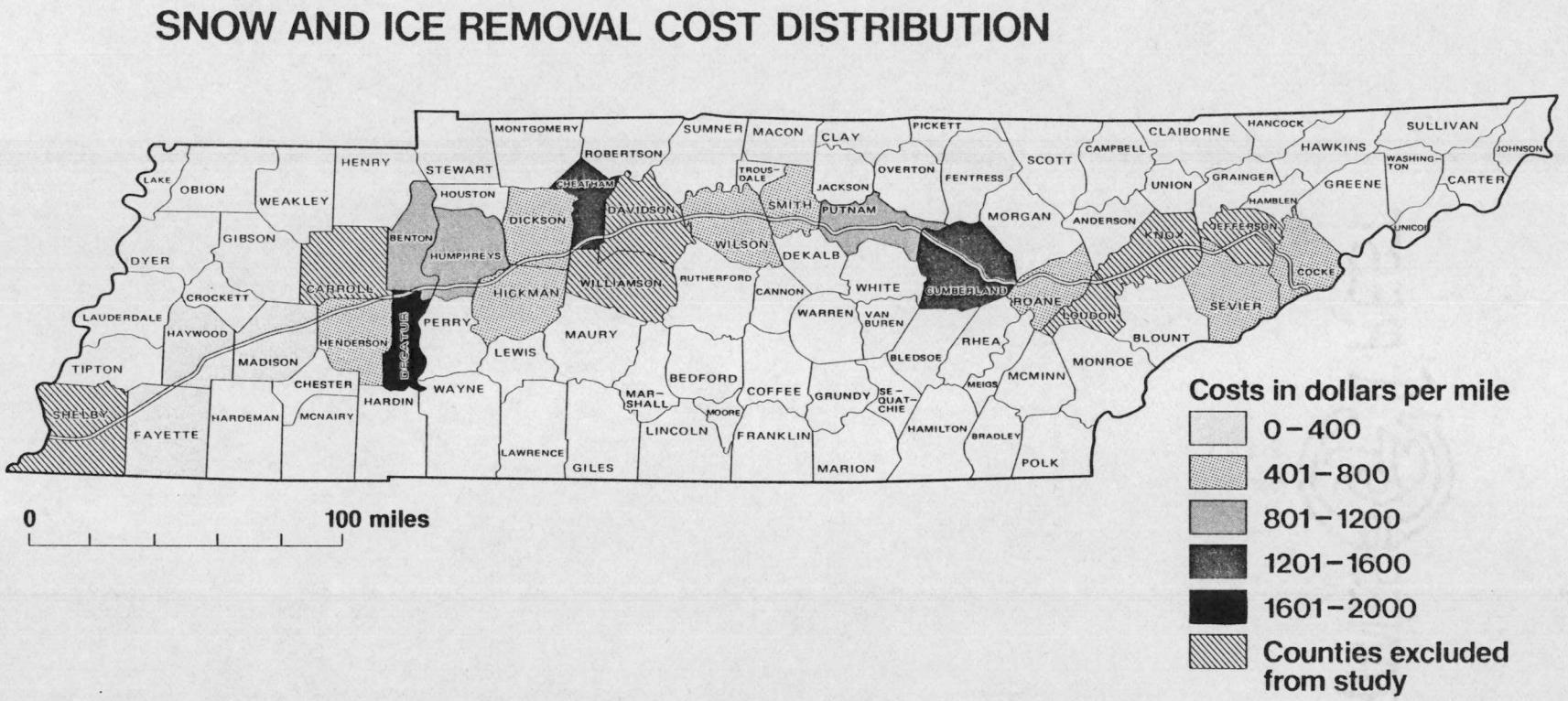


Figure 9. Distribution of Snow and Ice Costs.

Analysis of Costs

Many factors affect the impact of winter storms on highway conditions. These include temperature, wind (for wind-chill effect and snow drifting), rate and type of precipitation, total accumulation of precipitation, and cloud cover (effect on insolation).[33] Climate-related parameters alone, however, cannot explain all differences in snow and ice removal costs. Certain terrain-related factors also affect maintenance activities. Two such factors are roadway grades and the influence of side slopes on the length of time that snow and ice remain on the roadway. The latter effect is known as snow and ice persistence.

The trafficability of a roadway in a snow or ice storm is no better than the condition of the bridges and hills or grades on that route. Accordingly, maintenance crews focus their efforts on areas with grades--the steeper the grade, the greater the potential problem. The factor that magnifies the problem is the persistence of the snow on the roadway. This snowfall persistence is affected not so much by the depth of the initial snowfall, since a lowering of the snow depth could result from an increase in snow density because of aging,

---

[33] James F. Kelly, "Winter Maintenance: A Four-Season Job," American City & County, August 1978, p. 73.

compaction, or refreezing, but rather to the effects of solar radiation and the surface and subsurface horizontal melting of snow through snow drifting and meltwater flow.[34] Of these factors, the input of direct-beam, shortwave solar radiation is the most important. This type of solar radiation is dependent on the angle at which it strikes the surface. Thus, the radiation varies in intensity with the slope and azimuth angles presented by terrain. During the winter months (at 40° North Latitude), north-facing slopes of greater than 26.5° receive no direct-beam radiation, while south-facing slopes at any angle are in a favorable position.[35]

The crux of this discussion is that, theoretically, any county that has relatively high snowfall amounts, steep highway grades, and snowfall that persists on roadways because of limited access to the melting effects of direct-beam solar radiation and winds will have high snow and ice maintenance costs. In this study, Cheatham County ranked second, with expenditures of $1400 per mile. As previously mentioned, Cheatham County averaged 16.5 inches of snowfall, the second highest amount in the study. The eastern 1.5 miles of the I-40

---

[34] T. R. Oke, Boundary Layer Climates (New York: John Wiley & Sons, 1978), p. 76.

[35] Oke, op. cit., footnote 34, p. 150.

roadway in Cheatham County climb the escarpment from the Central Basin onto the western Highland Rim. This segment is characterized by steep grades and by cuts with high, nearly vertical, slopes on both sides of the roadway. The grade becomes gentle as it passes westward through the flood plain of the Harpeth River but becomes moderately steep as the roadway continues through areas of high cuts in the southwest corner of the county. These cut areas with relatively steep (15 to 20 percent) north-facing slopes shade the highway, particularly the eastbound lanes, and prevent direct-beam solar radiation from melting the snow. The terrain also blocks winds that might blow some of the snow off the roadway surface. Mr. Will F. Oliver, District 33 Highway Maintenance Supervisor (which includes Cheatham County), states:

> The high cost of snow and ice removal in the area was largely due to the climate and terrain. This section of I-40 is built in hilly terrain and borders Kingston Springs, Tennessee. Normally, this area has the coldest temperatures in the immediate area.[36]

Mr. Oliver's suggestion that the area of Cheatham County with I-40 is the coldest is supported by the climatological data for Kingston Springs. During the five-year period for the winter months of December, Janaury, and February, Kingston Springs' average temperature was

---

[36] Will F. Oliver, District Maintenance Supervisor, Tennessee Department of Transportation, Clarksville, personal letter, 19 March 1980.

33.8°F, the coldest of any area along I-40. The influence of terrain affects the winter conditions along I-40 in Cheatham County. For nearly four miles, the roadway follows the incised Harpeth River Valley, with local reliefs from the roadway of 200 to 250 feet (see Figure 10). Cold, subsiding air collects in the valley, providing somewhat colder than normal conditions. This factor, combined with a monthly average of 5.0 inches of precipitation during the winter, results in frequent icy and snow-covered road conditions on I-40.

Decatur County's high maintenance costs for snow and ice removal are even more dependent on terrain than Cheatham's, for this highest-ranked county averaged only 8.7 inches of snowfall a year. Mr. B. G. Dedmon, a highway maintenance engineer for District 44 of the Highway Department's Region IV, stated that the unusually high costs for snow and ice removal on I-40 in Decatur County occur because:

> The steeper grade and less sunlight due to the heavy growth of pines on each side of I-40 create more problems and contribute to the high cost of this activity.[37]

This effect of the pines (conifers provide more shade in winter than deciduous trees) would be most pronounced

---

[37] B. G. Dedmon, Highway Maintenance Engineer, Tennessee Department of Transportation, Jackson, personal letter, 26 February 1980.

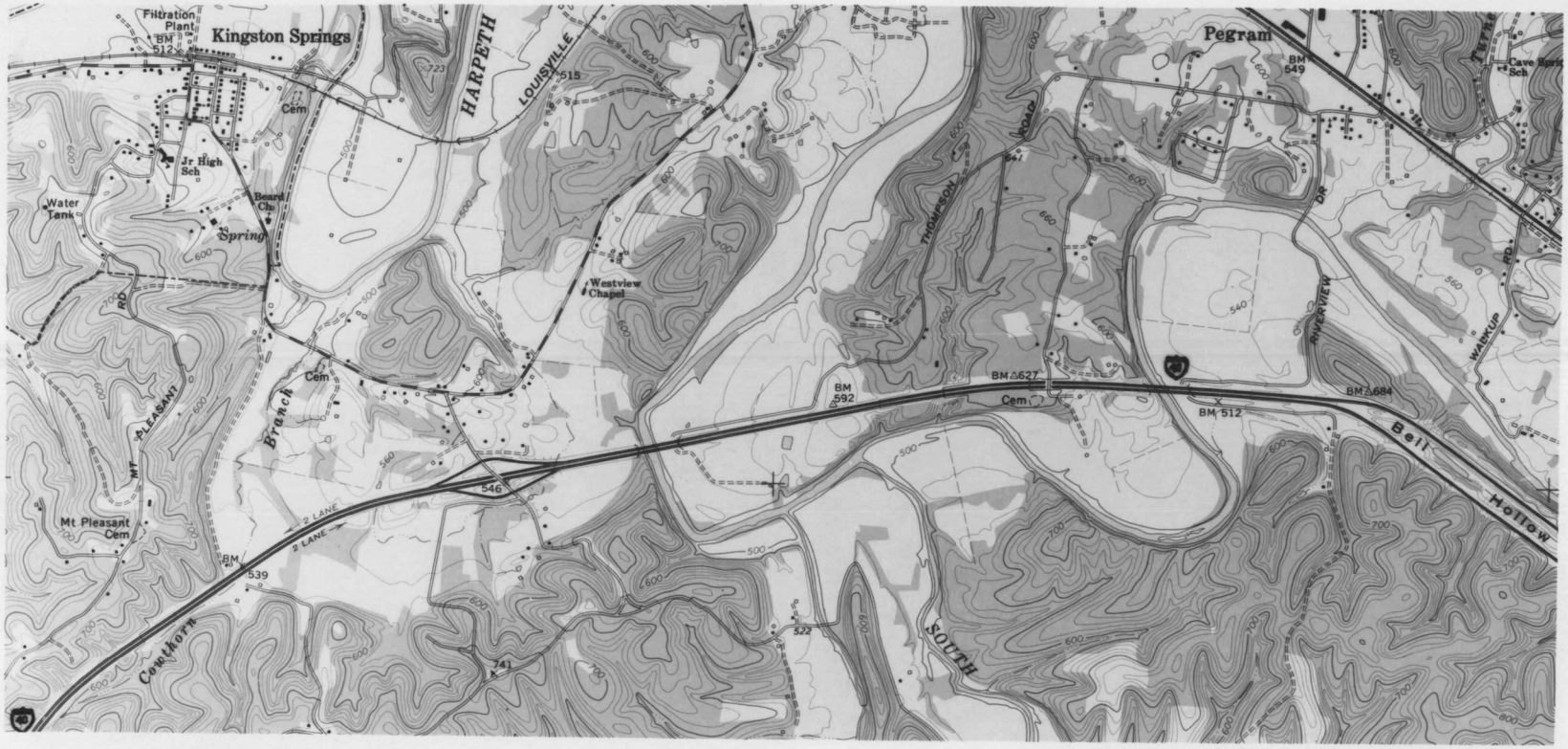


Figure 10. I-40 Roadway in the Harpeth River Valley in Cheatham County.

Scale: 1:24,000.

on north-facing slopes in proximity to the eastbound lanes. In spite of the relatively low snowfall amounts, the shading effect of the pines, especially on steep grades, allows the snow and ice to persist and creates high snow and ice removal costs.

The third-ranked county, Cumberland, averaged the highest snowfall amount, 17.3 inches. Cumberland County also has an area of steep-walled cuts in its seven miles of I-40 through Crab Orchard Mountain (see Figure 11). Obtaining precise information on the persistence of snow is somewhat difficult, but data were obtained for Cumberland and Dickson counties, ranked third and twelfth, respectively, in snow and ice removal costs. For the five-year period of the study, Cumberland County averaged 6.8 days per month (during the three winter months) with at least one inch of snow on the ground, while Dickson County averaged 2.7 days per month. Cumberland County received only 1.25 times as much snowfall as Dickson County, but the snow lasted 2.5 times as long.

Another county with areas of steep, high-walled cuts, the steepest grade in the study, and an average snowfall of 11.2 inches, is Roane. However, the area with the highest potential for difficulty in removing snow and ice, the eastern Cumberland Escarpment, is spared by the position of the roadway on the escarpment.



Figure 11. Extensive Cuts on the Eastbound Lane of I-40 in the Vicinity of Crab Orchard Mountain in Cumberland County.

As the roadway ascends the northeast-southwest-aligned escarpment, the roadway separates, with the westbound lanes positioned higher up the face of the escarpment than the eastbound lanes (see Figure 4, page 41). The advantage to this alignment is that both roadways are formed in side cuts on the south-facing slope, allowing all lanes to receive the maximum snow-melting benefit of the direct-beam solar radiation. This terrain-related feature of the I-40 roadway contributes to Roane County's unexpectedly low seventh ranking.

The three lowest-ranked counties were Haywood, Madison, and Fayette. The I-40 segments in these counties are undulating to slightly rolling, with slight grades and no shading effects produced by side slopes. The wind is relatively effective in blowing snow off the roadways in these rather flat, open areas of the Coastal Plain.

Snow and ice removal costs per mile for the study averaged $755.35, with a standard deviation of $492.76. This wide variability is largely attributable to the effects of terrain and climate rather than just the annual snowfall amounts as might at first be expected.

IV. EXTRAORDINARY COSTS

Under the category of extraordinary highway maintenance the major cost item is for landslide removal and repair of the surrounding embankments to preclude further slide occurrences. For the four highest-ranked counties--Cocke, Roane, Cumberland, and Putnam--expenditures for extraordinary maintenance are almost exclusively for landslide removal and repair. Other counties record expenditures for extraordinary costs in the form of roadway settlement repair and accident debris removal. This section shows the distribution of extraordinary costs with the analysis focusing on the landslide removal problems in Cocke and Roane counties.

Distribution of Costs

The distribution of extraordinary costs is shown in Table 4, page 38, and in Figure 12. As mentioned, the highest-ranked counties were Cocke, Roane, Cumberland, and Putnam. Of Cocke County's $1497 per mile, $1420, or 95 percent, was spent on landslides; of Cumberland County's $581 per mile, $524, or 90 percent, was spent on landslides. In contrast, only $103 of Smith County's $272 per mile, or 38 percent, was spent on landslides, while $114, or 42 percent, was spent on repairing major roadway settlements. Of the remaining counties, only Cheatham had any costs for landslide

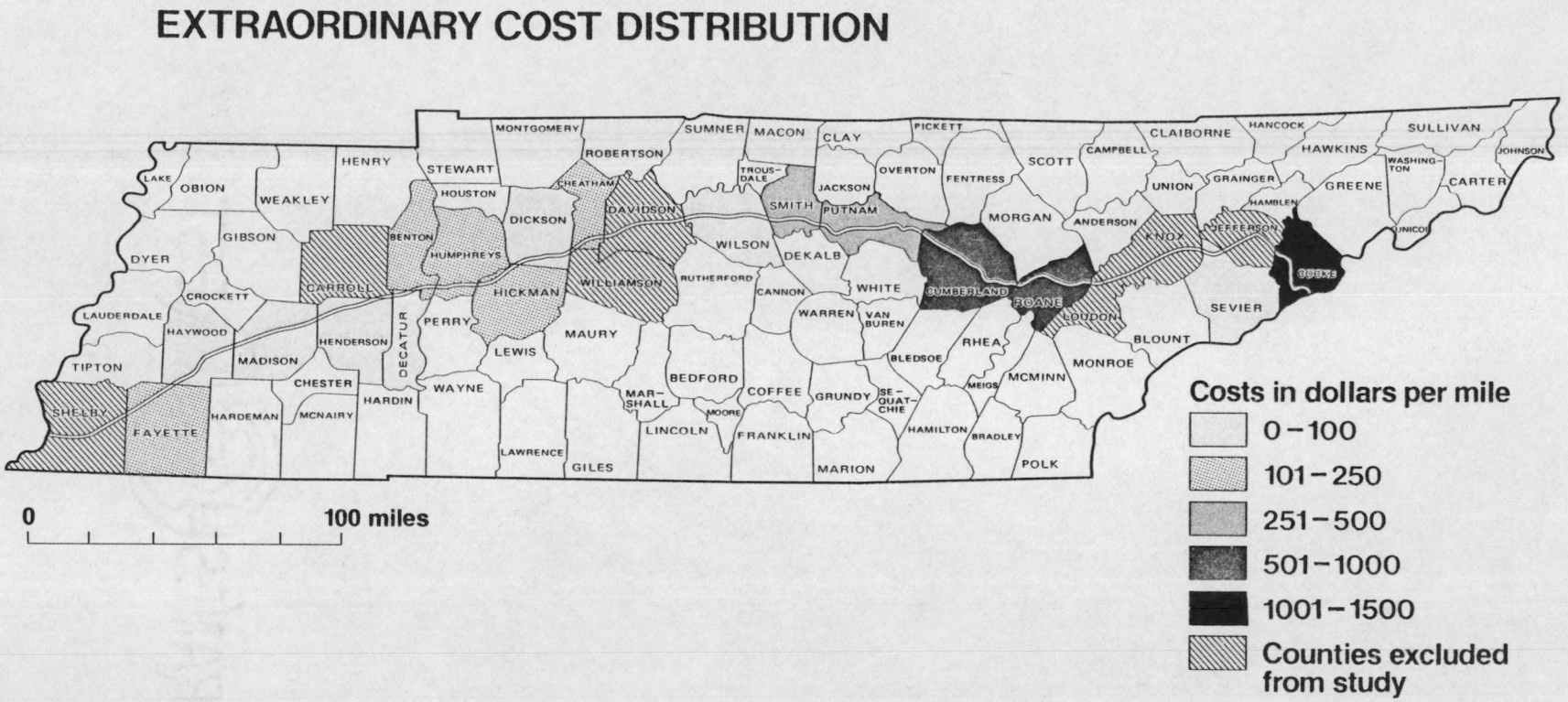


Figure 12. Distribution of Extraordinary Costs.

maintenance, and that was for $46 per mile, or 40 percent of its total extraordinary maintenance costs.

Analysis of Costs

The four highest-cost counties have common physical characteristics of high elevations and local relief, steep side slopes, and, with the exception of Cumberland and Cocke counties, relatively steep roadway grades along I-40. Mean values of roadway grade are 41.0 feet per mile for Roane County, 37.5 feet per mile for Putnam County, 19.0 feet per mile for Cumberland County, and 17.2 feet per mile for Cocke County. The second through fifth highest-cost counties--Roane, Cumberland, Putnam, and Smith--follow the east-west route of I-40 from the Valley and Ridge up the eastern Cumberland Plateau Escarpment, across the Plateau, down the western Cumberland Plateau Escarpment, and onto the Highland Rim. These counties represent distinct but complex areas of soils and geological conditions. The highest-ranked county, Cocke, in the Blue Ridge section, encountered major problems when I-40 was initially constructed and designed. The same problems have necessitated continued extremely high maintenance costs.

One of the key factors in producing landslides is the natural or artificial undermining of the foot or toe of a slope by stream erosion or highway excavation.

Another factor is the increased weight from the build-up of excess water in embankments and fills, leading to increases in sheer stress and in the pore-water pressure of clayey materials. Rain and snow meltwater penetrate into the joints of rocks and produce hydrostatic pressure. This increase in pore-water pressure causes a change in the consistency of the soil (liquification) accompanied by a decrease of cohesion and internal friction. Ground water flows also exert pressure on soil particles, washing away soluble cements and weakening the internal bond between soil particles. This action also results in decreased cohesion and internal friction. The flowing ground water also washes out fine sand and silt particles from slopes, leaving underground cavities and weakened slope stability. The weathering of rocks, both mechanical and chemical, produces changes in the stability of slopes. As water freezes in rock fissures, it expands, widens the existing fissures, and causes a decrease of cohesion in the rock. Chemical weathering from percolating water also contributes to instability. Oftentimes human activity triggers landslides by blocking natural drainage flows, removing protective vegetation cover, removing slope support at the base or toe, and inducing shocks and vibrations from explosions and heavy equipment or machines--activities usually found during the construction of highways. At

other times, natural occurrences such as intense rains or earthquakes cause the slides.[38]

As I-40 traverses Roane County and ascends the escarpment onto the Cumberland Plateau in a series of cuts and fills, many of the aforementioned conditions are encountered (see Figure 13). A major ridge-forming geologic formation in the Valley and Ridge section of Roane County is the Rome formation, consisting of mixtures of shale, sandstone, and siltstone. The formation is usually in steep and narrow ridges with considerable dip to the strata. A major landslide involving 75,000 cubic yards of material from the Rome formation occurred during the construction of I-40 in Roane County in 1962. The Chief of the Division of Soils and Geological Engineering for the Tennessee Department of Transportation suggested that the slide could have been prevented if the I-40 roadway had paralleled the dip of the strata (20° to 45°) rather than cutting obliquely across the bedding plane.[39]

The Pennington shale formation is found along the escarpment at Rockwood in Roane County in thickness

---

[38] Quido Zaruba and Vojtech Mencl, Landslides and Their Control (New York: Elsevier Scientific Publishing Co., 1969), pp. 26-27.

[39] David L. Royster, "Highway Landslide and Stability Problems in Tennessee," paper presented at the 46th Annual Tennessee Highway Conference, 9-10 April 1964.



Figure 13. Cut and Fill Areas of the I-40 Roadway in the Vicinity of Rockwood in Roane County.

Source: Tennessee Department of Transportation.

of about 500 feet. This type of shale weathers rapidly to a relatively weak, highly impervious clay. This is significant where the formation occurs in a slope that is overlain by colluvium--a heterogeneous mix of clay, silt, sand, rock, and boulder-sized particles that has moved downslope primarily from the force of gravity. In this location the colluvium covers or "veneers" the slope of the escarpment. It is highly permeable and allows both surface and ground water to pass through its layers. The underlying Pennington shale, however, is impermeable and allows ground water to collect and move parallel down the slope along the interface between the shale and colluvium. This situation creates instability, as the colluvium is overloaded by the water and the resistance to sliding between the two surfaces is overcome and failure occurs.[40]

Roane County possesses the necessary combination of high precipitation (61.8 inches, second highest average during the study) and steep slopes (10 to 30 percent in the Valley and Ridge and 25 to 45 percent on the escarpment) to create an area of potential landslides. Since construction began in late 1967 on the

---

[40] David L. Royster, "Highway Landslide Problems Along the Cumberland Plateau in Tennessee," Bulletin of the Association of Engineering Geologists 10, no. 4 (1973): 259-261.

six-mile segment of I-40 near Rockwood, there have been more than thirty major slides (see Figures 14, 15, and 16). All of these had to be corrected before all four lanes of the Interstate were finally opened to traffic in the late summer of 1974. Preventive or remedial maintenance measures have included partial to total removal of colluvial material above the roadway, minor grade and alignment changes, use of restraint devices such as rock buttresses (free-draining structures consisting mostly of large blocks of nondegradable sandstone or limestone) and gabion walls (wire-meshed baskets filled with coarse, nondegradable rock), as well as dewatering systems such as vertical wells equipped with automatically actuating pumps and horizontal drains (holes drilled into an embankment or cut slope and cased with a perforated metal or slotted plastic liner) (see Figures 17 and 18). In fact, more than 50,000 feet of horizontal drains were installed between 1972 and 1976.[41] These remedial measures have been successful in preventing major slides, but minor slides still continue, as reflected in Roane County's high extraordinary maintenance costs.

---

[41]David L. Royster, "Some Observations on the Use of Horizontal Drains in the Correction and Prevention of Landslides," paper presented at the 28th Annual Highway Geology Symposium, Rapid City, SD, August 1977.



Figure 14. Slide on the Eastbound Lane of I-40 in Roane County, February 1974, with View to the West.

Source: Tennessee Department of Transportation.



Figure 15. Slide on the Eastbound Lane of I-40 in Roane County, February 1974, with View to the Northwest.

Source: Tennessee Department of Transportation.



Figure 16. Slide on the Eastbound Lane of I-40 in Roane County, July 1971. View is from Foot of the Slide towards the Failed Roadway.

Source: Tennessee Department of Transportation.



Figure 17. Gabion Walls on the I-40 Roadway in Roane County.

Source: Tennessee Department of Transportation.

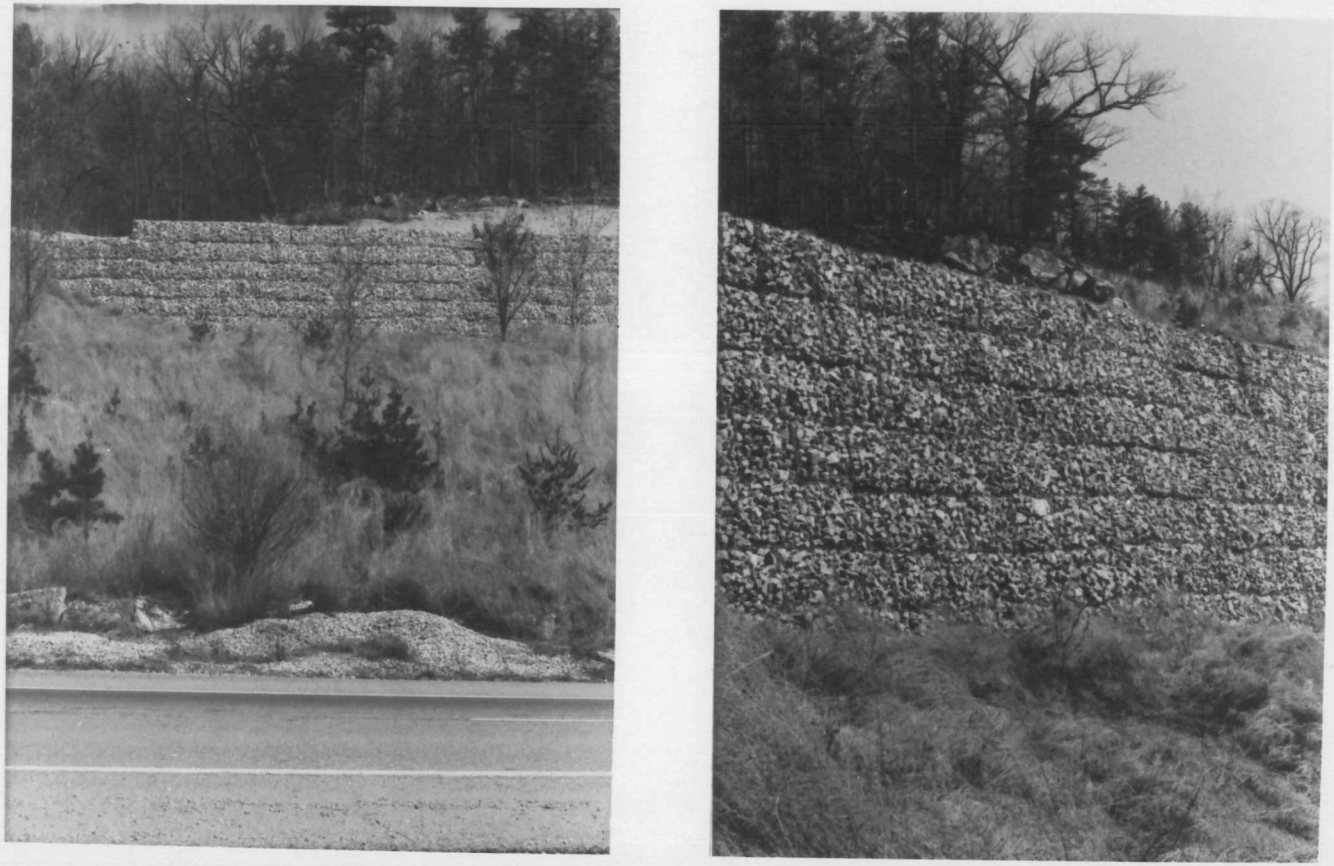


Figure 18. Gabion Walls above the Westbound Lane of the I-40 Roadway in Roane County.

Landslides have caused major highway maintenance problems at two primary sites along a nine-mile section of I-40 in Cocke County--Hartford and Waterville. The I-40 roadway follows the Pigeon River Gorge through a geologically complex area of Cambrian and Precambrian sediments and metasediments. Valleys in the area are V-shaped, with steeply sloping sides (some are 50 to 60 percent slopes) and narrow bottoms having considerable downstream gradient (see Figure 19). Most of the soils in the area, such as the Ramsey or Jefferson series, have shallow depths to bedrock and are excessively drained. Talus and debris deposits along some slopes are somewhat thicker. Local relief varies from 600 to 1600 feet above the roadway. The slide problem at the Waterville site actually began in 1968 when the Pigeon River channel was widened in conjunction with the placement of slope pavement (concrete slabs used to reinforce stream embankments). The failure occurred during excavation of the river channel, when the toe of a wedge-shaped deposit of soil and weathered rock was undercut near the river level. In the spring of 1972, heavy rains caused a large segment of the slope to slide into the Pigeon River, constricting the channel and causing the river to be diverted into the fill slope on the opposite side. Needless to say, this action resulted in the washing away of much of the slope pavement. While repairs were

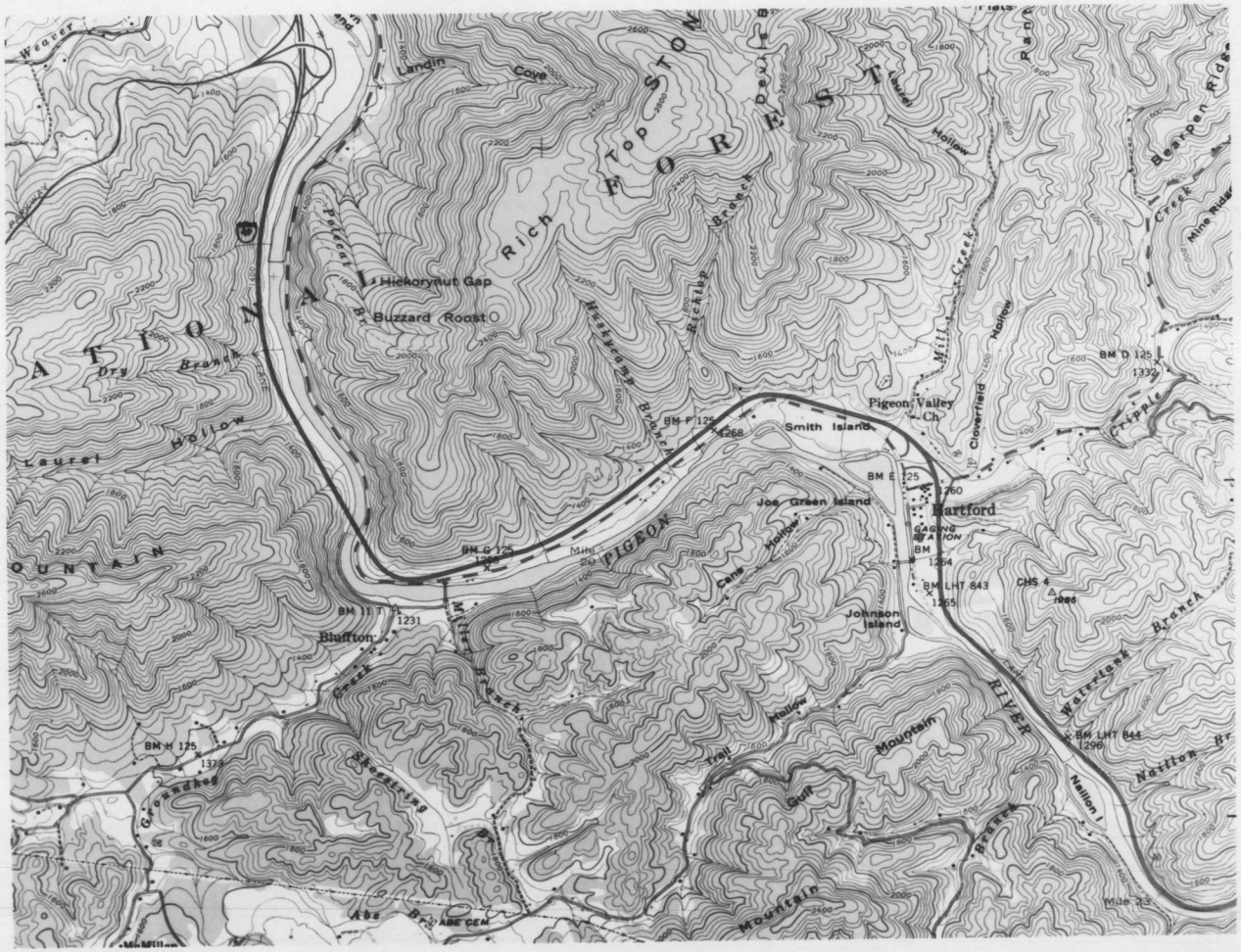


Figure 19. I-40 Roadway along the Pigeon River in Cocke County.

Scale: 1:24,000.

being conducted in the fall of 1972, another flood occurred and caused further slope movement and the loss of most of the remaining slope. In 1973, damage to the fill slope was repaired and the slope pavement was replaced with boulder rip-rap (boulders and rocks used to buttress and protect slopes). Other restraint measures were not condsidered feasible because of the large mass of earth that had to be supported and because of the poor foundation conditions along the river's edge. Dewatering measures were not employed, because it was considered impossible to control the surface infiltration and to remove enough water from the failure zone during heavy rainfall. The total repair cost for the Waterville slide area, in June 1974, was $2.25 million. The area still remains one of potential instability and continued maintenance.[42]

The Hartford slide area has been a problem since highway construction began in 1962. The Hartford slide is unique in that only the westbound lanes have been affected. Pavement heaving and the encroachment of slope materials into the ditchline north of the roadway have been the major maintenance problems. A V-shaped

---

[42] David L. Royster, "Landslide Remedial Measures," paper presented at the 37th Annual Southeastern Association of State Highway and Transportation Officials Convention, Nashville, TN, October 1978.

trough of permeable, highly weathered and broken rock is underlain by a zone of relatively unweathered, impermeable rock along a line that essentially parallels the centerline of the I-40 roadway. The unweathered rock zone blocks the ground water flow as it moves towards the Pigeon River. Consequently, during periods of heavy rainfall, the ground water confined in the trough rises rapidly, and, since it is under hydrostatic pressure, the roadway is lifted upward and slope movement occurs. Horizontal drains and pumping wells have been used as remedial measures in the area, but until the trapped ground water in the trough is removed or controlled, the Hartford slide will continue to be a source of high extraordinary maintenance costs in Cocke County.[43]

The remaining counties in the study, those ranked sixth through seventeenth, have relatively low extraordinary costs, because the terrain of these counties is not subject to landslides. Fayette, Humphreys, and Hickman counties have experienced some roadway settlement problems that account for most of their expenditures. Each of these counties is characterized by medium to fine-textured valley systems. The roadway settlement problems generally occur in the

---

[43] Royster, op. cit., footnote 41.

numerous fills that cross the poorly drained sections of each county. In Fayette County, for example, I-40 crosses nine streams, including the Loosahatchie River, for a ratio of 0.56 streams per mile. In Humphreys County, I-40 crosses five streams, including the Buffalo and Tennessee rivers, for a ratio of 0.34 streams per mile. In Hickman County, I-40 crosses ten streams, including the Duck River, for a ratio of 0.66 streams per mile. Drainage in these areas is discussed further in the Drainage Costs and Roadway Costs sections.

Another category of extraordinary maintenance costs is the usually low-cost activity of accident clean-up. Specifically, this activity involves the removal of accident debris from the roadway and the subsequent clean-up to provide safety to motorists. The average cost per mile for this activity was $13, with a median value of $9. Hickman County averaged an unusually high $48 per mile for accident clean-up. Mr. Mack Osburn, District 34 Highway Maintenance Supervisor, confirmed a high incidence of traffic accidents along I-40 in Hickman County.[44] A contributing cause of the accidents is the location of seven miles of I-40 (the total I-40 mileage in the county is

---

[44]Mack Osburn, District Maintenance Supervisor, Tennessee Department of Transportation, Columbia, personal letter, 26 February 1980.

15.11 miles) in the low-lying bottoms of the deeply entrenched Sugar Creek and Duck River--areas of frequent radiation or ground fog (see Figure 20). Here, terrain and climate have contributed to a situation in which higher than expected extraordinary maintenance costs occurred.

In summary, the most significant factor affecting extraordinary costs is the occurrence of landslides in areas of certain terrain settings. Climate is a factor in that most landslides occur in Tennessee during the spring months, when an already wet regolith is drenched further by the highest amounts of rainfall received during the year.

V. ROADSIDE COSTS

The category of roadside costs includes many diverse activities, such as machine mowing of medians and slopes along the right-of-way, controlling weeds with chemicals, cutting brush and trees to restore sight distances, maintaining roadside landscaped areas, and the reseeding, fertilizing, and mulching of backslopes for erosion control and beautification. Mowing is further divided into maintenance activity code 435, which entails normal mowing by tractors within designated limits along the right-of-way, and maintenance activity code 436, slope mowing, which includes mowing,

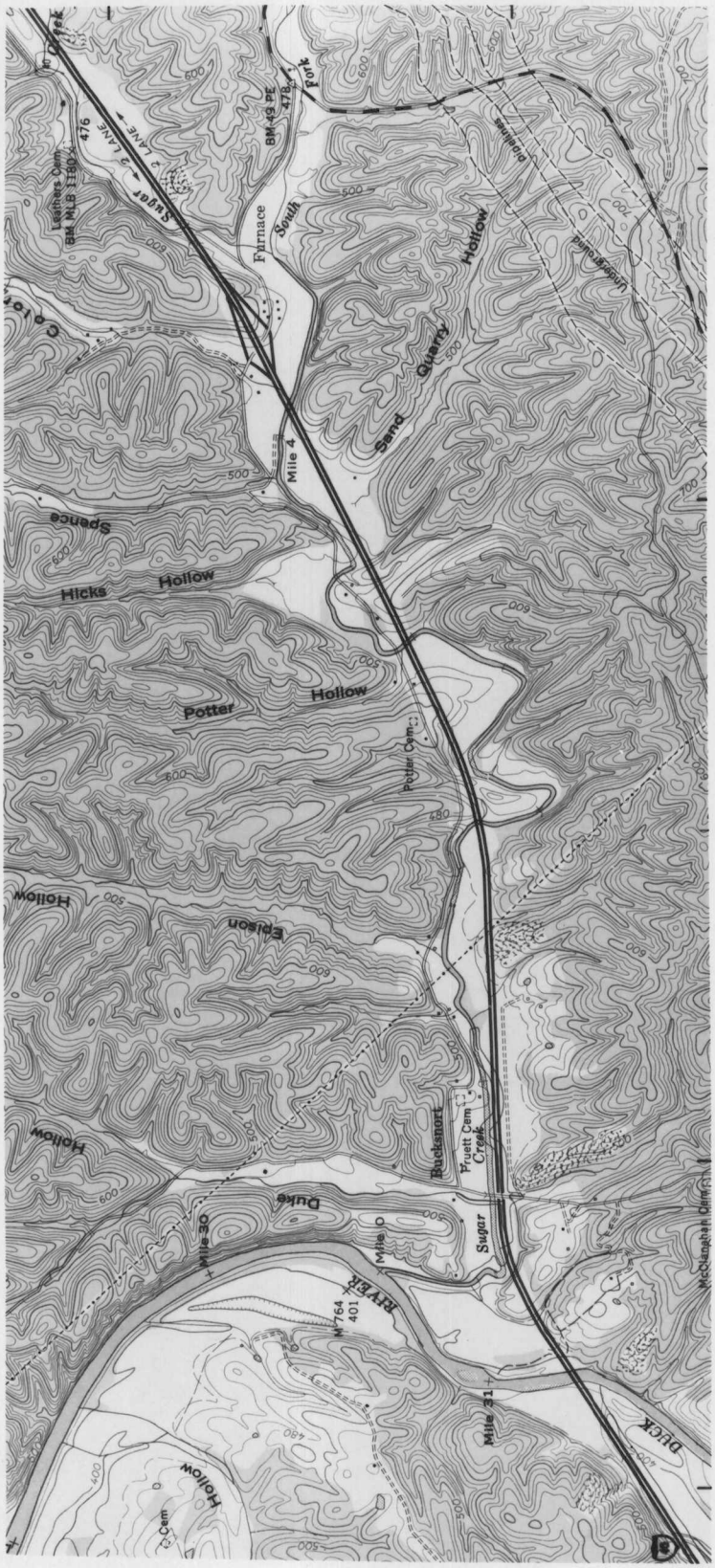


Figure 20. I-40 Roadway along the Sugar Creek Valley in Hickman County.

Scale: 1:24,000.

with a "mo-trim" or extension-arm mower, of vegetation behind guardrails or other designated slope areas that are not accessible to regular tractor mowers. This section on roadside costs shows the distribution of costs and analyzes the high and low-cost areas in terms of the associated environmental factors.

Distribution of Costs

As an aid to the discussion of roadside costs, Table 5 is presented, showing a summary of the roadside costs by counties in their ranked order of total roadside costs. Single dollar differences between the totals in Table 4, page 38, and Table 5 are due to round-off procedures. The distribution of roadside maintenance costs is shown in Figure 21. The highest-ranked counties are Sevier, Benton, and Henderson with over $1400 per mile in roadside maintenance costs. The least-cost county is Dickson with $604 per mile.

Analysis of Costs

Sevier County ranks first in roadside costs because of its high expenditures for machine mowing and reseeding and mulching. The median (statistical parameter) value for all counties' reseeding and mulching costs is $3 per mile, while Sevier County averaged $563 per mile. The explanation has little to do with the effects of terrain or climate, but reflects the

TABLE 5

SUMMARY OF ROADSIDE COSTS[1]

County	Machine Mowing	Slope Mowing	Chemical Control of Vegetation	Brush Cutting	Landscaping	Reseeding & Mulching	Total
Sevier	852	0	26	0	24	563	1465
Benton	711	83	118	318	210	14	1454
Henderson	915	253	72	94	96	2	1432
Madison	645	69	214	61	60	341	1390
Cheatham	836	23	288	73	89	0	1309
Cocke	1079	59	37	82	14	7	1278
Humphreys	719	16	146	182	147	17	1227
Fayette	693	16	288	48	92	4	1141
Hickman	741	0	18	106	212	4	1081
Haywood	707	126	105	22	54	0	1014
Wilson	557	56	37	11	242	0	903
Putnam	647	75	65	68	0	3	858
Smith	665	6	44	31	84	6	836
Roane	379	157	39	122	33	21	751
Decatur	397	20	124	176	18	0	735
Cumberland	538	0	53	18	6	3	618
Dickson	430	0	97	44	33	0	604

[1]Costs are five-year averages in dollars per mile.

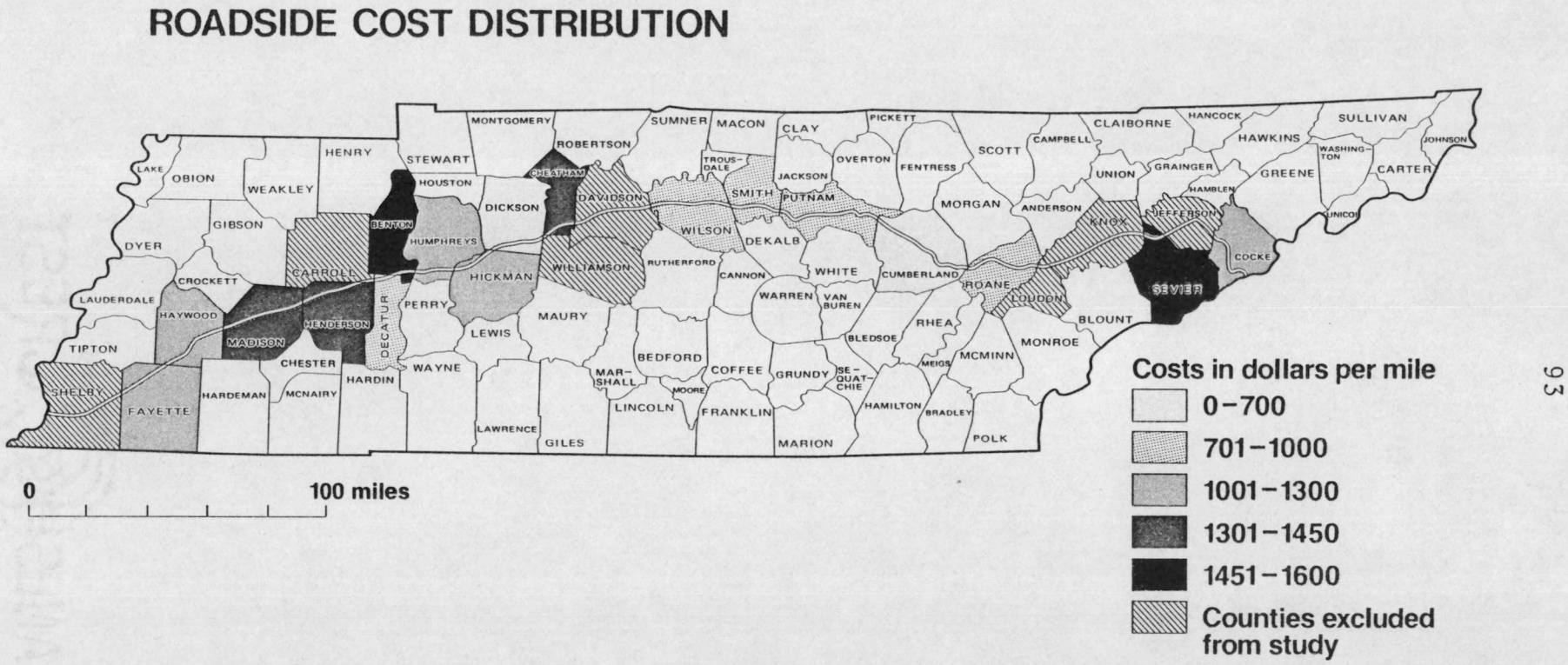


Figure 21. Distribution of Roadside Costs.

fact that the I-40 segment in Sevier County was under construction during the first two years of this study (maintenance costs were charged throughout the study period, however), and emphasis was placed on establishing and maintaining an adequate vegetation cover.

Benton, the second-ranked county, shows a significant allocation of costs in all phases of roadside maintenance operations. Of interest is the county's highest ranking in the area of brush cutting. On slopes in Decatur, Humphreys, and Benton counties, pine trees grow on moderate slopes down to the edge of the roadway. It was observed that some of the trees grow perpendicularly from the slope, extend over the roadway, and then curve skyward. These trees must be continually trimmed to preserve sight distances and safety (see Figure 22).

The third-ranked county in roadside costs is Henderson, with an average expenditure of $1432 per mile. Eighty-two percent of these expenditures were for machine and slope mowing. The I-40 roadway in the eastern five miles of the county is undulating, with gravel-edged, narrow medians, but the remaining eighteen miles of the roadway have flat grades with wide grassy medians and roadsides, necessitating extensive machine mowing. The roadway is constructed on fills throughout the lowland areas of the Big Sandy and the Middle Fork of the Forked

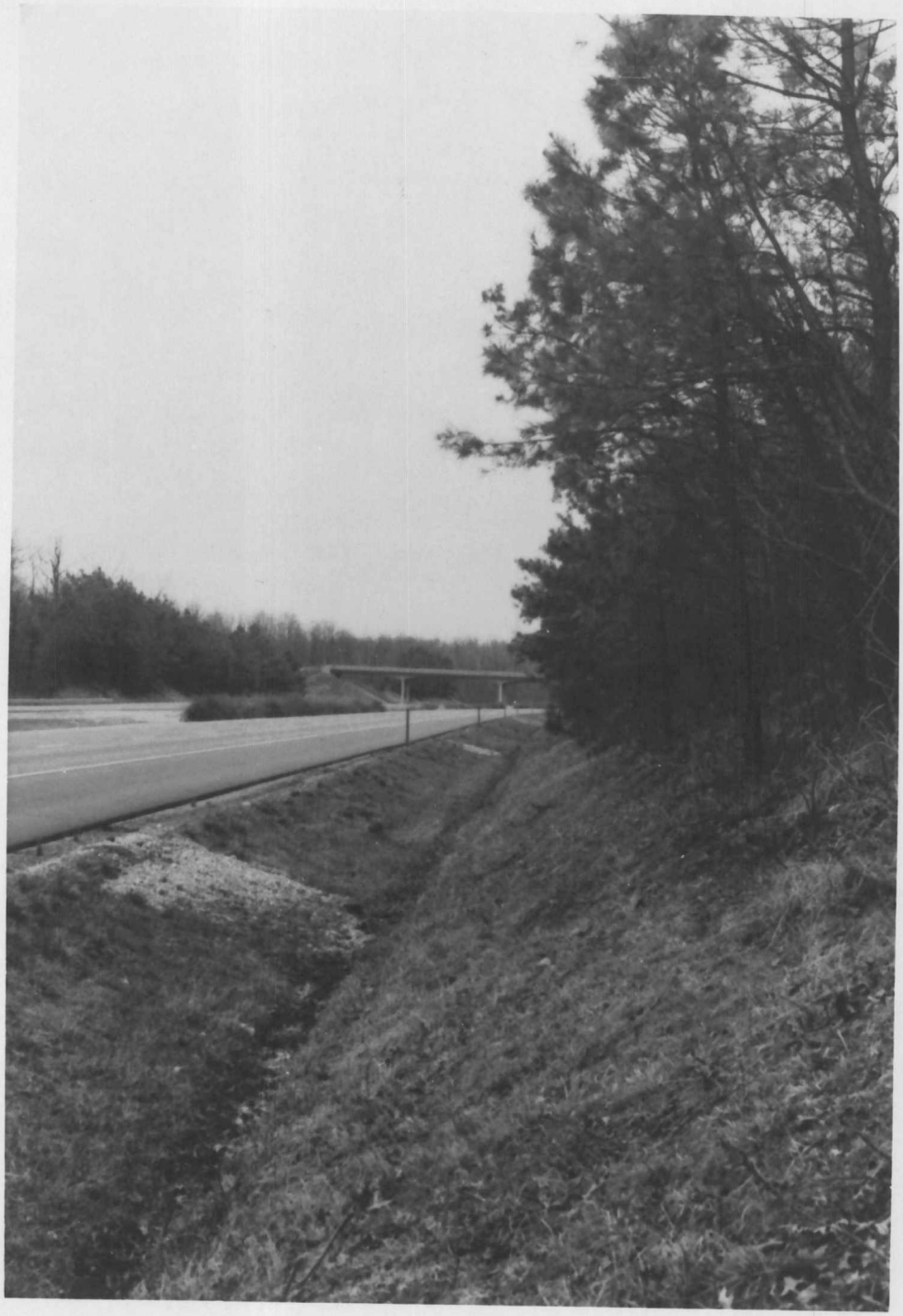


Figure 22. Pine Trees along the I-40 Roadway in Benton County.

Deer River bottoms. The exceptionally high cost for slope mowing is necessitated by the short, steep side slopes of the roadway fills, which are inaccessible to tractor mowers. Extension arms are needed to mow these slopes.

The least-cost county, Dickson, presents some variability in its medians, with six miles of open, grassy areas and the remaining twelve miles a combination of grassy medians lined with shrubs and medians inaccessible because of dense brush and trees. I-40 in Dickson County is not influenced by steep or even moderate side slopes, but trees do grow close to the roadway in some areas. The result is moderate expenditures for slope mowing and reseeding and mulching.

A further look at Table 5 shows that the highest-cost category of roadside maintenance is machine mowing. Costs range from $1079 per mile in Cocke County to $379 per mile in Roane County. The influence of precipitation and temperature (solar radiation) on differential vegetation growth is discounted in this case, since the Department of Transportation stipulates that the grass be mowed a certain number of times a year (the frequency has been reduced from four to three times during the growing season to reduce costs) regardless of the height or the thickness of the

vegetation.[45] Since the costs are reduced to a dollar per mile value, the variability in mowing costs actually reflects the difference in the amount of area mowed. While minimum widths of right-of-way for four-lane divided interstates in rural areas are specified as 150 feet without frontage roads and 250 feet with frontage roads, the maximum right-of-way widths vary with terrain and highway design and construction requirements.[46] This variability is usually manifested in the varying width of the medians. A tractor-mowing machine mowing a mile-long, 36-foot wide median (the minimum with in rural areas) would mow an area of 4.36 acres, while a mile-long, 100-foot wide median would entail mowing 12.12 acres. Another factor affecting roadside costs is the nature of vegetation in the median. Is it completely grass covered or grassy with gravel edges? Is the median lined with bushes and shrubs or covered in forests with only grassy edges? Some median areas are totally inaccessible because of the steep slopes involved; this is most pronounced in areas of severe cuts and fills. These same factors

---

[45] Gerald Gregory, Chief, Maintenance Management Division, Tennessee Department of Transportation, Nashville, personal interview, 17 May 1979.

[46] Thomas F. Hickerson, Route Location and Design (New York: McGraw-Hill Book Co., 1964), p. 15.

generally apply to the roadsides of the highway, but mowing limits are usually established close to the shoulders. Exceptions to this rule exist, especially in areas around interchanges and frontage roads.

Roane County ranks fourteenth in roadside costs and is the lowest of all counties in machine mowing. The terrain in Roane County dictates a limited amount of area for mowing. As I-40 passes through the Valley and Ridge section, the roadway has grassy medians of minimum width and only a few feet of roadside area to mow. Examples of this are the steep side slopes along I-40 as it cuts through Dug and Pine ridges. For a two-mile stretch in the cut just west of Kingston, the median is replaced by a guardrail. As I-40 climbs the escarpment, the roadway splits for six miles, resulting in an area with little or no machine mowing accessibility (see Figure 4, page 41). The remaining roadside maintenance done in Roane County is mostly slope mowing and brush cutting.

Cocke County ranks highest in machine mowing, reflecting the greatest number of "mowable" acres within the designated mowing limits. This fact may be surprising in view of the fact that 18.1 miles, or 80 percent, of the I-40 segment is in the Blue Ridge Province. However, in all but the very mountainous sections (the first eight miles of I-40 inside the

Tennessee-North Carolina line have a guardrail median), the right-of-way includes wide, grassy medians and gentle, expansive roadside slopes. In spite of the high cost of mowing, Cocke County ranks only sixth in total roadside costs. The reason is that machine mowing accounts for 84 percent of Cocke County's total roadside costs, with few expenditures for the other maintenance activities.

While some aspects of roadside costs, such as reseeding and mulching, landscaping, and the use of chemicals for vegetation control, do not particularly lend themselves to analysis in terms of terrain and climate, other maintenance activities do reflect a relationship of the roadway to surrounding slopes, width of the roadway, and vegetation cover.

Finally, two of the three highest-ranked counties for roadside costs--Sevier and Benton--are counties with short segments of I-40 (see Table 1, page 6). Perhaps the counties with shorter segments reflect a diseconomy of scale in that the same number of personnel and pieces of equipment are required to travel between the maintenance headquarters and the work site to carry out the maintenance action whether five or twenty-five miles of I-40 are serviced. Consequently, a disproportionate share of the roadside maintenance costs for these counties is spent on fixed costs (costs

that do not vary with output), such as labor and equipment costs for time enroute to the work site.

VI. TOTAL COSTS

For the five-year period of this study, the average total maintenance costs per mile (for the selected maintenance activities and along the 328 selected miles of I-40) was $60,213. Of this total, $22,485 was spent for roadway maintenance (37 percent); $18,106 for roadside maintenance (30 percent); $13,323 for snow and ice removal (22 percent); $4510 for extraordinary maintenance (7 percent); and $2789 for drainage maintenance costs (4 percent). Certain activities are inherently higher costing, because of the requirements of labor, materials, and equipment.

Distribution of Costs

The map showing the distribution of total maintenance costs (see Figure 23) represents the cumulative effect of all maintenance activities. Roane County ranked highest, followed by the Tennessee River counties of Benton, Humphreys, and Decatur, and then by Cocke County.

As might be expected, counties that ranked high in the high-cost activities, such as roadway and roadside, ranked high overall (see Table 4, page 38).

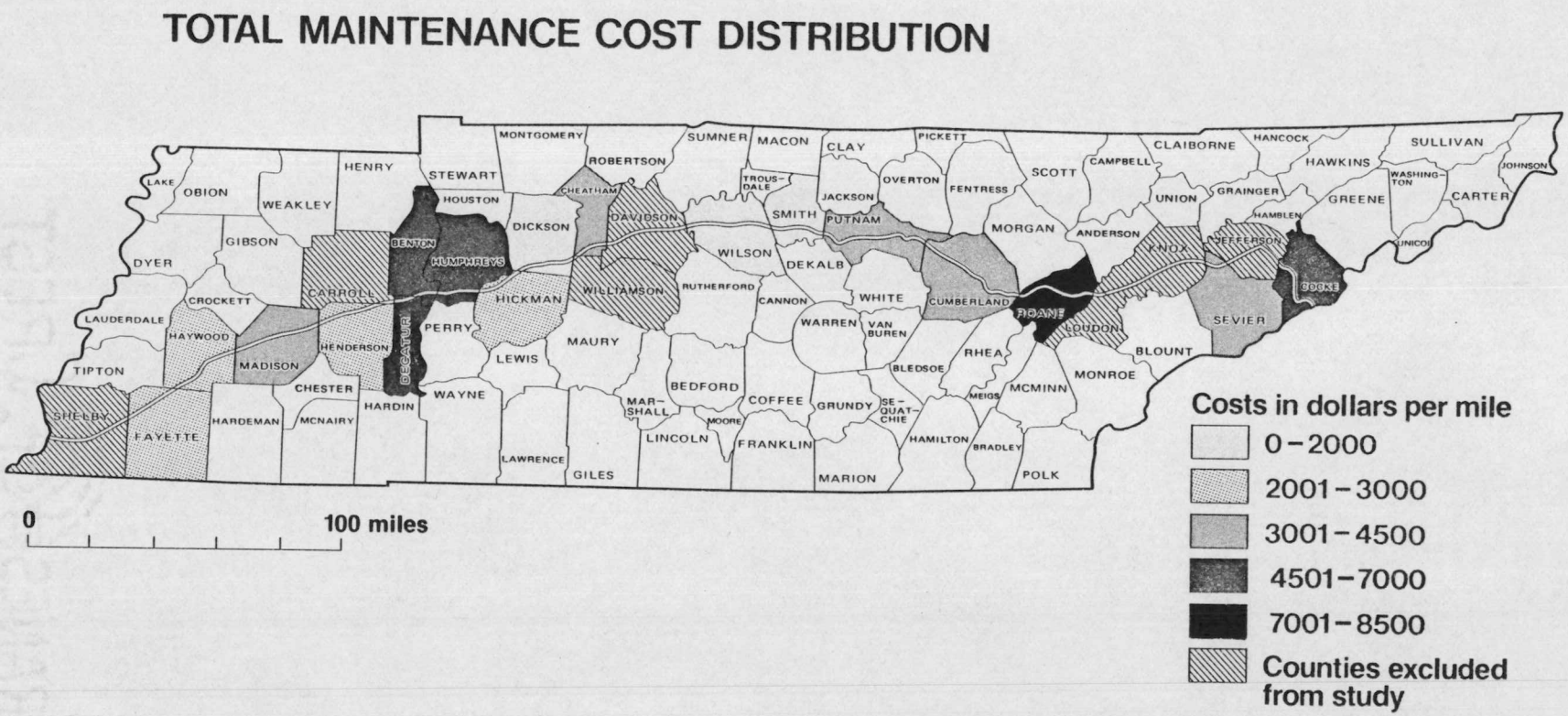


Figure 23. Distribution of Total Maintenance Costs.

Roane, Benton, Humphreys, and Decatur counties were the top four counties for both roadway and total maintenance costs, although Benton and Humphreys swapped second and third positions. Of Roane County's high total maintenance costs of $8191, 68 percent of the total costs were due to roadway maintenance. Overall, Decatur County ranked fourth, with total expenditures of $5057, yet 82 percent of that figure was attributed to only roadway and snow and ice removal costs. Benton County ranked second overall because it ranked third in the two highest-cost categories of roadway and roadside maintenance, accounting for 75 percent of its total costs.

Analysis of Costs

The distribution of total maintenance costs is also related to the terrain of Tennessee. Roane, the highest-ranked county, faces a myriad of problems as the I-40 roadway climbs from the Valley and Ridge section to the Cumberland Plateau along the eastern escarpment. The hilly terrain of the western Highland Rim along the Tennessee River, soil stability problems, and heavy truck traffic generate problems and high costs for Benton, Humphreys, and Decatur counties. The I-40 segment in Cocke County must negotiate steep and geologically complex terrain along the Pigeon River. Figure 2, page 20, also indicates that the counties with

low highway grades, such as Wilson, Dickson, and Fayette, ranked low in total maintenance costs.

Mr. James H. Aycock, Department of Transportation Region I Engineering Geologist, stated that, in his opinion, the key factor to Tennessee's highway maintenance problem is precipitation.[47] Interestingly enough, the two areas in the study with the highest amounts of precipitation were the I-40 segments in Benton and Humphreys counties, with an annual average of 63.7 inches, and the I-40 segment in Roane County, with 61.8 inches per year. This study has shown that it is precipitation acting in conjunction with several other important factors, such as soils, vegetation, highway grade, and amount of cuts and fills, to name but a few, that serves to determine the distribution of total maintenance costs on I-40 in Tennessee. Moreover, the effect of precipitation alone is largely determined by the efficiency of the local drainage systems.

---

[47] James H. Aycock, Region I Engineering Geologist, Tennessee Department of Transportation, Knoxville, personal interview, 12 October 1979.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The Transportation Research Board has stated that one of their overall research objectives was to develop ways to eliminate or at least reduce the need for highway maintenance. This could only be achieved through the integration of maintenance needs and requirements into highway design procedures and construction practices. The Transportation Research Board also felt that a large portion of the maintenance cost burden could be avoided with better initial construction.[48] These research objectives are important and should be recognized, but a frequently neglected solution to the problem, and one this paper espouses, is an emphasis on location decisions in highway layout.

Rights-of-way, grade, and alignment are usually the main considerations in highway location. Until recently, however, the geography and geology of the potential site were not always fully considered at the time the highway location decision was made. One

---

[48] Howard H. Raiken, "Federal Role in Supporting Research and Development for Reducing Transportation Maintenance Costs," in Transportation Research Record 598, Maintenance Management, The Federal Role, Unionization, Pavement Maintenance, and Ice Control (Washington, D.C.: Transportation Research Board, National Academy of Sciences, 1976), p. 6.

problem was that highway engineers seldom personally examined the highway location site but rather relied on information received from survey parties. Unfortunately these survey crews had neither the training nor the equipment to evaluate geographical and geological conditions.[49] Mr. James H. Aycock, Department of Transportation Region I Engineering Geologist, stated:

> In East Tennessee the cost of landslide and related repairs on Interstate 75 in Campbell County and Interstate 40 in Cocke and Roane counties alone is near the $30 million mark. Except during the remedial work, there was very little geotechnical input into these projects.[50]

Recently, there has been better coordination between the soils engineer, the geologist, and the highway design and construction engineers.

Other considerations must be taken into account when planning highway locations, such as the availability of land purchases, interference with existing traffic flows, tie-in with existing bridges across rivers, inclusion of urban centers, and minimizing lane-miles to reduce initial construction costs. These factors, however, do not diminish the need for a more

---

[49] Royster, op. cit., footnote 39.

[50] James H. Aycock, "Construction Problems Involving Shale in a Geologically Complex Environment, State Route 32," paper presented at the 37th Annual Southeastern Association of State Highway and Transportation Officials Convention, Nashville, TN, October 1978.

thorough reconnaissance and site selection process with ample geotechnical input as a means to reduce maintenance costs in the long run. Questions to be asked include the following: Can areas of extensive cuts and fills be avoided through alternative alignments? Are south-facing slopes considered as an aid in allowing the sun to melt snow and ice? Are natural drainage patterns altered by the highway right-of-way?

This research effort has attempted to illustrate a geography of maintenance costs along a major highway route in Tennessee. While generalized relationships between maintenance costs and environmental factors are difficult to determine on a statewide basis, detailed analysis of specific high-cost segments of I-40 suggests correlations between certain microenvironmental factors and costs. These localized relationships between maintenance costs, terrain, and climate can assist highway planners in developing guidelines for reducing maintenance costs for future highways.

Extensions of this study to other regions and other highway systems could provide the data necessary to formulate models that predict maintenance costs on planned highways based on local terrain and climate inputs. Complete analysis of existing highway systems might provide sufficient data to map regions on the basis

of potential maintenance costs, although the need for careful local analysis will persist.

In closing, this study suggests that maintenance costs are influenced by environmental factors related to the highway's location in areas of varying terrain and climate. Highway planners should consider environmental factors, not only for the initial construction and operating costs, but also for the subsequent long-term maintenance costs.

BIBLIOGRAPHY

BIBLIOGRAPHY

Aldrich, H. P. "Discussion, Frost Penetration: Relationship of Air Temperatures and Other Factors." In Highway Research Board Bulletin 225. Washington, D.C.: National Research Council, 1969.

American Association of State Highway Officials. A Policy on Design of Urban Highways and Arterial Streets. Washington, D.C.: American Association of State Highway Officials, 1973.

The Asphalt Institute. Asphalt in Pavement Maintenance. College Park, MD: The Asphalt Institute, 1967.

_____. Drainage of Asphalt Pavement Structures. College Park, MD: The Asphalt Institute, 1966.

_____. Thickness Design. College Park, MD: The Asphalt Institute, 1970.

Aycock, James H. "Construction Problems Involving Shale in a Geologically Complex Environment, State Route 32." Paper presented at the 37th Annual Southeastern Association of State Highway and Transportation Officials Convention, Nashville, TN, October 1978.

_____. Region I Engineering Geologist, Tennessee Department of Transportation, Knoxville. Personal interview, 12 October 1979.

Ayres, Steven Edward. "Measuring the Difficulty for Railroad Operation: Northeastern United States." M.A. thesis, Syracuse University, 1969.

Baker, Robert F., ed. Handbook of Highway Engineering. New York: Van Nostrand Reinhold Co., 1975.

Baker, Robert F., and R. Chieruzzi. "Regional Concept of Landslide Occurrence." In Highway Research Board Bulletin 216. Washington, D.C.: National Research Council, 1959.

Berger, Robert, and Irving C. Lloyd. "Highway Maintenance Doesn't Stop at the End of the Shoulder." American City & County, June 1978, pp. 83-84.

Berry, R. W. "Relief Map of the State of Tennessee." Washington, D.C.: U.S. Geological Survey and the State of Tennessee Division of Geology Cooperating, 1936.

Carson, M. A., and M. J. Kirkby. Hillslope Form and Process. New York: Cambridge University Press, 1972.

Coleman, J. D., and K. Russam. "The Effect of Climatic Factors on Subgrade Moisture Conditions." Geotechnique 11 (1964): 22-28.

Corum, Fred. Region I Chief Highway Maintenance Engineer, Tennessee Department of Transportation, Knoxville. Personal interview, 12 October 1979.

"Deaths, Road-Wear Up with Truck Weight." The Knoxville News-Sentinel, 24 July 1979, sec. I, p. 1.

Dedmon, B. G. Highway Maintenance Engineer, Tennessee Department of Transportation, Jackson. Personal letter, 26 February 1980.

_____. Highway Maintenance Engineer, Tennessee Department of Transportation, Jackson. Telephone interview, 28 March 1980.

Department of the Army. FM 21-33, Terrain Analysis. Washington, D.C.: Government Printing Office, 1978.

_____. FM 30-10, Military Geographic Intelligence (Terrain). Washington, D.C.: Government Printing Office, 1972.

Dickson, Robert R. "The Climate of Tennessee." In Climates of the States. Vol. 1: Eastern States. Port Washington, NY: Water Information Center, 1974.

Elder, J. A., and M. E. Springer. "General Soil Map of Tennessee." Washington, D.C.: U.S. Soil Conservation Service and the Tennessee Agricultural Experiment Station Cooperating, 1978.

Eno, F. H. "The Influence of Climate on the Building, Maintenance, and Use of Roads in the United States." In Proceedings of the Highway Research Board. Vol. 9. Washington, D.C.: National Research Council, 1930.

Fales, E. D., Jr. "Our Crumbling Interstates: A National Dilemma." Popular Mechanics, July 1978, pp. 66-69, 118.

Fenneman, Nevin M. Physiography of the Eastern United States. New York: McGraw-Hill Book Co., 1938.

Frailey, Fred W. "America's Highways: Going to Pot." U.S. News & World Report, 24 July 1978, pp. 36-38.

Friedlaender, Ann Fetter. The Interstate Highway System: A Study in Public Investment. Amsterdam: North-Holland Publishing Co., 1965.

"Georgia Road Wears On and On with Just $6 a Mile Maintenance." Rural and Urban Roads, August 1978, pp. 36, 49.

Gregory, Gerald. Chief, Maintenance Management Division, Tennessee Department of Transportation, Nashville. Personal interview, 17 May 1979.

Hails, John R., ed. Applied Geomorphology. New York: Elsevier Scientific Publishing Co., 1977.

Hammond, Edwin H. "Analysis of Properties in Land Form Geography: An Application to Broad-Scale Land Form Mapping." Annals of the Association of American Geographers 54 (March 1964): 11-19.

_____. "Classes of Land-Surface Form in the Forty-Eight States, U.S.A." Map supplement no. 4, Annals of the Association of American Geographers 54 (March 1964).

Hawkins, W. J. "Geothermal Road De-Icing." Popular Science, January 1976, p. 55.

Hickerson, Thomas F. Route Location and Design. New York: McGraw-Hill Book Co., 1964.

Highway Research Board. National Cooperative Highway Research Program Report 132, Relationships Between Physiographic Units and Highway Design Factors. Washington, D.C.: Highway Research Board, National Academy of Sciences, 1972.

Highway Research Board and U.S. Army Cold Regions Research and Engineering Laboratory Cooperating. Special Report 115, Snow Removal and Ice Control Research. Washington, D.C.: National Research Council, 1970.

Hunt, Charles B. Natural Regions of the United States and Canada. San Francisco: W. H. Freeman & Co., 1974.

Kelly, James F. "Winter Maintenance: A Four-Season Job." American City & County, August 1978, pp. 73-74.

Labatut, Jean, and Wheaton J. Lane. Highways in Our National Life. Princeton: Princeton University Press, 1950.

"Managing Snowfighting Dollars." American City, August 1975, pp. 30-32.

Mather, John. Workbook in Applied Climatology. Revised Edition. Elmer, NJ: C. W. Thornthwaite Associates, 1977.

"New Route for the Highway Trust Fund; Money to be Used for Road and Bridge Repair." Business Week, 17 January 1977, pp. 84-85.

Nie, Norman H., C. Hadlai Hull, Jean G. Jenkins, Karin Steinbrenner, and Dale H. Bent. SPSS, Statistical Package for the Social Sciences. New York: McGraw-Hill Book Co., 1975.

Ogelsby, Clarkson H., and Laurence I. Hewes. Highway Engineering. New York: John Wiley & Sons, 1963.

Oke, T. R. Boundary Layer Climates. New York: John Wiley & Sons, 1978.

Oliver, Will F. District Maintenance Supervisor, Tennessee Department of Transportation, Clarksville. Personal letter, 19 March 1980.

Organization for Economic Cooperation and Development. Maintenance Techniques for Road Surfacings: Assessment, Choice of Treatment, Planning, Implementation. Paris: Organization for Economic Development, 1978.

Osburn, Mack. District Maintenance Supervisor, Tennessee Department of Transportation, Columbia. Personal letter, 26 February 1980.

Paquette, Radnor J., Norman Ashford, and Paul H. Wright. Transportation Engineering. New York: Ronald Press Co., 1972.

Parizek, Richard R. "Impact of Highways on the Hydrogeologic Environment." In Environmental Geomorphology and Landscape Conservation. Vol. III: Non-Urban. Donald R. Coates, ed. Stroudsburg, PA: Dowden, Hutchinson, & Ross, 1973.

"Potholes, Cracks: U.S. Highways Going Downhill." U.S. News & World Report, 17 January 1977, p. 68.

"Prevent Soil Erosion on Highway Slopes." American City, July 1975, p. 39.

Raiken, Howard H. "Federal Role in Supporting Research and Development for Reducing Transportation Maintenance Costs." In Transportation Research Record 598, Maintenance Management, The Federal Role, Unionization, Pavement Maintenance, and Ice Control. Washington, D.C.: Transportation Research Board, National Academy of Sciences, 1976.

Raisz, Erwin. Map--"Landforms of the United States." Cambridge, MA: By the Author, 1957.

Ring, George W. "Drainage Design Criteria for Pavement Structures." Public Roads, December 1978, pp. 105-110.

_____. "Seasonal Strength of Pavements." Public Roads, September 1974, pp. 62-68.

Ritter, Leo J., and Radnor J. Paquette. Highway Engineering. Third Edition. New York: Ronald Press Co., 1967.

"Road, Bridge Repairs to Cost $2.8 Billion." American City & County, April 1977, p. 18.

The Road Information Program. The Effect of Substandard Roads on Tennessee Drivers' Costs. Nashville: Tennesseans for Better Transportation, 1979.

Roberts, Paul O., and John H. Suhrbier. M.I.T. Report No. 5, Highway Location Analysis: An Example Problem. Cambridge: M.I.T. Press, 1966.

Royster, David L. "Construction of a Reinforced Earth Fill Along Interstate 40 in Tennessee." Paper presented at the 25th Annual Highway Geology Symposium, Raleigh, NC, 24 May 1974.

_____. "Highway Landslide Problems Along the Cumberland Plateau in Tennessee." Bulletin of the Association of Engineering Geologists 10, no. 4 (1973): 255-287.

_____. "Highway Landslide and Stability Problems in Tennessee." Paper presented at the 46th Annual Tennessee Highway Conference, 9-10 April 1964.

_____. "Landslide Remedial Measures." Paper presented at the 37th Annual Southeastern Association of State Highway and Transportation Officials Convention, Nashville, TN, October 1978.

_____. "Some Observations on the Use of Horizontal Drains in the Correction and Prevention of Landslides." Paper presented at the 28th Annual Highway Geology Symposium, Rapid City, SD, August 1977.

Schroeder, W. L. Soils in Construction. New York: John Wiley & Sons, 1975.

Schuster, Robert L., and Raymond J. Krizek, eds. Transportation Research Board Special Report 176, Landslides: Analysis and Control. Washington, D.C.: Transportation Research Board, National Academy of Sciences, 1978.

Sherrill, Robert. "Truckers Blitz the Interstate." Nation, 29 April 1978, pp. 498-502.

Snow, William Brewster. The Highway and the Landscape. New Brunswick, NJ: Rutgers University Press, 1969.

Tennessee Department of Highways. Maintenance Field Operations Manual. Nashville: Tennessee Department of Highways, 1971.

Tennessee Department of Transportation. Bureau of Highways. Maintenance Division Clerk's Manual. Nashville: Tennessee Department of Transportation, 1976.

_____. Bureau of Planning and Programming. 1975 Report on the Vehicle Classification Counts. Nashville: Tennessee Department of Transportation, 1976.

_____. Bureau of Planning and Programming. 1977 Average Daily Traffic on Highways and City Streets in Tennessee. Nashville: Tennessee Department of Transportation, 1977.

_____. "Official Highway Map of Tennessee." Nashville: Tennessee Department of Transportation, 1979.

Transportation Research Board. National Cooperative Highway Research Program Synthesis of Highway Practice 26, Roadway Design in Seasonal Frost Areas. Washington, D.C.: Transportation Research Board, National Research Council, 1974.

_____. National Cooperative Highway Research Program Synthesis of Highway Practice 60, Failure and Repair of Continuously Reinforced Concrete Pavement. Washington, D.C.: Transportation Research Board, National Research Council, 1979.

_____. Special Report 148, Innovations in Construction and Maintenance of Transportation Facilities. Washington, D.C.: Transportation Research Board, National Research Council, 1974.

_____. Transportation Research Record 532, Frost, Moisture, and Erosion. Washington, D.C.: Transportation Research Board, National Research Council, 1975.

_____. Transportation Research Record 551, Mitigating Adverse Environmental Effects of Highway Construction. Washington, D.C.: Transportation Research Board, National Research Council, 1975.

U.S. Army Engineer School. Engineer Subcourse 359-3, Drainage. Fort Belvoir, VA: U.S. Army Engineer School, 1973.

_____. Engineer Subcourse 360-1, Soils Engineering. Fort Belvoir, VA: U.S. Army Engineer School, 1974.

_____. Engineer Subcourse 365-2, Roads and Airfields II. Fort Belvoir, VA: U.S. Army Engineer School, 1975.

_____. Engineer Subcourse 366-1, Paving and Surfacing Operations. Fort Belvoir, VA: U.S. Army Engineer School, 1966.

U.S. Army Engineer Waterways Experiment Station. Climatic Effects on Airport Pavement Systems; State of the Art, by Barry J. Dempsey. Contract Report S-76-12. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, 1976.

U.S. Department of Agriculture. Bureau of Plant Industry, Soils, and Agricultural Engineering, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Cumberland County, Tennessee, by E. H. Hubbard. Washington, D.C.: Government Printing Office, 1950.

_____. Bureau of Plant Industry, Soils, and Agricultural Engineering, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Humphreys County, Tennessee, by G. M. Welles. Washington, D.C.: Government Printing Office, 1946.

_____. Bureau of Plant Industry, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Roane County, Tennessee, by M. E. Swann. Washington, D.C.: Government Printing Office, 1942.

_____. Soil Conservation Service and Tennessee Agricultural Experiment Station Cooperating. Soil Survey of Fayette County, Tennessee, by R. L. Flowers. Washington, D.C.: Government Printing Office, 1964.

_____. Soil Conservation Service and Tennessee Agricultural Experiment Station Cooperating. Soil Survey of Madison County, Tennessee, by W. T. Brown, G. L. Keathley, and C. T. Conner. Washington, D.C.: Government Printing Office, 1978.

_____. Soil Conservation Service and Tennessee Agricultural Experiment Station Cooperating. Soil Survey of Putnam County, Tennessee, by G. T. Jackson, S. R. Bacon, B. C. Cox, and C. R. Gass. Washington, D.C.: Government Printing Office, 1963.

_____. Soil Conservation Service, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Benton County, Tennessee, by L. E. Odom. Washington, D.C.: Government Printing Office, 1953.

_____. Soil Conservation Service, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Cocke County, Tennessee, by T. E. Beesley. Washington, D.C.: Government Printing Office, 1955.

_____. Soil Conservation Service, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Decatur County, Tennessee, by L. E. Odom. Washington, D.C.: Government Printing Office, 1954.

_____. Soil Conservation Service, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Henderson County, Tennessee, by R. L. Flowers. Washington, D.C.: Government Printing Office, 1960.

_____. Soil Conservation Service, Tennessee Agricultural Experiment Station, and Tennessee Valley Authority Cooperating. Soil Survey of Sevier County, Tennessee, by E. H. Hubbard. Washington, D.C.: Government Printing Office, 1956.

U.S. Department of Commerce. National Oceanic and Atmospheric Administration. Climatology of the United States No. 60, Climate of Tennessee. (1977).

_____. National Oceanic and Atmospheric Administration. Climatological Data: Tennessee, 1974-1979.

_____. National Oceanic and Atmospheric Administration. Heating and Cooling Degree Days for Tennessee. Technical Memorandum 24 (1978).

U.S. Department of the Interior. Geological Survey. A Proposed Streamflow-Data Program for Tennessee, by V. Jeff May, George H. Wood, and Donald R. Rima. Nashville: U.S. Department of the Interior, 1970.

_____. Geological Survey. Various topographic maps covering the route of Interstate 40 analyzed in this study. Washington, D.C.: Government Printing Office, various dates.

Zaruba, Quido, and Vojtech Mencl. Landslides and Their Control. New York: Elsevier Scientific Publishing Co., 1969.

VITA

Thomas Brock Maertens, Jr. was born at Fort Benning, Georgia, on 17 October 1948. As the son of a career military officer, he attended schools in many different areas of the United States and overseas. In 1966, he graduated from Robert E. Lee High School in Springfield, Virginia. In July of that year, he entered the United States Military Academy at West Point where he received a Bachelor of Science degree in June 1970.

From 1970 to 1978, he served in varying assignments as an artillery and later as a transportation officer in the U.S. Army. These assignments included a combat flying tour in the Republic of Vietnam. In 1976, while stationed at Fort Eustis, Virginia, he received a Master of Science degree in Transportation Management from the Florida Institute of Technology.

In September 1978, he entered the Graduate School of The University of Tennessee at Knoxville. He was awarded a Master of Science degree in Geography in June 1980.

The author is a member of the Association of American Geographers. After graduation, Captain Maertens will be assigned to the United States Military

Academy at West Point, New York, where he will serve as an instructor in the Department of Geography and Computer Science.

He is married to the former Karen Kellar of Cocoa Beach, Florida.