To the Graduate Council:

I am submitting herewith a thesis written by Larry A. Reynolds entitled "The Geography of the Hazard of Groundwater Contamination in Claiborne Co., Tenn." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

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Vice Chancellor
Graduate Studies and
Research

THE GEOGRAPHY OF THE HAZARD OF GROUNDWATER CONTAMINATION IN CLAIBORNE CO., TENN.

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Larry A. Reynolds

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ABSTRACT

The purpose of this study was to determine the risk of groundwater contamination from septic tank systems in the Ridge and Valley section of Claiborne County, Tennessee. During the past decade the rural landscape of Claiborne County was altered by a sharp increase in population, associated building of new housing, improvements in existing housing, and the introduction of subdivisions in previously rural areas of the county. These trends along with the increasing use of groundwater and a related increased use of septic tanks for effluent disposal, and the sensitive aquifer underlying the karst terrain in the county portend serious serious future problems of groundwater contamination.

The necessary steps used to reach the objectives of this study were: (1) to describe the environmental components of the study area--the bedrock lithology, the soils, the local hydrologic systems that recharge groundwater resources; (2) to describe the changing nature of the cultural landscape that affects water use and sewage disposal; and to evaluate the water resource situation of the study area by overlaying the environmental situation and the cultural lansdcape features.

The conclusion of this research is that the risk of biological contamination of groundwater depends on the environmental setting and water systems in use in the

different sections of Claiborne County. In the northern Powell Valley, because of the highly susceptible aquifer, dense settlement pattern, and high use of groundwater in the 1970's, contamination problems have developed or are not a threat to water supplies. In the area around the towns of Tazewell and New Tazewell which has a similar environmental setting, water contamination is less a problem because of the rapid expansion of the local utility district.

Recommendations for improving residential water supplies are: 1. Improve the residents' perception of the risk of using raw groundwater; 2. Encourage greater monitoring by decreasing the cost of testing water samples for coliform bacteria; 3. Connect more rural households to utility water supplies; 4. Improve sewage disposal techniques with aeration systems and gray-water/black-water separation.

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CHAPTER I

INTRODUCTION

The objective of this thesis is to investigate the water resource situation of the Ridge and Valley section of Claiborne County. Because of the changes in residential water use during the 1970's and the nature of the environment, the long-term stability of the groundwater supplies is in question in an area of limited prospects for utility water and sewage systems. By fitting together the physical and cultural components of the environment of the study area, the current water resource situation will be presented along with consideration of the future issues involved.

1. SITE AND SITUATION

The study area, which includes all of the Ridge and Valley section of Claiborne County, is located in upper East Tennessee next to the Cumberland Escarpment (Fig. 1). The significance of this study area is that the increasing rural population, along with the changing nature of the water demand, has caused an increasing dependence on the groundwater supplies and a related increased use of septic tanks for effluent disposal. These trends, along with the environmental and economic barriers to utility water and

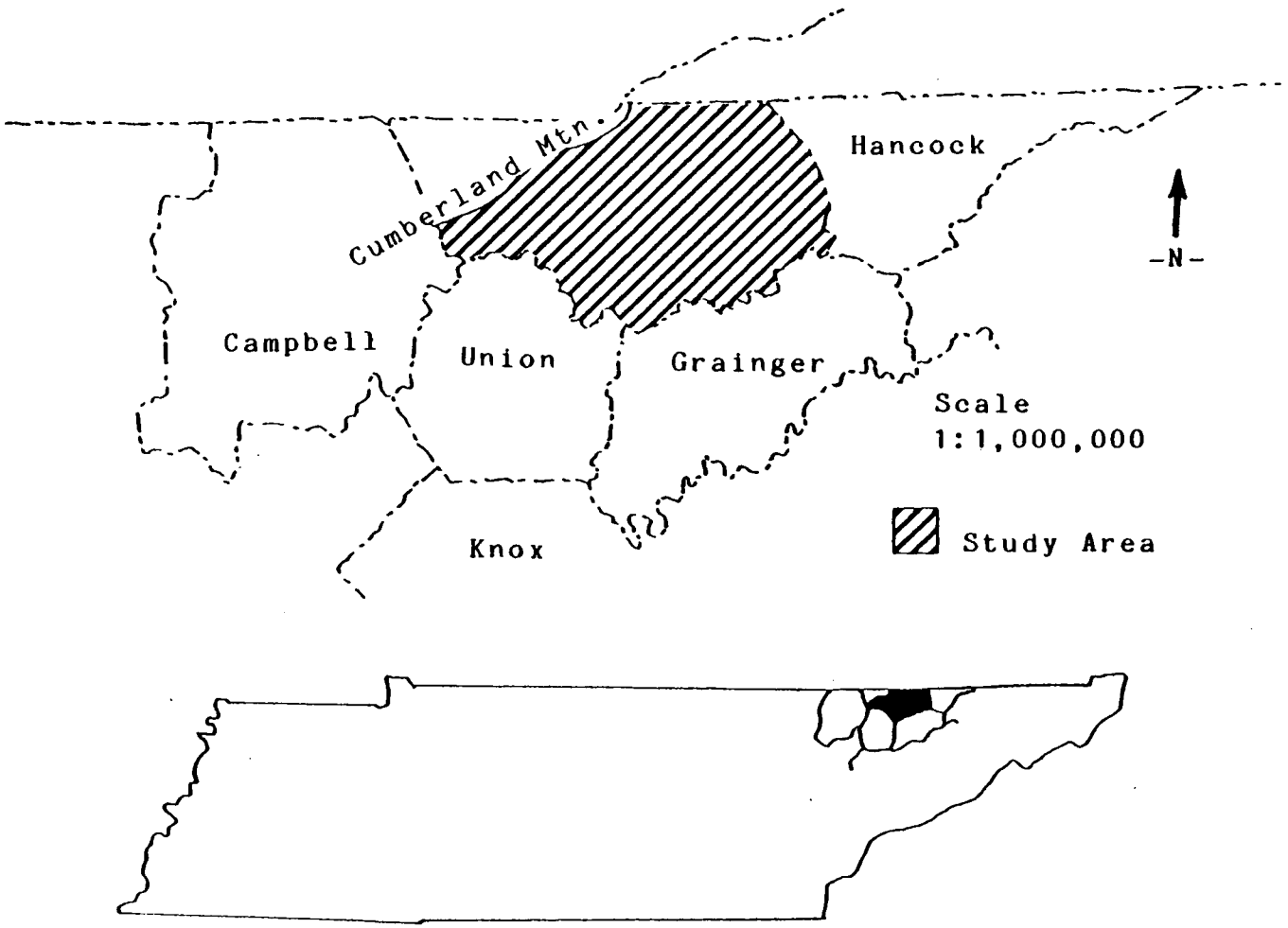


Fig. 1. LOCATION OF THE STUDY AREA.

sewage service and the sensitivity of the aquifer underlying the karst terrain in the majority of the study area, are likely to result in serious water resource problems.

From an historical perspective, the increase in population back to the levels of the mid-fifties should not cause any substantial increase in the liklihood of groundwater contamination. However, the residential environment has changed with the resettlement pattern now more concentrated than it was in the past. Other changes have occurred in the nature of residential water use. No longer are springs, cisterns, or shallow wells the dominant water resources used, or the outhouse the dominant disposal system used in the rural landscape. With increased population and new housing, deep wells have been dug, indoor plumbing is common across the county, water-using appliances are in greater use, and an increase in septic tank systems to dispose of the waste have all occurred. With these transformations and greater water use, the county's residents can no longer depend on the less reliable and unprotected resources of the past. Concomitantly, effluent generation has increased and the settlement pattern has become more clustered. These changes are taking place in an environment that may not be able to handle the increased effluent without contaminating groundwater.

2. METHODS

Four steps will be needed to reach the objectives of this study. First, the environmental components of the study area, especially bedrock lithology and soils will be described together in order to provide the environmental situation in which the local hydrologic system and water resources occur. Second, the changing nature of water use will be presented. Third, the distribution of the water resource systems and sewage disposal systems will be compared. Fourth, the connection between the environment and residential water use will be discussed by associating the sensitive carbonate aquifer, the increase in population and water use, the increase in sewage being disposed through septic tanks, and the increased use of groundwater.

The environmental components that have direct influence on the degree of groundwater sensitivity to surface contamination are the bedrock lithology, surface topography, and the soils. Geologic and related information will be used to describe the surface geohydrology that influences the withdrawal of groundwater. An analysis of well depths and well yields will be used to draw a simplified picture of the complex and heterogeneous structure of the carbonate aquifer that underlies the region. The geomorphology of the region shows a large degree of karstification, which affects both the subsurface and surface hydrology. By mapping the area covered by sinkholes, karst areas can be

defined. From these environmental clues, areas with shallow pollution-sensitive aquifers are differentiated from areas where groundwater supplies are better protected from surface contamination.

With increased sewage disposal through septic tank systems, the soil column becomes critical for decomposition of organic contamination. Since these individual systems are the major source of pollution in the study area, the soil conditions that affect septic tank efficiency will be analyzed by using county soil survey data. From these soil data the study area will be differentiated into areas with high, moderate and low susceptibility to surface contamination.

The cultural components are drawn from census data and local information gathered personally. To document the increase in water demand in the study area, population and housing census data were used along with figures from the Arthur-Sewanee Utility District and the Claiborne County Utility District on water use per household. During the last decade the population of the study area increased substantially. These changes in settlement makeup were documented by using topographic maps and county highway maps of the area to assess the population density and its spatial relationship to the sources of potable water and disposal systems. A cartographic approach was used. Data were obtained from the utility districts and the well log files of the Water Resource Division of the Tennessee

Department of Conservation. From maps of the settlement pattern, the water systems in use, and the sewage generation, cultural components of the study were compared with the results of the environmental analysis of potential risk of groundwater contamination to assess the water resource situation of the study area.

The location of all place names used in this report are shown on the general reference map (Fig. 2).

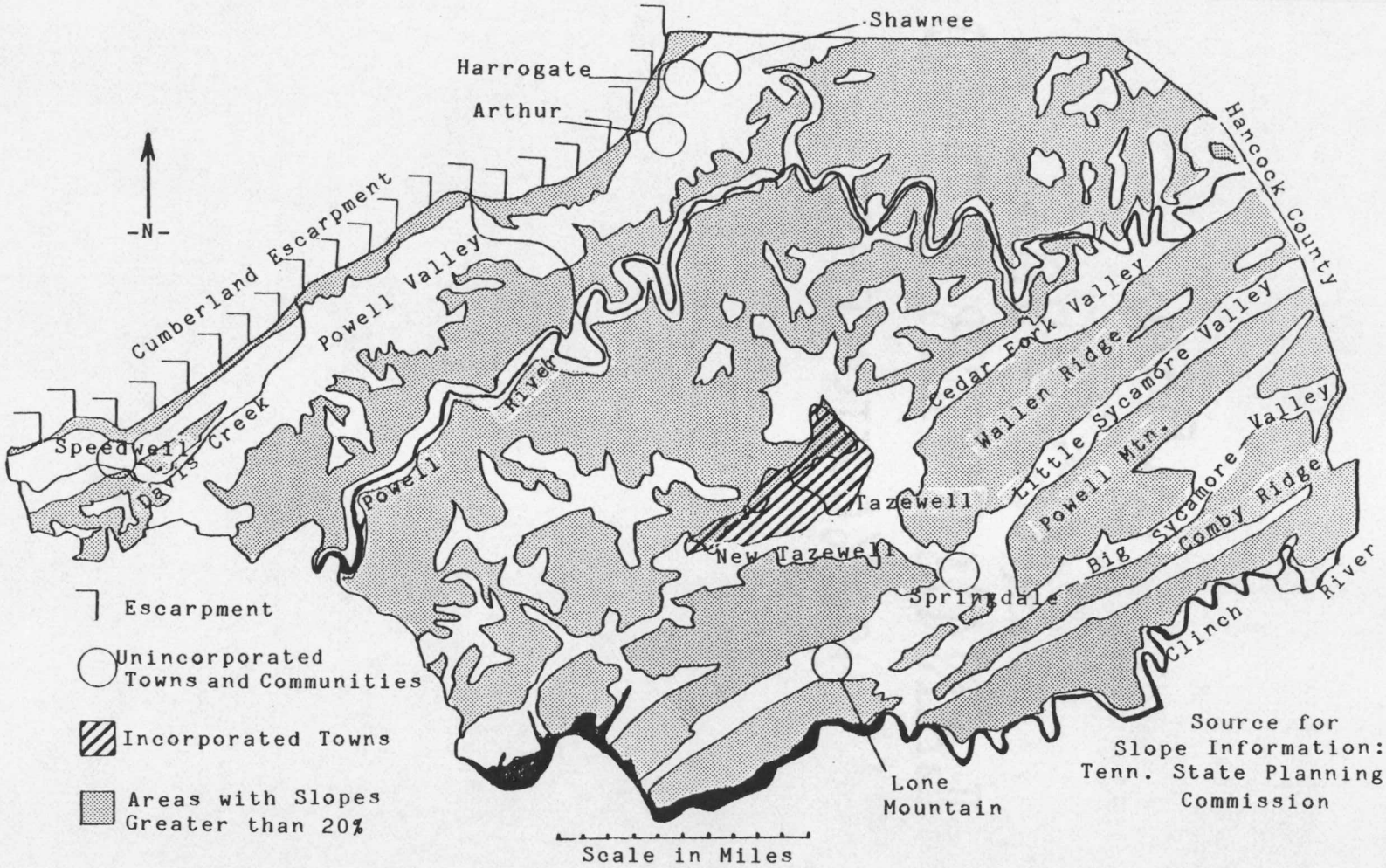


Fig. 2. GENERAL REFERENCE MAP OF THE RIDGE AND VALLEY SECTION OF CLAIBORNE COUNTY.

CHAPTER II

PHYSICAL ENVIRONMENTAL SETTING

The interaction between the homeowners and the water cycle (Fig. 3) has the potential to modify the quality of water available for residential use. By examining the bedrock geology and the soils, areas most susceptible to groundwater contamination can be identified. The bedrock in the study area which acts as the dominant aquifer system can be classified by lithology and degree of access to surface run-off. Soil conditions, especially permeability, govern the second part of the homeowner/groundwater cycle by affecting the efficiency of the septic tanks to degrade residential waste. The more critical soil characteristics are clay content and depth to bedrock. By overlaying the bedrock and soil components, the susceptibility of different parts of the study area to groundwater contamination can be classified. The second part of this chapter examines how the climatically driven local hydrologic cycle affects current levels of groundwater contamination and the pathways by which contamination moves into the groundwater.

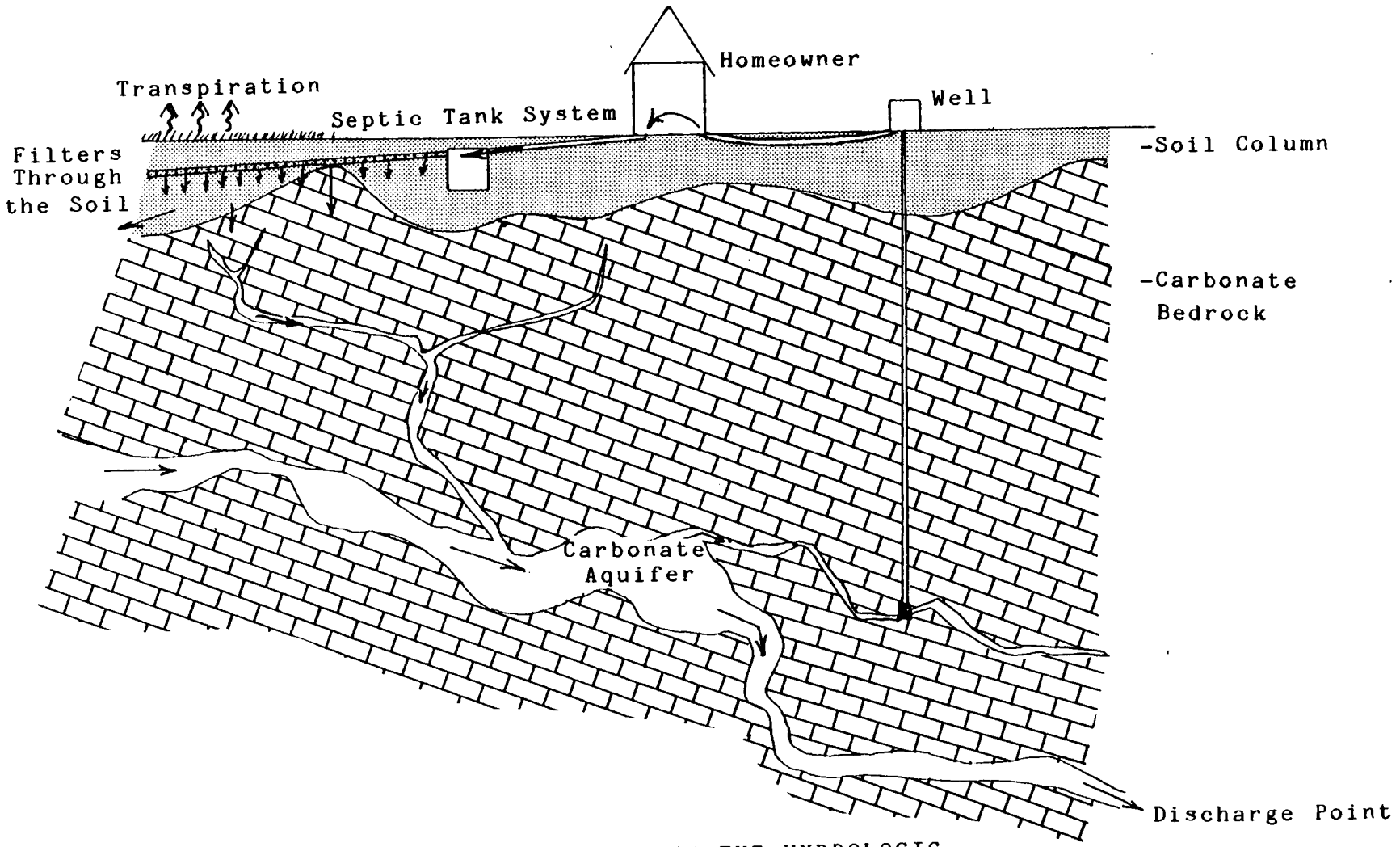


Fig. 3. INTERACTIONS OF THE HOMEOWNER WITH THE HYDROLOGIC CYCLE IN THE AREAS OF THE CARBONATE BEDROCK.

1. BEDROCK GEOLOGY

The study area is located in the Ridge and Valley physiographic province adjacent to the Cumberland Escarpment. It is underlain primarily by limestones and dolomites with some intercalated shales and sandstone of early Cambrian through Ordovician ages (Fig. 4). The carbonates serve as aquifers. Because of the low primary permeability of limestones, dolomite, and shales the development of these bedrocks as aquifers depends on secondary permeability brought about by solution enlargement of openings along bedding planes, joints, and fractures. The limestone and dolomites, especially the purer carbonate limestones, are much more soluble than shales and are the best aquifers. Shales are generally poor sources of groundwater. The water-bearing zone of the shale uplands of the eastern section of the county is mainly confined to the unconsolidated regolith and isolated joints and fractures.

The carbonate aquifers underlying the limestone valleys and dolomite uplands have irregularly spaced water-bearing channels. Well logs from the Tennessee Department of Conservation show that well yields and aquifer depth vary greatly over short distances (Tenn. Dept. of Conservation, 1981). Discussion with well-drillers also bears this out. Many caves and large springs in these areas point to a complex network of solution and subterranean streams capable

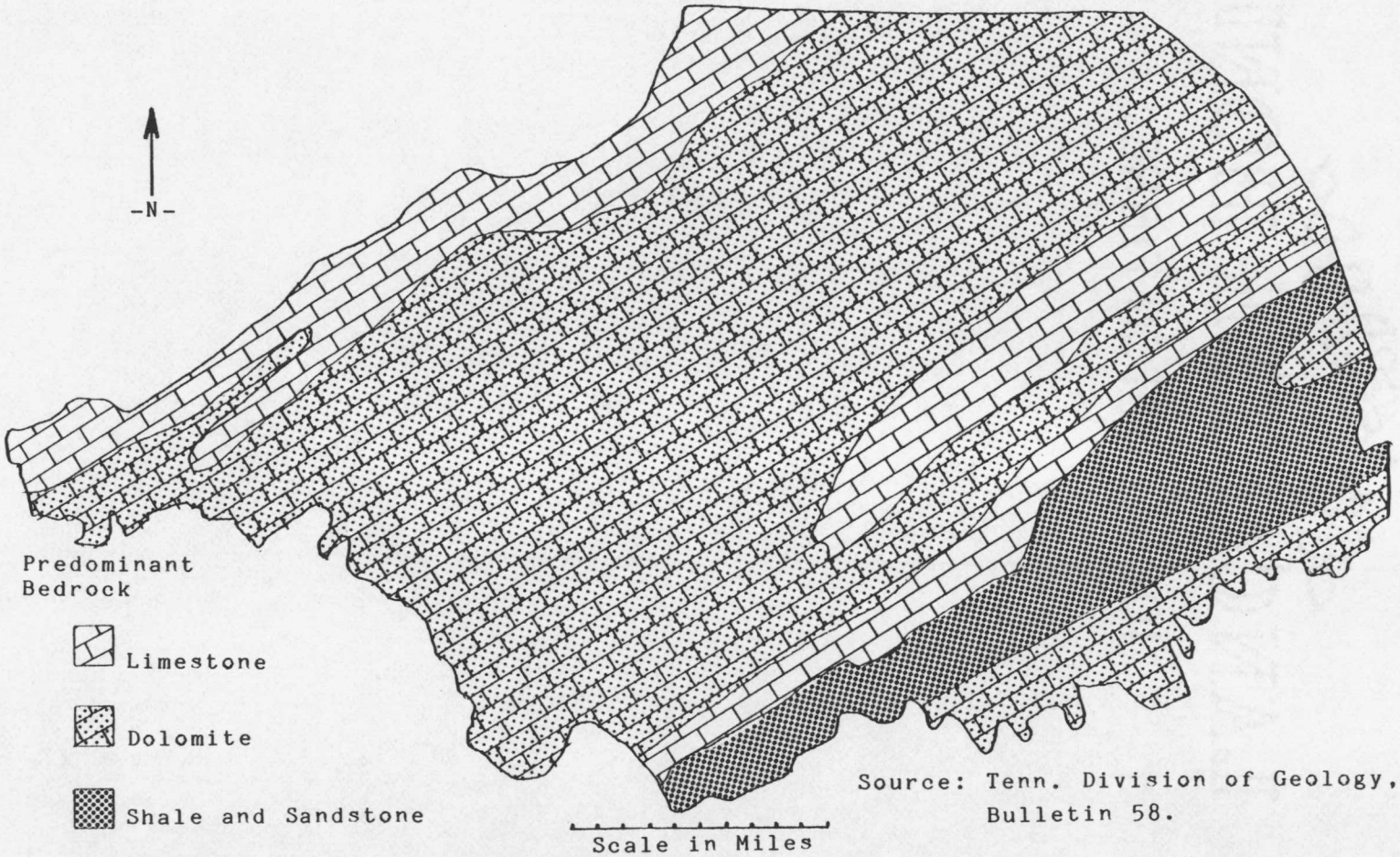


Fig. 4. BASIC LITHOLOGY OF THE RIDGE AND VALLEY SECTION OF CLAIBORNE COUNTY.

of quickly draining away surplus water from the surfaces of the limestone valleys and dolomite uplands.

The susceptibility of groundwater to surface contamination can be estimated by looking at the primary and secondary permeability of the bedrock, depth of regolith, degree of surface karstification, and surface and subsurface drainage patterns. Three general classes of susceptibility are used: high, moderate, and low. Areas with well developed subsurface solution aquifers, sinkhole terrain, and shallow soil have high susceptibility to contamination. Areas with deeper soil cover which reduces percolation rates, and isolated sinkhole topography are moderately susceptible. Low susceptibility is in areas without carbonate aquifers where groundwater occurrence is low and contamination is not easily dispersed in these relatively impermeable bedrocks.

2. SOILS

With the increasing movement of people to rural communities and the lack of public sewers in these areas, the use of septic tanks has increased greatly. For the septic tank system to protect adequately the underlying water supply, the soil must absorb large quantities of water and should at the same time filter out organic matter, bacteria, and viruses so that the downward moving water is cleaned by the time it reaches the groundwater (Lietzke,

1977, p. 1). With the average home of three to four bedrooms, the daily load on the septic tank system is 300 to 400 gallons or about 146,000 gal/y (Lietzke, 1977, p. 2). This means that the soil of a septic tank drain field must dispose of 150 to 200 inches of rainfall-equivalent each year. Many soils of the study area cannot filter this much water because of one or more unfavorable soil properties that affect waste biodegradation: high clay content, restrictive layers that permit only slow percolation, shallow depth especially on steep slopes, and undesirable slope position (Lietzke, 1977, p. 2). These properties are detrimental to the operation of septic systems and result in failures, such as lateral seepage or creeping failure.

The protection of the underlying carbonate aquifer depends primarily on the filtering capacity of the subsoil. Unlike creeping failure where the system slowly backs up, or lateral seepage where untreated waste rises to the surface, contamination of the groundwater is hidden from the homeowner and eventually may contaminate the local water supplies. When the subsoil percolation is low because of high clay content and limestone pinnacles are present in the drain field network, direct internal drainage of waste into the limestone bedrock will occur (Lietzke, 1982). Because of the low permeability of clays formed from high grade limestones, little filtering of the residential sewage will take place. Because this is commonly coupled with rapid

movement of waste down the calcite weathering front on the surface of limestone bedrock, little filtering occurs before the waste leaves the decomposition environment of the soil. For a one-inch-diameter limestone pinnacle in contact with the drain field, the amount of drainage equals 100 ft. of ideal soil drainage in the rest of the system (Lietzke, 1982). With the majority of decomposition taking place in the soil column, soils with these characteristics (Fig. 5) are the most limiting for septic tank use and aquifer protection.

3. SUSCEPTIBLE AREAS FOR GROUNDWATER CONTAMINATION

With the criteria set forth on the overviews of bedrock geology and soil, the study area was regionalized into high, moderate, and low susceptibility areas of groundwater contamination (Table 1 and Fig. 6). In the high-risk areas the environmental factors allow rapid vertical and horizontal movement of surface pollution into and through the carbonate aquifer. In the moderate-risk areas, the possibility for rapid movement of surface pollution into the underlying aquifer is lower, but seasonal rapid vertical movement can still occur. In the low-risk areas, isolated groundwater contamination can result from improper construction and placement of wells and septic tanks, but widespread contamination should not occur. For each of these susceptibility zones, the areas differentiated will

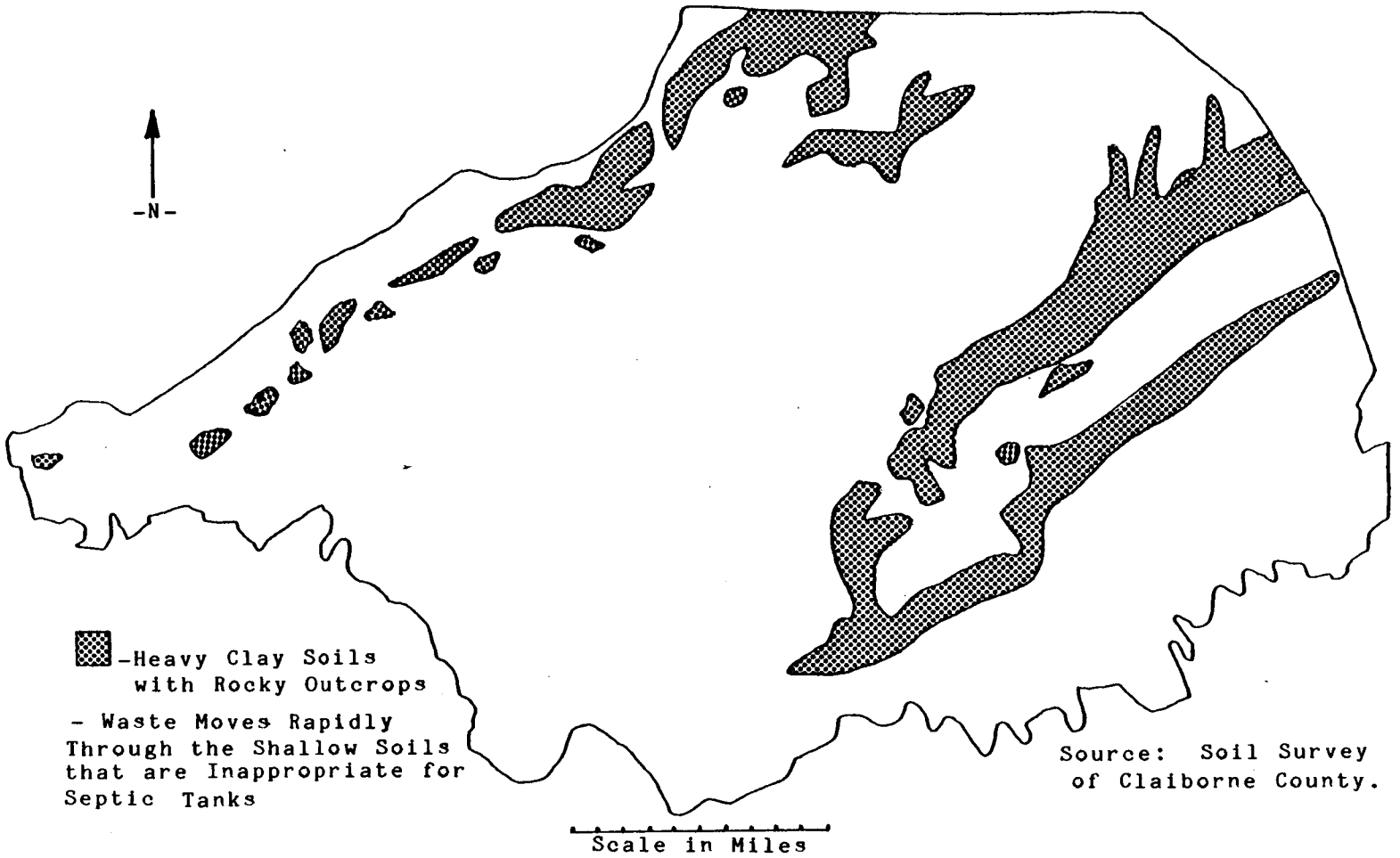


Fig. 5. AREAS WITH HAZARDOUS SOIL CONDITIONS FOR SEPTIC TANK USE.

TABLE 1. Hydrologic Units of the Ridge and Valley Section of Clairborne County

Hydrologic Unit	Development of Aquifer	Amount of Surface Karst	Drainage Network Development	Amount of Regolith	Soil Conditions for Septic Tanks	Aquifer Susceptibility Ranking
Limestone Valleys	High	High	Low	Low	Poor	High
Karst Dolomite Upland	High	High	Moderate	High	Good	Moderate
Dolomite Upland	High	Low	High	High	Good	Low
Shale/ Sandstone Highlands	Low	Low	High	Low	Poor	Low
Shale Valleys	Moderate	Low	High	Moderate	Moderate	Low

Source: USGS Geologic Maps - GQ-842, GQ-188, GQ-301, and GQ-405

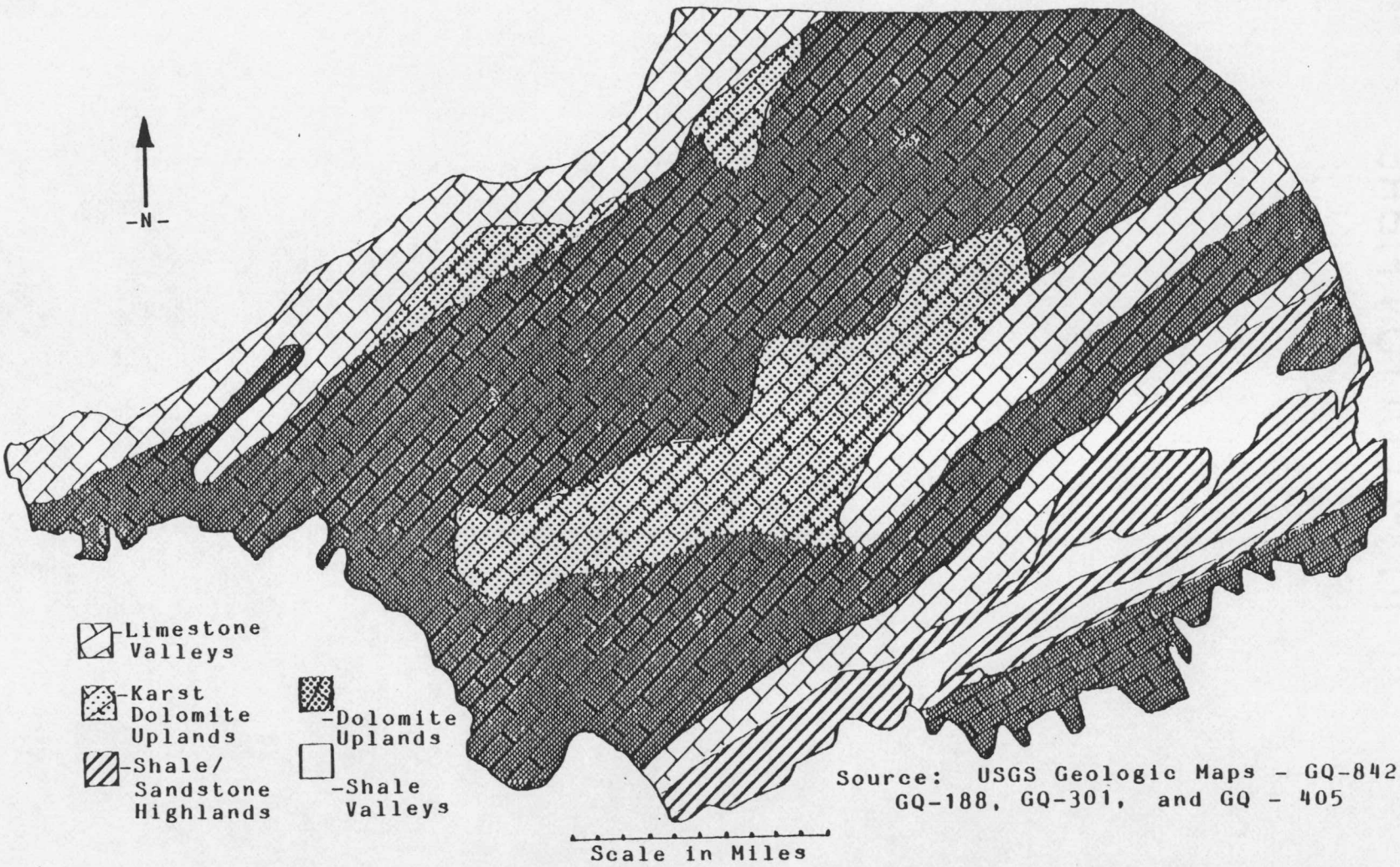


Fig. 6. HYDROLOGIC UNITS OF THE RIDGE AND VALLEY SECTION OF CLAIBORNE COUNTY.

be identified and and the reasons for the ratings are discussed.

High Susceptibility Areas

The three areas of high-risk aquifer contamination, moving west to east, are Powell Valley, Cedar Fork Valley, and Little Sycamore Creek Valley (Fig. 6). In each of these valleys the underlying bedrock is high-grade Chickamauga limestone. The aquifer and surface geomorphology that has evolved from the bedrock makes these three valleys susceptible to rapid vertical and horizontal movement of surface contamination to and throughout the carbonate aquifer. The folded and fractured formations underlying these valleys and the poor development of a surface drainage network points to a complex internal network of solution-enlarged channels and subterranean streams that drain the valley floors.

In these valleys many hydrologic clues can be found from the surface geomorphology that has evolved. Secondary landform features brought about through karstification of the carbonate bedrock causes rapid internal drainage of these areas. The distribution of sinkholes found on USGS 1:24,000-scale topographical maps was used to locate surface karst areas (Fig. 7). In each of these wide-floored valleys many sinkholes have developed, along with well-drained shallow soils and many disappearing streams. The many karst surface features in the head sections of these valleys are

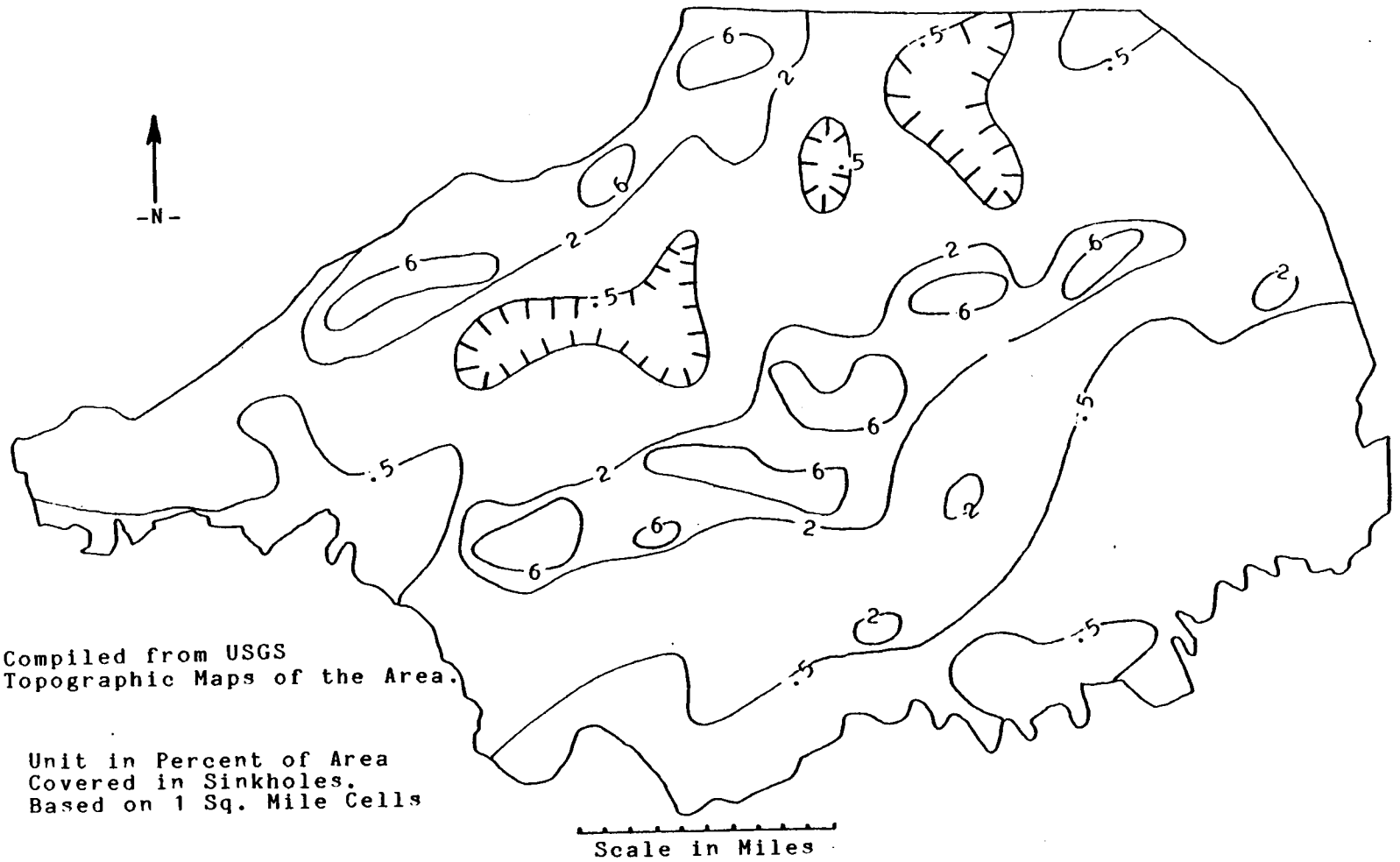


Fig. 7. DISTRIBUTION OF SINKHOLES IN THE RIDGE AND VALLEY SECTION OF CLAIBORNE COUNTY.

unusual for East Tennessee. There are differences in degree of karstification, but the major environmental influence on the landscape and hydrology of these valleys is the karst that has evolved. The following is a description of each of these limestone valleys.

The Powell Valley, which is 13 miles long and averages between one to three miles wide, is the largest of the three high-risk valleys in the county. Because of the gently dipping bedrock that forms the western wing of the Powell Valley anticline, Powell Valley has a different hydrology from the Cedar Fork and Little Sycamore Valleys. Like the other two limestone valleys, however, there is a progression from the predominantly karst terrain at the head of valleys to the concealed karst under alluvial and colluvial deposits downslope. In the northern part of the valley streams flow more or less directly across the valley from the Cumberland Escarpment to the Powell River. The towns of Harrogate and Arthur, and the area south to Town Creek, have this drainage pattern. It is an area of well-developed karst and lacks extensive alluvial deposits which might mask the karst characteristics of the surface. The limestones here are of the Chickamauga group and are low in impurities. These limestones weather quickly leaving little residue (Austin, 1948, p. 9). Streams in this area disappear and reappear several times in crossing the area.

Southwest of the Town Creek watershed, surface drainage of the Powell Valley is towards the southwest down the axis

of the valley through Davis Creek. As the alluvial deposits deepen downstream, the smaller solution sinkholes are fewer and limestone outcrops are fewer, but cave-collapsed sinkholes are still found on the isolated hills. "The masking of the karst development in the lower reaches of these valleys does not mean that the effects of solution are not significant. The term 'covered valley karst' is appropriate because the limestone surface is karstified and the irregularities on the bedrock surface are concealed by the widespread residual soil." (Stringfield, 1974, p. 29)

The soil conditions in the Powell Valley allow rapid movement of septic contamination into the bedrock. The majority of the soils are of the Talbott-Rock outcrop complex. These soils, also found in the other two limestone valleys (Fig. 5), have heavy red-clay subsoils, are 18 to 40 inches deep, and are well drained, having moderately slow permeability. Though outcrops of limestone in the Powell Valley are fewer and less conspicuous than in the other two valleys, their presence under the shallow soil cover can result in rapid piping and drainage of effluent from the drain-field network of septic tank systems. The attendent loss of filtering capacity causes a hidden failure of septic tank systems and is the most widespread potential hazard to the groundwater supply of the Powell Valley.

The Cedar Fork Valley, located northeast of Tazewell, is a narrow valley, one-half to one mile wide, that extends to the border of Hancock County to the northeast. Unlike

that in the Powell Valley, the high-grade limestone bedrock is severely warped and fractured. Because of the narrow width and low development of the surface drainage network, the geomorphology is not as complex as in the Powell Valley. The Powell River, which cuts through the isolated hills on the northwestern edge of the valley, is the dominant hydrologic influence on the valley's drainage. Of the twelve streams that descend Wallen Ridge to the east, only six flow across the valley floor into the Powell River. The terrain of the valley is dominated by disappearing streams, numerous sinkholes, and extensive limestone outcrops that extend the length of the valley. The relief of 120 feet between the valley floor and the Powell River causes a corresponding drop in the phreatic zone towards the river bed. Thus the entire valley is up-gradient relative to the groundwater discharge points along the river. Likewise the carbonate aquifer is shallow and can be quickly contaminated by rapid movement of surface water downward to the aquifer.

As in the Powell Valley, the soil conditions of the Cedar Fork Valley are hazardous for septic tank use. The presence of limestone outcrops is even more noticeable because of the severe erosion of the overlying soil. The soil that has formed from the high-grade limestones has high clay content with moderately slow permeability. Not only does the shallow soil and associated slow permeability affect installation and visible efficiency of septic tank

systems, but hidden failure of the systems can occur which endangers the quality of the water supply. Because of this condition, along with the rapid movements of surface water into and through the carbonate aquifer, this area is susceptible to widepread contamination of the groundwater.

The Little Sycamore Valley, unlike the first two limestone valleys, is isolated from the hydrological influences of a major surface drainage network or nearby subterranean discharge points, except at the mouth of the valley. A mask of alluvium on the valley floor and on the steep, adjacent uplands of Little Ridge and Powell Mountain restricts the area of karst features visable at the surface to the head section of the valley. The Lone Mountain community, southwest of Little Sycamore Valley, which is underlain by the same geologic formation, has a similar karst hydrology. As with the other highly susceptible areas, the Little Sycamore Valley and the Lone Mountain area have high risk of contamination because of the rapid movement of surface water into the aquifer.

Because of the extensive alluvium that has been deposited in the lower elevations of the Little Sycamore Valley, the occurrence of soils poorly suited to septic tank systems is generally on convex-slope positions. The majority of older housing is on these same slopes. The soil conditions of the Lone Mountain Community are similar to those of the Cedar Fork Valley--shallow, with slow percolation rates and rocky outcrops of limestone.

Moderate Susceptibility Areas

The uplands closely associated with the Powell and Cedar Fork Valleys are underlain by the Knox dolomite--a major aquifer of East Tennessee (Zurawski, 1978, p. 12). A majority of the caves in East Tennessee were formed in the Knox stratigraphic units (Barr, 1961, p. 13). Likewise the majority of the caves in the study area are found in these units, and many springs are found on the ridge slopes in the northern section of the study area. Unlike the limestone of the valleys, however, the cherty dolomite bedrock produces large amounts of regolith when weathered. The thicker regolith and associated soils over the majority of the area reduces the potential for contamination to enter the groundwater compared with the limestone valleys. Although the aquifer of the Knox dolomite is somewhat protected from surface contamination by deeper soils, patches of surface karst exist that are quite susceptible to groundwater contamination because of rapid internal drainage.

In this area of moderate-risk contamination (Table 1 and Fig. 6), there are fewer rock outcrops, steeper slopes with associated increases in surface runoff, and a better developed dendritic drainage pattern than in the limestone valleys. Where sinkholes are prevalent (Fig. 7), intermittent flushing of surface contaminants into the aquifer could take place but not to the degree found in

the limestone valleys because most of the surface is covered with sufficient depth of regolith and soil to protect the aquifer as water percolates through the soil column.

Low-Susceptibility Areas

The low-risk areas of aquifer contamination fall into two categories: (1) area underlain by dolomite bedrock with deep regolith and no surface karstification, and (2) areas underlain or influenced by massive formations of sandstone and shale (Table 1 and Fig. 6).

The steep, broad, dissected plain of knobs and hollows underlain by Knox dolomite in the central section of the study area and the area along the Clinch River in the eastern part of the county are major regions of low groundwater contamination potential. In the eastern part of the study area, the steep uplands of the Powell Mountain, Brushy Ridge, Comby Ridge, and the associated Big Sycamore and Caney Valleys are a second region of low susceptibility to groundwater contamination. The rugged relief and impermeable shale bedrock dominate the hydrology of this section of the study area.

Both Big Sycamore and Caney Valleys have a cover of alluvial material, derived from the sandstone and shale uplands, overlying predominantly calcareous shales. The impervious shale strata on the floor of the Big Sycamore Creek valley form a cap to groundwater movements which causes many springs to occur at the breaks between upslope

sandstones and downslope shales. A well-developed surface drainage network exists in both valleys and there is little evidence of karst. The lack of intensive internal drainage and surface karstification points to a poorly formed carbonate aquifer with few access channels for rapid downward movement of surface contaminants.

The young soils of these valleys have formed from the sandstone and shale alluvium washed from the surrounding uplands (Austin, 1948, p. 7). Relatively broad areas of Big Sycamore Valley and the narrow sections of Caney Valley are covered by fine sandy loam several feet deep. This soil has good permeability but has a seasonal high water table because of relatively low elevation. This causes problems with lateral seepage from septic tank systems during the wet seasons. As a consequence, wells must be drilled upgradient from septic tank drain fields and must be protected from surface water flow.

4. MOVEMENT OF CONTAMINATION THROUGH THE HYDROLOGIC CYCLE

From the analysis of bedrock susceptibility and risk areas for septic tank use, the limestone valleys of the Powell, Cedar Fork, and Little Sycamore Rivers have landscapes with potential groundwater contamination problems. From a hydrologic standpoint the movement of contamination from septic tanks to the carbonate aquifer is controlled by the balance of precipitation and

environmental water demand. Meteorological data from the Tazewell weather station (NOAA, 1970-1980) can be used to divide an average climatic year into phases that can be used to predict the efficiency of septic tank systems and movement of pollution into the aquifer throughout the year.

Precipitation for the average year at the Tazewell weather station (Table 2) shows a moderately wet climate with no water deficit during the year. A water budget for an average year shows three phases: cool-wet late winter and spring months of surplus, hot-dry summer months, and a recharge period in the fall.

From December through May precipitation is greater than potential evapotranspiration. This causes a high degree of runoff and saturated soil conditions. In turn this produces rapid movement of water into underground aquifer. Beginning in mid-March the potential evapotranspiration begins to increase greatly and by June it is greater than precipitation. This causes depletion of soil moisture and virtual cessation of surface runoff and water percolating through the soil. Groundwater levels drop to a minimum in the absence of recharge during the summer. In October precipitation is again greater than evaporation and soil water is recharged; in November and December the groundwater recharge is renewed.

Because of the changing soil environment and amount of water flowing into the bedrock during the year, efficiency of septic tank systems and movement of pollutants

TABLE 2. Water Budget for Tazewell Weather Station Data 1970-1980

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature	31.4	33.5	43.7	53.4	60.6	68.9	72.8	72.7	67.4	53.7	44.0	36.1	53.2
Precipitation	5.4	3.6	6.0	4.9	5.3	4.1	4.4	3.8	3.5	3.9	4.2	4.6	53.7
Potential Evaporation	0.0	0.1	0.9	2.0	3.3	4.8	5.6	4.9	3.7	1.7	0.8	0.2	28.0
Change in Storage	0.0	0.0	0.0	0.0	0.0	-0.7	-1.2	-1.1	-0.2	+2.2	+1.0	0.0	
Storage	4.0	4.0	4.0	4.0	4.0	3.3	2.1	1.0	0.8	3.0	4.0	4.0	
Actual Evaporation	0.0	0.1	0.9	2.0	3.3	4.8	5.6	4.9	3.7	1.7	0.8	0.2	28.0
Deficit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surplus	5.4	3.5	5.1	2.9	2.0	0.0	0.0	0.0	0.0	0.0	2.4	4.4	25.7
Carry Over	2.8	4.1	3.8	4.5	3.7	2.8	1.4	0.7	0.3	0.1	0.0	1.2	
Total	8.2	7.6	8.9	7.4	5.7	2.8	1.4	0.7	0.3	0.1	2.4	5.6	
Runoff	4.1	3.8	4.4	3.7	2.9	1.4	0.7	0.4	0.2	0.1	1.2	2.8	25.7

Source: Climatological Data - Tennessee Annual Summary 1970-1981

to the aquifers should also show seasonal trends. The expected seasonality of contamination of groundwater based on the water budget would be low contamination in the fall following no inflow during the preceeding summer months. During the winter to late spring as groundwater recharges, contamination should increase as the effluent from septic tanks is moved downward by percolating water. In late spring through summer levels of pollution reaching the groundwater should stabilize and decrease as percolation of water through the soil decreases. Also, surface water surplus decreases and reduces water available to flow into sinks and other avenues that connect directly to the underground aquifer.

Data on coliform bacteria are the standard indicator of groundwater contamination. "A high degree of correlation between the evidence of coliform and the occurrence of pathogens in surface water and water distribution problems has been formally established. This same correlation has, in general, been assumed to be valid for evaluating the potential health hazards of groundwater sources." (Allen, 1975, p. 47).

Well test data show 63% of the wells and 85% of the springs were positive for coliform bacteria (Table 3). In a more wide ranging report on rural water supplies in Tennessee and Georgia, coliform bacteria were present in about 50% of the domestic supplies and fecal coliforms were in 27% of the wells (Allen, 1975, p.47). This study

Table 3. Seasonality of Water Testing and Results

	Wells				Springs			
Month	Number tested	Results +	Results -	%+	Number tested	Results +	Results -	%+
Jan	46	28	20	58	9	8	1	89
Feb	44	29	15	65	10	7	3	70
Mar	51	29	22	56	10	8	2	80
Apr	48	31	17	64	9	8	1	89
May	57	34	23	60	12	9	3	75
Jun	64	41	23	64	16	15	1	93
Jul	75	57	18	76	11	10	1	90
Aug	68	41	27	60	24	21	3	88
Sep	85	63	32	62	19	17	2	90
Oct	52	30	22	57	9	5	4	55
Nov	39	18	21	46	22	20	2	90
Dec	42	26	16	61	11	9	2	81
TOTAL	673			62.5	162			85

Source: Claiborne County Public Health Office.

concluded that wells drilled in consolidated aquifers were more likely to yield water containing coliform bacteria than wells drilled in unconsolidated formations. Further, the high percentage of rural supplies contaminated with coliform bacteria was attributed to inadequate sanitary safeguards and faulty construction practices" (Allen, 1975, p. 48). The high levels of coliform bacteria in the groundwater of the study area strongly suggests aquifer contamination from effluent seepage.

The percentage of wells and springs with coliform contamination is high over most of the year (Table 3). Yearly lows for springs were during October and for wells were in November, as expected from the seasonality of recharge hydrology. Another aspect of coliform data is the rapid change in test results over short periods of time. Retesting of wells for coliform bacteria levels often shows rapid change in levels over a period of only a few weeks. Such oscillations suggest rapid movement of contaminants from faulty installations of septic tank systems and poor well locations. "Commonly accepted well-location criteria designed to prevent bacterial contaminatin of wells require a minimum spacing of 50 ft. between septic tanks, drain lines, tile sewers, or privies" (Walker, 1973, p. 21). Even with this requirement, the fractured carbonate bedrock permits rapid lateral movement of groundwater which can transport microorganisms many miles before they become harmless.

5. CONCLUSION

The pathways by which contaminants from domestic sewage reach the carbonate aquifer can be divided into two groups--surplus driven inflow during the wet-cool months and year-around inflow where there is rapid internal drainage through the subsoil. Seasonal movement of surface contamination through sinkholes and unprotected, poorly-capped wells occurs during the wet cool months when natural biodegradation of domestic and agricultural wastes is low. During the warmer and drier months these pathways would not be used because of little runoff and there would be more time for biodegradation to take place in the soil. Year-around contamination is likely from septic tanks where soils are shallow and the limestone bedrock outcrops on the surface. The movement of water in the carbonate solution network, though often complex, can be very rapid. Pollutants can travel many miles or only a few feet, depending on the network of water-bearing channels in the aquifer system. Once untreated waste reaches this network little biodegradation occurs, leaving only dilution to lessen its contamination of groundwater.

CHAPTER III

CULTURAL SETTING

Residential patterns of the study area have changed greatly during the last decade. Rural population has increased causing much greater use of groundwater and a related increased use of septic tanks for effluent disposal. These trends, along with the environmental-economic barriers to central water and sewage services, and the sensitive aquifer underlying the karst terrain in the county, are likely to result in serious future problems for water resources. From an historical perspective, the increase in population has only returned population to levels of the mid-fifties and by itself need not increase groundwater contamination, although the residential pattern is now more concentrated than it was in the past.

The nature of residential water use has also changed; no longer are shallow wells, springs, or cisterns the dominant water source, or the outhouse the dominant disposal system in the rural landscape. With new housing deep wells are used, indoor plumbing is common, and water use per household has increased greatly. Increases in waste water and the use of septic systems for sewage disposal increases the potential flow of domestic contaminants into the

underground environment. This transformation is a major change from the much lower per capita generation of sewage in the past. The much greater output of effluents that accompanies new housing, especially where such housing relies on septic tanks, may overload the local environment to the extent that it is unable to degrade the contaminant load effectively and it is passed into the groundwater by the the hydrologic cycle.

1. POPULATION AND HOUSING TRENDS

During the past decade the rural landscape of Claiborne County was altered by a sharp increase in population, associated building of new housing, improvements in existing housing, and the introduction of subdivisions into previously rural areas of the county. Since the study area includes the majority of Claiborne County, with the exception of the Clairfield Census Division on the Cumberland Plateau, census material is an excellent data source to show these trends. Between the 1970 and 1980 census, population in the study area jumped 27%, from 18,158 to 23,170, and housing jumped 45%, from 6,117 housing units to 8,918. Rapid immigration was the major reason for this increase in population and housing.

From a historical perspective the 70's upswing reversed the trend of negative net migration that started in the 1950's (Table 4). "During the decade from 1950 to 1960

Claiborne County experienced the same out-migration that affected many other non-urban counties in the United States. This resulted in a population decline of more than 23%" (Tenn. State Planning Commission, 1971, p. 50). This out-migration rate decreased from 36% during the 1950-60 decade to 6.6% for the 1960-70 period. As a result the county experienced an increase in population of only 2% from 1960 to 1970 (Tenn. State Planning Commission, 1971, p. 52).

Table 4. Population of Claiborne County, Tenn.*

	1940	1950	1960	1970	1980
Claiborne County	24,657	24,744	19,067	19,420	24,595
Study area				18,158	23,170
Census divisions					
Big Batten Creek				2,002	2,374
Cumberland Gap				3,753	4,968
Powell Valley				3,758	5,367
Tazewell				5,668	10,461
Sycamore				2,977	**
Towns					
Tazewell				1,192	1,167
New Tazewell				1,800	2,090
Harrogate-Shawnee				***	2,530

* Source: U.S. Census.
** Combined into Tazewell Division.
*** Not applicable.

The recent growth of population has concentrated in the Powell Valley and the New Tazewell area (Table 4 and Fig. 8). These areas had a 40% increase in population during the decade. The rest of the study area experienced population increases of 10% to 20%. The rural character of the central and eastern parts of the county remains in an area of low-intensity agricultural land uses with scattered residences. In the high-growth areas new subdivisions, mobile home parks, and small clusters of new houses now occupy land that was recently farmland.

With the population increase during the last decade has come a housing transformation. Census data show that the study area experienced a 46% increase in housing units and there was a substantial upgrading of preexisting housing. The distribution of housing closely follows the pattern of population growth (Table 5). The towns of Harrogate, Shawnee, and New Tazewell, and the Powell Valley region all experienced large gains in housing units--over 50% increases from the 1970 census (Table 5). This increase exceeded the housing stock built before 1940 (Table 6).

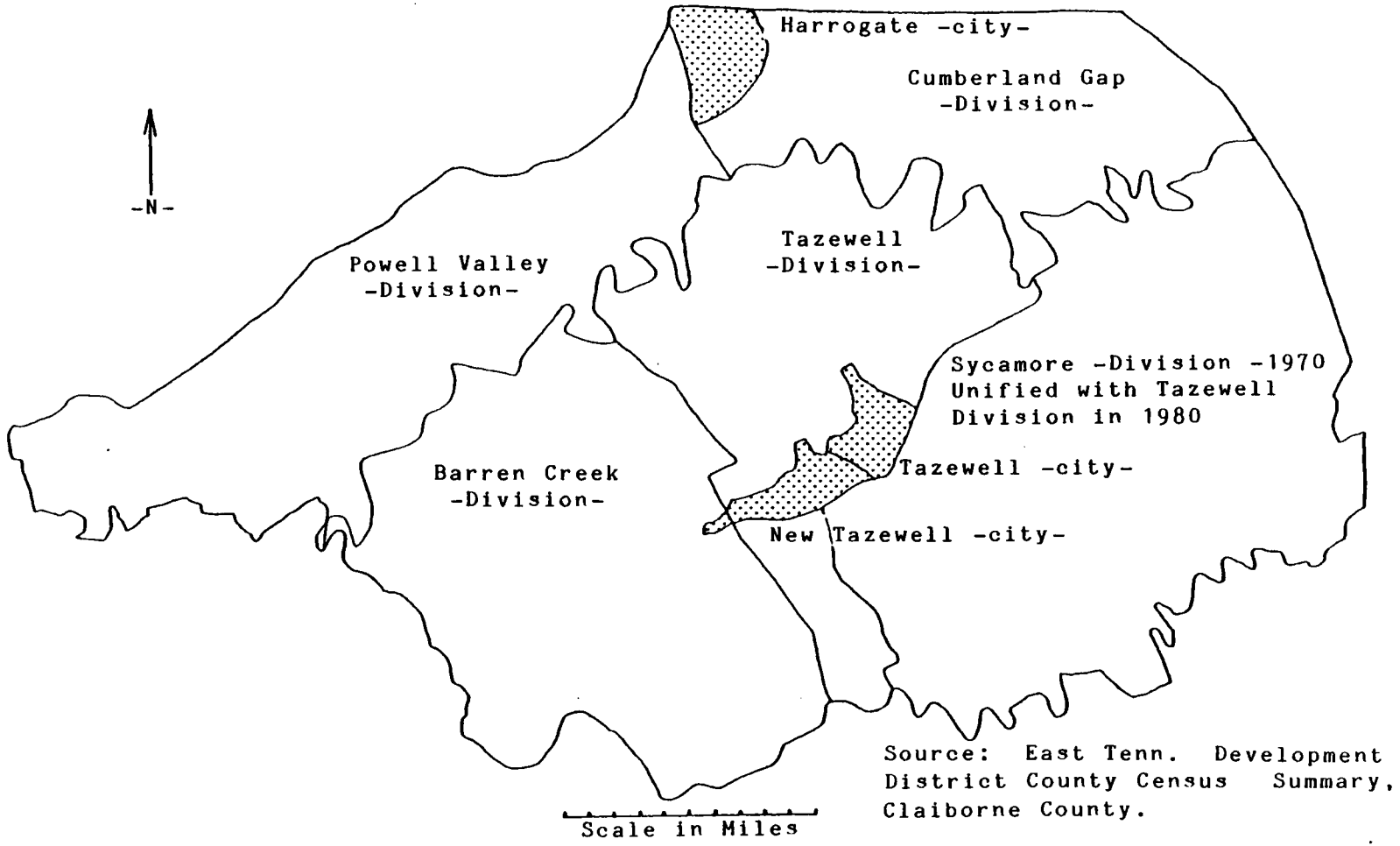


Fig. 8. U.S. CENSUS DIVISONS OF THE STUDY AREA.

Table 5. Housing Units in Claiborne County, Tenn.*

	1970	1980
Claiborne County	6,484	9,385
Study Area	6,117	8,918
Census divisions		
Big Barren Creek	684	1,102
Cumberland Gap	1,196	1,843
Powell Valley	1,247	1,994
Tazewell	**	3,979
Sycamore	**	***
Towns		
New Tazewell	440	650
Tazewell	671	734
Harrogate	**	942

* Source: U.S. Census.
** Not applicable.
*** Combined into Tazewell Division.

Table 6. Age of Housing in Claiborne County, Tenn.*

Date built	Number of units	
	1970 Census	1980 Census
1970-1980		3,324
1960-1969	1,315	1,561
1950-1959	884	1,010
1940-1949	1,107	1,090
1939 or earlier	2,964	2,242

* Source: U.S. Census.

This modernization of housing units influenced water use. Data on housing units for 1970 and 1980 suggest the growth in water demand and effluent generation (Table 7). During the decade completely plumbed housing units more than doubled and residences having no plumbing facilities declined. With improved plumbing and associated increased water demand, there were changes in sources of domestic water supply. The expansion of utility districts and the drilling of deep wells permitted a 100% increase in housing units that used central water utility systems, and an 88% increase of housing units directly connected to wells. These changes resulted in a drop in the use of springs and cisterns during the decade, as reflected in the 20% decrease in the "Other source" category (Table 7).

Table 7. Water Use and Sewage Disposal by Housing Units*

	1970	1980
All year-round housing unit	6,471	9,239
Water use characteristics		
Complete plumbing	3,600	7,502
Lacking complete plumbing	2,871	1,737
No plumbing	1,647	1,034
Source of water		
Public or private system	1,776	3,560
Well drilled	1,461	2,742
Well dug		335
Other source	3,233	2,590
Sewage disposal		
Public sewer	761	1,087
Septic tank	2,495	6,288
Other means	3,214	1,852

*Source: U.S. Census.

Residential sewage disposal characteristics also changed. Septic tank use increased 152% during the decade to become the most common method of disposal for the county. The public sewer system of the New Tazewell area had a 43% increase in residential units and now handles 12% of the county total--the same percentage as in 1970. The 42% drop in the "Other means" category, which covers outhouses or open dumping, also occurred during the decade. Nevertheless, 1,852 occupied housing units still have no improved disposal system and make up 20% of the county total.

2. CHANGES IN PER CAPITA WATER DEMAND

Information from the two utility districts shows that the average residential water use has increased 50% over the last 20 years. For the Claiborne County Utility District the average monthly residential water use is now 4,000 gallons with a range of 2,000 to 15,000 gallons (Love, 1982). An even greater increase in rural household water use has no doubt occurred compared with the past when springs, cisterns, and shallow wells provided water that had to be carried. There is an accompanying increase in sewage and when coupled with the switchover to septic tanks, a subsurface system, from outhouses, a surface, low-liquid disposal system, there is a much greater amount of contaminated water being flushed into the environment.

3. DISTRIBUTION OF CULTURAL COMPONENTS

The distribution of the population in the study area largely determines the location of sewage discharge into the environment. Population distribution for towns and census division tracts are shown in Table 4 and Fig. 8. To determine the rural settlement pattern in more detail the 1968 edition of the General Highway Map of Claiborne County provides information on pre-1970 housing distribution. To update this information the location of new wells drilled during the 1970's was also used as an indicator of new housing units

Another indicator of new housing is the location of new roads that have been taken over by the Claiborne County Road Department from subdivision developers. By combining census information and the indicators of new rural population growth, a general settlement map of the study area was constructed (Fig. 9). Because of the dependence of water systems and water demand/effluent generation patterns on the settlement pattern, the concentration of settlement is an important consideration in the following discussion on water systems, effluent generation, and contamination of the underlying aquifer.

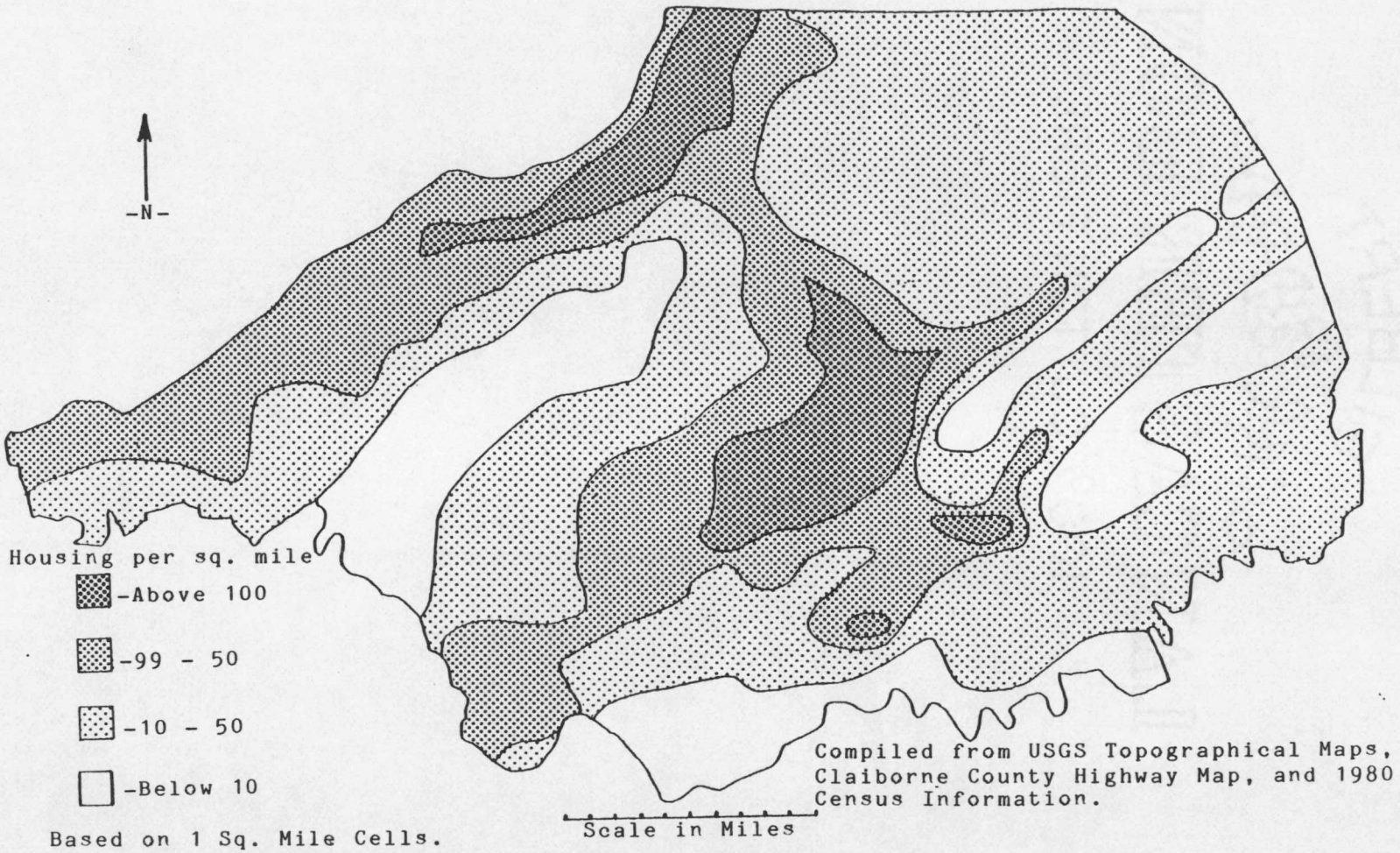


Fig. 9. SETTLEMENT PATTERN OF STUDY AREA IN 1980.

The Pattern of Water Supply and Sewage Disposal Systems

Household demand for water is met either by central utility systems or individual wells, both of which rely on groundwater. A few households use cisterns. The two primary modes of disposal of sewage are septic tanks and central sewer systems. Because of the rural nature of the county, municipal utilities have been slow to spread until recently.

The three water utilities in the study area are the Claiborne County Utility District, the Arthur-Shawnee Utility District, and the Lincoln Memorial University water system (Fig. 10). The Claiborne County Utility District serves the Tazewell-New Tazewell area and the surrounding new subdivisions. Since 1973, the area it serves has doubled (Love, 1982). Two new storage tanks, increased pipe diameters, and a new water treatment plant were installed in 1977. With these improvements the number of customers on the system has risen from 1,100 to 2,050 (Love, 1982). The source of water for the system comes from a large spring that yields 3,500 gal/min (Tenn. State Planning Commission, 1971, p. 220). Tazewell and New Tazewell have the only central sewage system in the county and it serves 1,087 residential customers. It has a capacity of 500,000 gal/d and currently processes 280,000 gal/d (Tenn. State Planning Commission, 1971, p. 221). After processing through a trickling filter the sewage is released into Bull Creek.

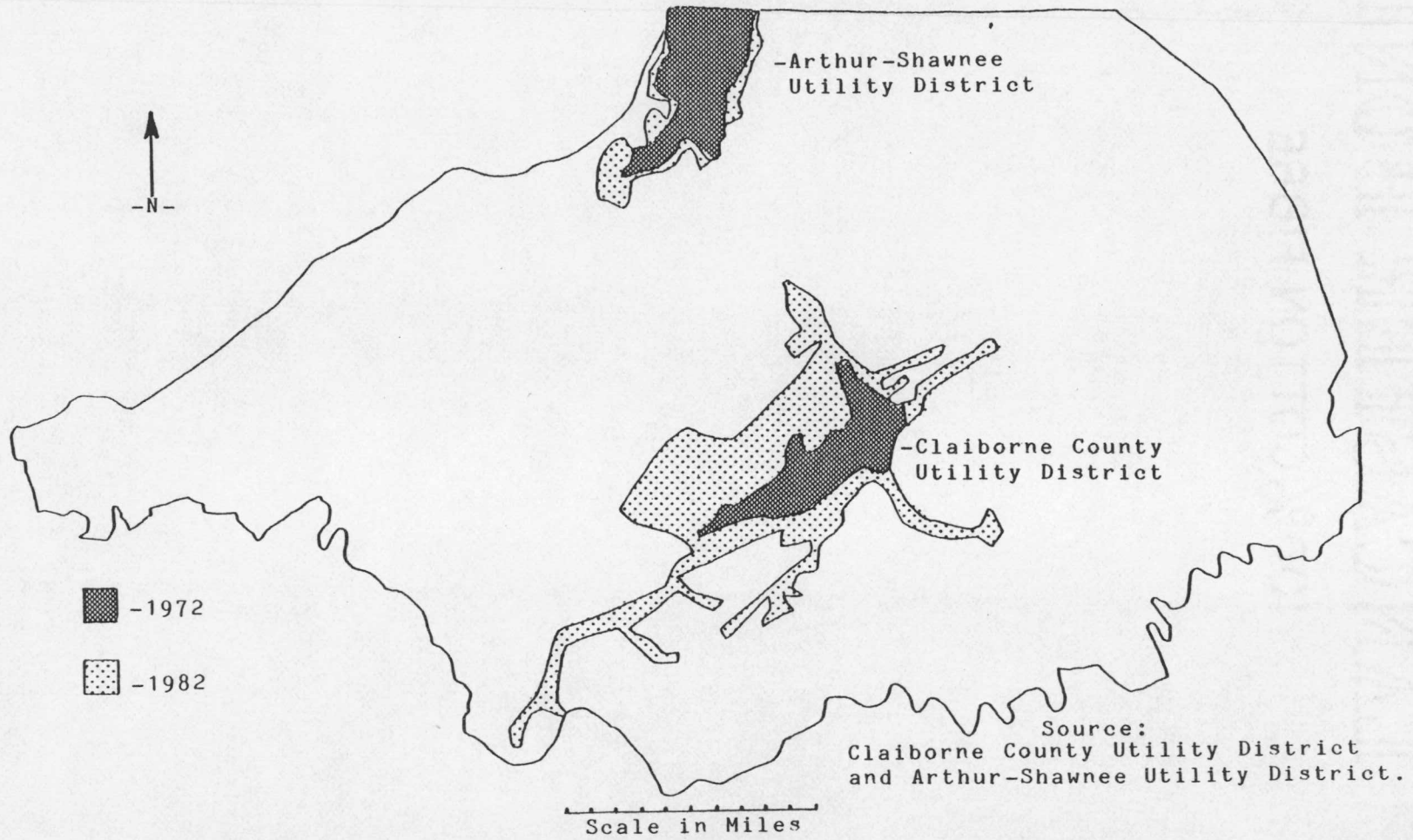


Fig. 10. SERVICE AREAS OF UTILITY DISTRICTS.

The joint water systems of Arthur-Shawnee Utility District and Lincoln Memorial University serve the Harrogate-Cumberland Gap area. The Harrogate area experienced substantial increases in population during the 1970's as many subdivisions clustered around these towns. Since 1971 the customers served has increased from 638 to 1,244 today (Toug, 1982). The raw water supply comes from the Powell River. Other than for scattered cisterns this is the only water system in the county not depending on groundwater. At the present time there is no central sewage service for the Harrogate area.

The Lincoln Memorial University water system serves the university and the town of Cumberland Gap. The water supply for the system is a spring at Cudjo Caverns, which has a yield of 100 gal/min. (Tenn. State Planning Commission, 1971, p. 222). During periods of drought the flow is not sufficient to supply the demand, so water from the Arthur-Shawnee system supplements the Lincoln Memorial University system (Tenn. State Planning Commission, 1971, p. 223). A localized central sewage system serves the university. Its outflow is released into a small creek which promptly disappears into a sinkhole.

Outside the areas served by the above central water systems residents use springs and wells. Since 1970 the number of wells for residential use increased from 1,461 to 2,742 and represents 33% of the residential units in the county. Another 2,590 housing units are classified

by the Census of Housing as using water sources other than central water or well water. These residential units are probably using springs, cisterns, or a neighbor's well. This represents 28% of the households down from 50% or 3,233 units in 1970.

The distribution of wells in the study area was obtained from records on file with the Tennessee Division of Water Resources. Of the 1,385 wells on file, 738 well sites are known precisely (Fig. 11). The majority of these wells are drilled into aquifers that are very susceptible to surface-originating contaminants. The location and number of springs that are specifically for residential use are not known. Many fast flowing springs east of the Powell River were located using maps prepared by the USDA and information gathered from local persons. No quantitative information is kept by the state on spring locations or characteristics. It appears that the use of spring water is most widespread in the eastern section of the study area.

Except for a small area in the Tazewell-New Tazewell city limits, sewage disposal for the majority of the households in the study area is through septic tank systems. The distribution of septic-tank systems should be similar to the that of wells.

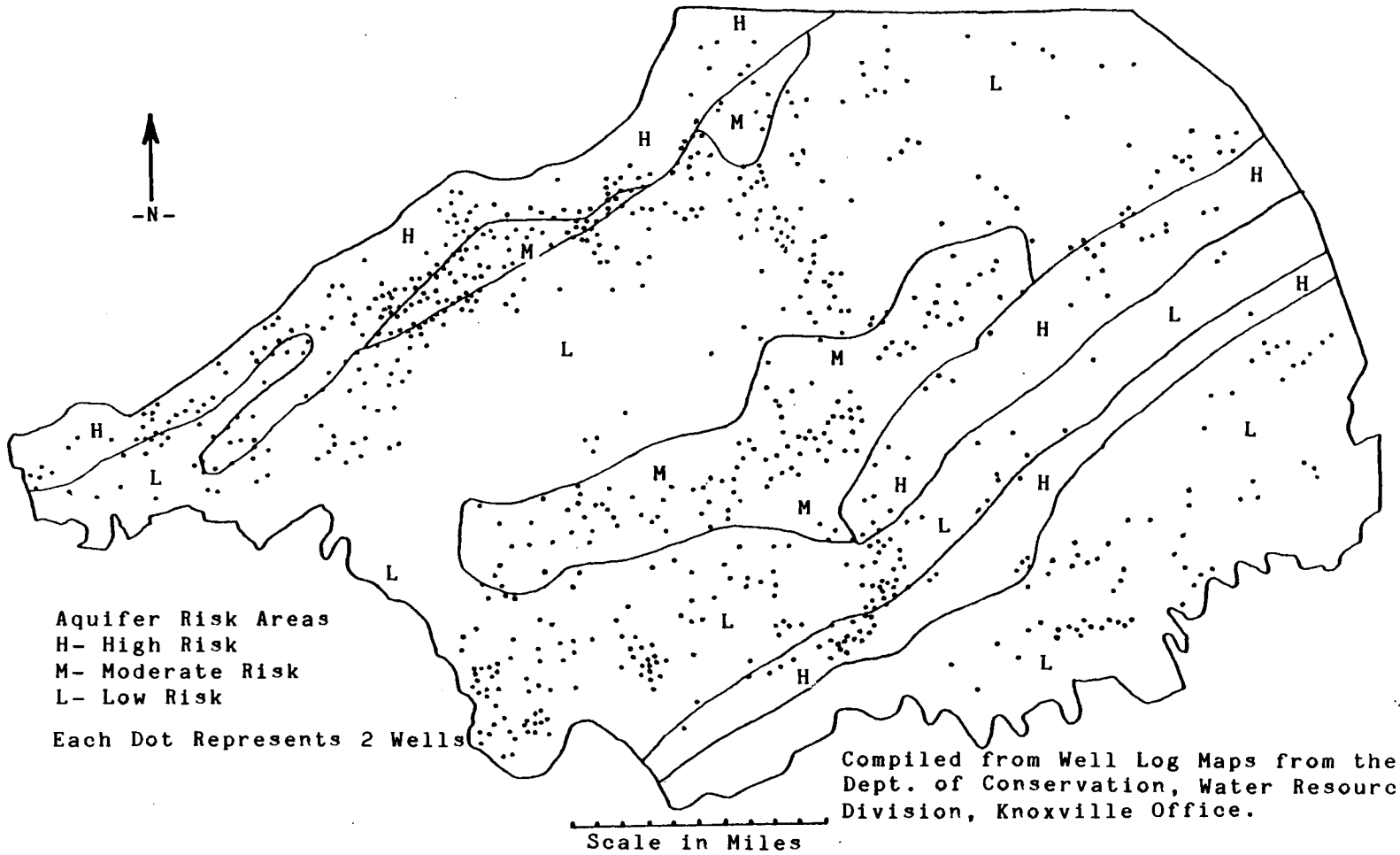


Fig. 11. PATTERN OF WELL DISTRIBUTION IN THE RIDGE AND VALLEY SECTION OF CLAIBORNE COUNTY.

4. CONCLUSION

Using the distribution of population (Fig. 9) and the known pattern of septic-tank systems, an effluent generation map was constructed (Fig. 12). The areas of high concentrations of septic tanks are the northern Powell Valley and around the towns of Tazewell and New Tazewell. These two areas are underlain by carbonate aquifers that are very susceptible to surface contamination. This, together with the high density of septic tank systems and the high use of groundwater in the Powell Valley and around Tazewell and New Tazewell, poses a potential threat to residents who depend on groundwater. The EPA regional reports on groundwater identifies communities with high densities of subsurface disposal systems as having groundwater quality problems (EPA, 1980, p. 15). The problem is magnified in many rural communities, especially because the subsurface disposal systems is paralleled by a reliance on private wells for drinking water supplies. Because of the environmental situation and high density of septic tank systems in upper Powell Valley and the Tazewell area, contamination risk to the water supply of households is substantial. During the past three years, however, only an average of 20 wells per year were tested by the Claiborne County Health Department, suggesting a low perception of the contamination potential by residents.

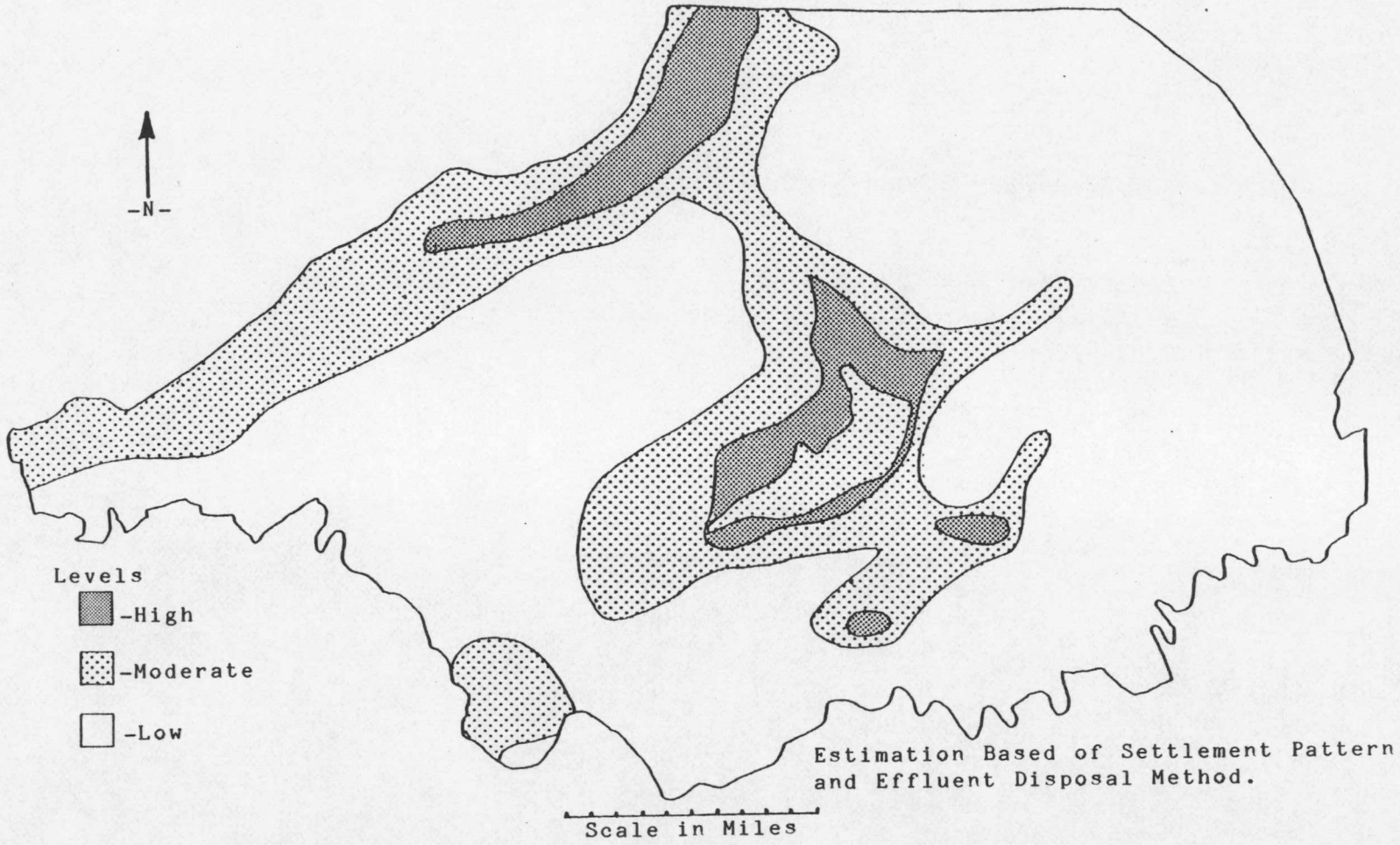


Fig. 12. DISTRIBUTION OF EFFLUENT GENERATION.

CHAPTER IV

CONCLUSIONS

From the information presented in the preceding chapters, areas with high incidences of groundwater contamination can be identified by considering the susceptibility of the carbonate aquifer, the distribution of the water systems, and the density of settlement. Of special significance in this discussion is the large difference in risk of contaminated water that exists between the heavily populated and the lightly populated areas. The concluding section of this chapter covers what can be done to minimize present and future water resource problems.

The following environmental and cultural conclusions have been presented: First, the majority of the groundwater supplies in the densely developed areas are very susceptible to surface contamination. The limestone valleys were classified as having the highest aquifer susceptibility rating because of a bedrock eroded with solution channels, shallow heavy-clay soils, and a terrain with many rocky outcrops and sinkholes. Because of these conditions the operation of septic tank systems has increased the risk of groundwater quality problems. Second, the majority of the population of the area is located in the high or moderate risk areas. The housing boom during the 1970's

has concentrated the settlement pattern in the Powell Valley, around the towns of Tazewell and New Tazewell and in the small communities to the south in the Little Sycamore Valley. Third, water use by both old and new residents has caused an increase in residential consumption and a related increase in effluent generation. Fourth, because of the spreading of the utilities service areas the majority of the densely populated areas do not now depend on raw groundwater, but adjacent housing which does depend on groundwater is down-gradient from these high effluent-generating areas.

1. THE PRESENT WATER RESOURCE SITUATION

These observations suggest that the current water resource situations of the study area can be classified in four groups: high density housing served by utility water, low density housing served by utility water, isolated communities depending on raw groundwater and isolated housing depending upon raw groundwater (Fig. 13). The high density areas of housing and sewage generation can be classified as areas of organic pollution sources, because they are underlain by carbonate bedrock which has solution channels that can transport biological contamination for many miles with little biodegradation.

Areas close by these developed areas thus have an increased risk of polluted groundwater supplies. Low

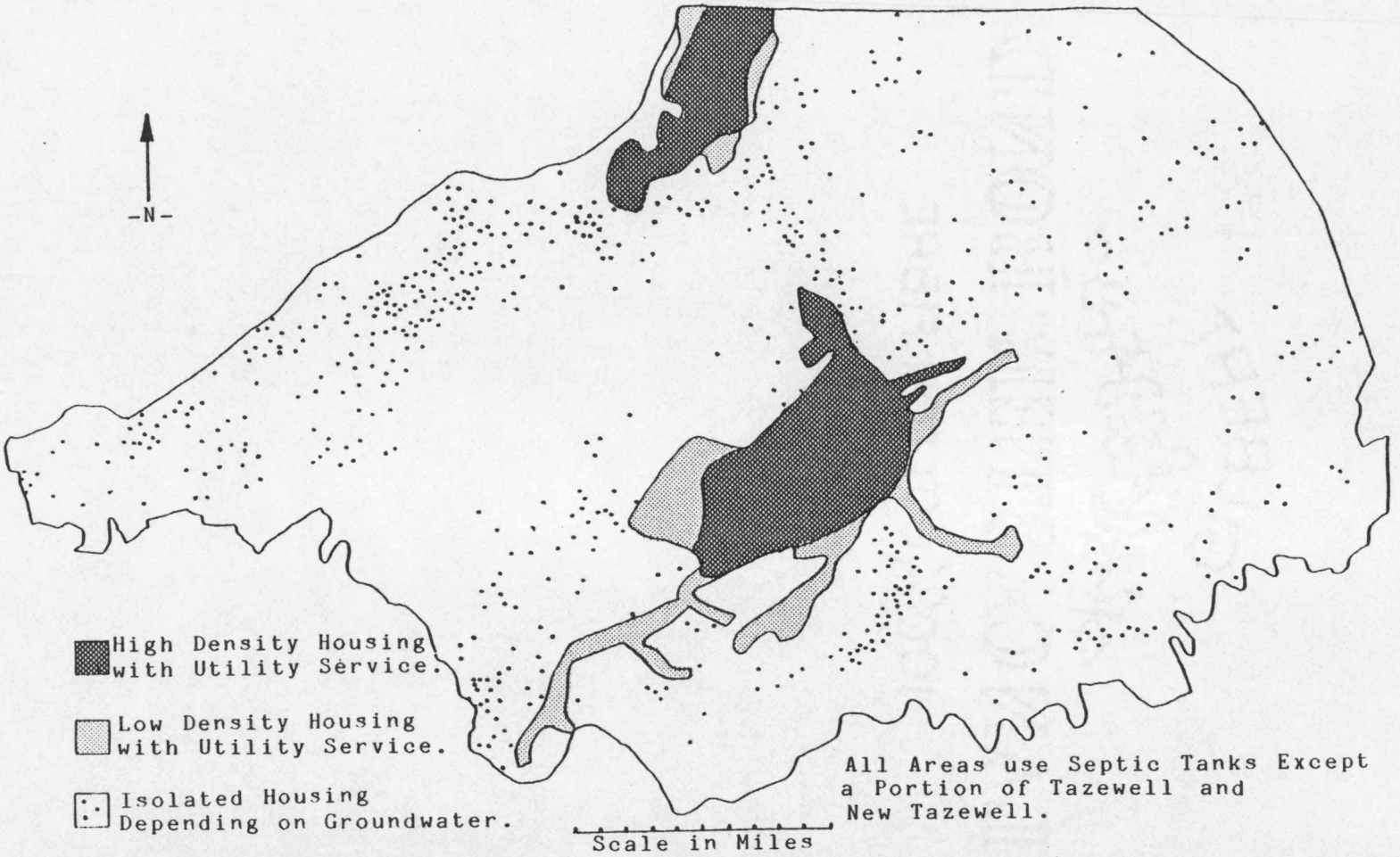


Fig. 13. WATER RESOURCE SITUATION FOR THE RIDGE AND VALLEY SECTION OF CLAIBORNE COUNTY.

density housing areas that use utility water are a buffer between areas of dense sewage generation and residential groundwater users. The rapid growth of the Claiborne County Utility District, which serves the central part of the county, has improved the water quality for the rural homeowners and has created a wide buffer between the developed towns of Tazewell and New Tazewell and the users of raw groundwater. Because of the rapid change to utility water in this area the high density areas of effluent generation have been isolated from groundwater users.

In contrast the situation in the northern Powell Valley is more likely to produce water quality problems for the groundwater user. With no central sewer service in this developed area, all effluent generated is disposed of through septic tanks under hazardous soil conditions. This with the thin buffer between the utility water service area and the surrounding rural groundwater users causes a low dilution time for the effluent plume to dissipate. The Arthur-Shawnee Utility District has met the increased water demand from the concentration of growth in the towns of Harrogate, Shawnee, and Arthur, but has not spread out to meet the demand of rural close-by groundwater users. This has resulted in isolated occurrences of groundwater contamination of springs used by some residents close by but outside the utility service area.

The rural groundwater users in isolated small communities and individual housing have adequate potable

water supplies if care is taken to follow standard sanitation practices in construction and operation of septic tank systems and wells. In the Lone Mountain Community to the south of Little Sycamore Valley, isolated feedback pollution between the homeowners and the groundwater supplies has occurred because of the local geology and dense settlement pattern. In the rest of the study area, the rural nature of the county away from the developed sections causes a low risk of contamination of groundwater by septic tanks, but improper construction and use of individual water systems causes local water quality problems to develop, with individual homes polluting their own wells.

In conclusion, the spread of the utility water services in the central section of this area has prevented the use of tainted water which could have occurred with the housing boom of the 1970s. The large zone of low density settlement supplied with utility water around the Tazewell area acts as a buffer to divert use of groundwater from wells and thus may allow the sewage contamination from this zone to be diluted before reaching well users outside the utility water zone. The other developed section of the study area, the northern Powell Valley, has at the present an unfavorable groundwater situation because of the high density of septic tanks and residences that depend on local wells and springs. Isolated communities (except the Lone Mountain community) and scattered housing are in no present danger of widespread regional contamination of groundwater.

2. THE FUTURE WATER RESOURCE SITUATION

The future risk of widepread contamination of groundwater supplies will be conditioned by the continued growth rate of the area and the improvements in the water systems. Since the population and housing boom of the mid-70's the area has been stalled in transition between substantial subdivision development and slow rural growth rates which typified growth during the 1960's. With the likehood of increased growth in the Powell Valley and around the Tazewell/New Tazewell parts of the study area, a projection of increasing groundwater contamination can be made from the increasing use of septic tanks resulting from the sporadic growth during the 1980's. Water quality problems will continue to occur in the northern Powell Valley where the high use of septic tanks has already caused some groundwater contamination from sewage disposal. The spread of uncontaminated utility water into the surrounding countryside is critical, because effluent disposal in this area is by septic tanks and because the continually heavier input from pollution sources, is certain to increase contamination of the carbonate aquifers underlying the populated valleys in the future. As the sources of potable water are slowly polluted, utility water must be able to meet the water demand of both the city and rural homeowners.

3. RECOMMENDATIONS FOR IMPROVING RESIDENTIAL WATER SUPPLIES

1. Improve the residents' perception of the risk of using raw groundwater. Many well-owners have their wells tested once or twice, with mixed results, and then forget about testing for many months. In other instances well-owners have dropped lye in their wells in a belief it will purify the water (Brogen, 1982). Information about upkeep and trouble shooting should be distributed by the state through the County Public Health Offices.

2. From early 1978, when a fee was imposed on water testing by the local Public Health Offices, the number of wells and springs being tested has steadily decreased. In 1978, 32 groundwater sources were tested for a fee of $3.00 each. In 1979, 21 groundwater sources were tested at a fee of $5.00. In 1980, 17 groundwater sources were tested. In 1981 the fee was raised to $15 per test and the number of groundwater sources dropped to five. Because of the high cost of the testing, the willingness of the public to check water quality has dropped. To counteract this trend and to improve the safety of suspected contaminated wells, the cost of testing for coliform bacteria in water samples should be decreased to encourage greater monitoring.

3. The third recommendation is to improve residential water supplies by aggressively increasing the number of rural households connected to utility water supplies. To

be sure that the trend of expansion of utility service areas continues, the two systems will probably have to increase rates or hookup fees because of the low population density in the majority of the area. The utility districts need to continue to branch out in these rural areas before the population increases cause localized feedback contamination of the wells from septic-tank disposal.

4. The last and most costly recommendation is to use improved methods to dispose of residential sewage. Because of the rugged terrain and low-population density of the study area, the use of central sewage networks has been slow to develop and unlikely to increase beyond the current small network in the Tazewell area. Since individual disposal systems are dominant today and will remain so for the next decade, these low efficiency systems need to be improved with better designs and methods. Improved methods that would increase efficiency of residential disposal include: separation of gray water and black water, and surface disposal of the sewage through spray irrigation. By separating sewage from gray water the amount of water running through septic tank systems would be decreased. By using spray irrigation to dispose of waste all of the work of biodegradation would occur on the surface at a higher rate and away from the groundwater recharge channels of the aquifer. These systems would decrease the amount of contamination reaching the groundwater and protect the future use of the aquifer.

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VITA

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