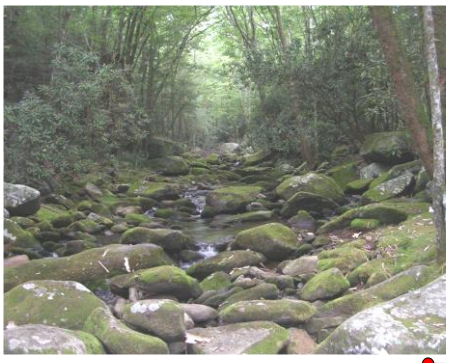
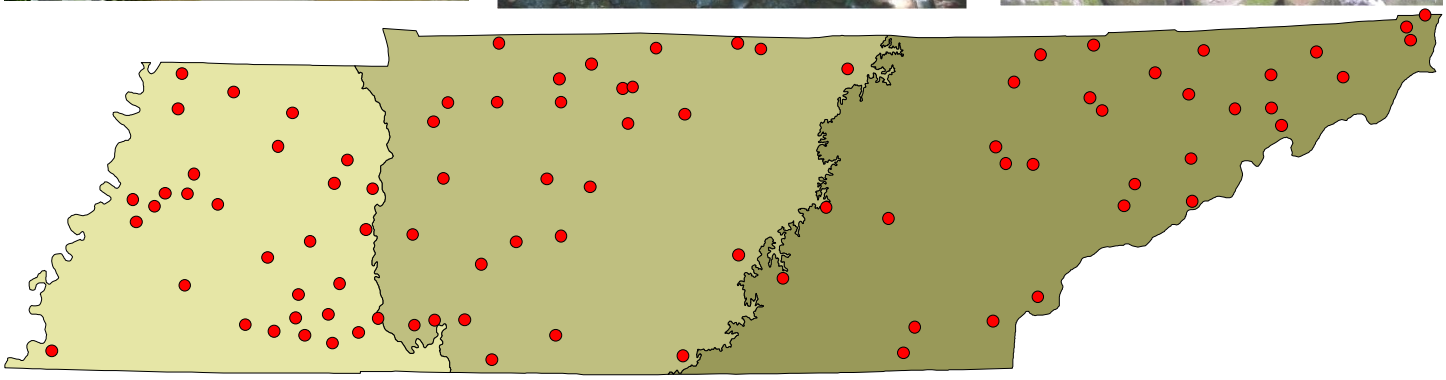
2007-8 PROBABILISTIC MONITORING OF WADEABLE STREAMS IN TENNESSEE

Volume 2: Study Design and Stream Characterization

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Study Design and Site Characterization

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Tony Olsen with the USEPA Western Ecology Division in Corvallis, Oregon assisted with the statistical survey design and provided a subsample of randomly selected wadeable streams for each of the three regions. Barbara Rosenbaum, INDUS Corporation, contractor for EPA, assisted with the random selection process.

Water Pollution Control staff from the eight Environmental Field Offices conducted the field surveys which included reconnaissance, sample collection, field measurements and habitat assessments. The managers of these staff during the study period were:

Chattanooga EFO	Dick Urban	Johnson City EFO	Jeff Horton
Columbia EFO	Tim Wilder	Knoxville EFO	Paul Schmierbach
Cookeville EFO	Rob Howard	Memphis EFO	Terry Templeton
Jackson EFO	Pat Patrick	Nashville EFO	Joe Holland

Taxonomists with the Aquatic Biology Section, Tennessee Department of Health (TDH) and the Aquatic Resources Center (contractor for TDH) processed the macroinvertebrate samples. The manager of the Aquatic Biology Section is Pat Alicea. The director of the Aquatic Resources Center is Todd Askegaard. Periphyton samples were processed and identified by Dr. Kalina Manoylov with Georgia College and State University. Periphyton QA/QC samples were analyzed by Dr. Marina Potapova with the Academy of Natural Sciences in Philadelphia. The TDH Inorganic Chemistry Laboratories analyzed the chemical samples. The director of the TDH chemistry and biological laboratories is Dr. Bob Read. The TDH Environmental Microbiology Laboratories analyzed the E. coli samples. The director of the TDH microbiology laboratory is Jim Gibson.

Cover photos of sample sites provided by Water Pollution Control staff biologists in Jackson, Memphis, Nashville, Knoxville and Johnson City Environmental Field Offices.

1. INTRODUCTION

There are two generally accepted data collection schemes for studying the characteristics of a population. The first is a census, which entails examining every unit in the population of interest. For large-scale ecological studies, however, a census is impractical. For example, measuring biological, chemical and physical components at multiple reaches of every stream within a watershed is prohibitively expensive.

Traditionally, the Division of Water Pollution Control (WPC) has used targeted monitoring to assess streams (Denton et al, 2008). This involves site visits to as many streams as possible in each watershed during each monitoring cycle. Screening level biological surveys without water quality or bacteriological data are done in many cases to increase the number of sites that can be visited.

A more practical approach for studying an extensive resource, such as a watershed, is to examine parts of it through probability (or random) sampling. Probabilistic surveys are based on statistical samples rather than complete coverage. These surveys are cost-effective, and the principles underlying such surveys are well developed and documented. In 2000, the division began to incorporate probabilistic monitoring into its monitoring program. The pilot project in 2000 was restricted to a single ecological subregion (Arnwine et al, 2003). A probabilistic study in 2003 was designed to investigate the effects of impoundments on headwater streams across the state (Arnwine et al, 2006).

The 2007 study is a probabilistically-based survey of wadeable streams in Tennessee which builds upon EPA's 2004 Wadeable Streams Assessment survey of the nation's streams (USEPA, 2006). Biological, bacteriological, physical, and chemical data from a random sub-sampling of Tennessee streams were extrapolated to all wadeable streams in Tennessee. These data provide a baseline to which future efforts can be compared, thus providing an opportunity for scientifically valid trend analysis.

a. Background

In 2004, the division participated in the national probabilistic study of wadeable streams (USEPA, 2006). Results of the national assessment differed from Tennessee 305(b) assessments which were based primarily on targeted monitoring (Figure 1). Note 2008 305(b) report was not used because it includes assessments based on the 2007 probabilistic study.

There were several possibilities for the discrepancies between the state and national studies. For example, the biological sampling methods used in the national study differed from those used by WPC. However, comparisons between macroinvertebrate samples collected using both methods at the 20 sites in Tennessee showed no difference when both were compared to the same reference condition (Figure 2).

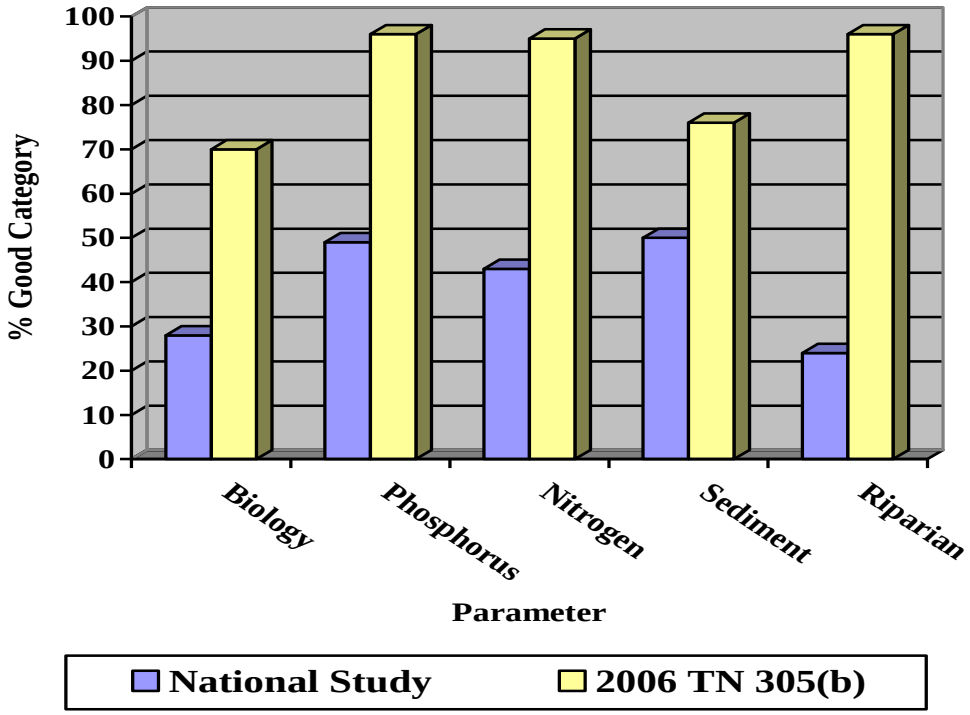


Figure 1: Comparison of 2004 national wadeable stream assessments with 2006 Tennessee 305(b) assessments. The nitrogen parameter is total nitrogen for the national study and nitrate+nitrite for the Tennessee report.

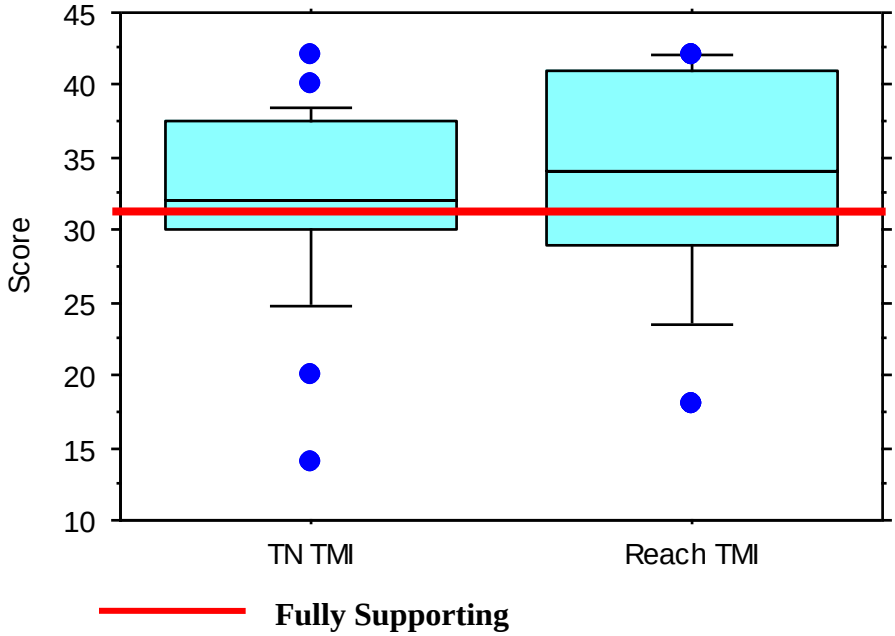


Figure 2: Comparison of macroinvertebrate index between WPC single-habitat samples (TN TMI) and EPA reachwide samples (Reach TMI) at 20 randomly selected streams.

A more likely cause for the discrepancies is that reference regions used in the national study combined multiple level III ecoregions found in several states. Tennessee references are calibrated at a more sensitive scale. For example, there are 31 Level IV ecoregions (ecological subregions) in Tennessee. During the national study, the entire nation was divided into only eight ecoregions with Tennessee divided into two of these.

Eighteen streams in the Southern Appalachian ecoregion of Tennessee were monitored as part of EPA's national wadeable streams assessment project. Table 1 compares the results of these 18 sites using TDEC's Level IV ecoregion approach to the results for all the sites in the region published by EPA. The national wadeable streams report combined reference streams from multiple ecological subregions to create the Southern Appalachian Ecoregion in order to produce enough data points for statistical defensibility. This means that reference data from such 17 diverse regions in Tennessee as the Blue Ridge Mountains and the Inner Nashville Basin as well as ecoregions not found in the state were combined. The approach used by TDEC is much more sensitive and divides the Southern Appalachian Ecoregion into smaller units found within the state for assessment purposes (Arnwine et al, 2000).

Table 1: Comparison of 18 study sites between national wadeable streams assessment guidelines and Tennessee Level IV ecoregion biocriteria.

	WSA (Good Category)	Tennessee (Met Regional Expectations)
Ecological Condition	21%	61%
Nitrogen	39%	100%
Phosphorus	44%	72%
Acidity	96%	94%
Riparian Disturbance	23%	56%
Fine Sediments	41%	28%
Riparian Vegetative Cover	54%	50%
Instream Habitat	62%	39%

One of the problems with this comparison is there are too few sample sites in Tennessee for statistical certainty. It was still unclear whether differences were due solely to sensitivity of reference condition, were a result of random sample selection or indicated that water quality in Tennessee was better than other areas in the Southern Appalachians.

b. Targeted versus Probabilistic Monitoring

Targeted and probabilistic monitoring have different strengths and weaknesses. They are designed to answer different water quality questions and meet different objectives. It is the division's goal to incorporate both monitoring types into a comprehensive program.

Advantages of Probabilistic Monitoring:

- Probabilistic monitoring can reduce sampling costs dramatically in some cases. If designed properly, a relatively small number of sites can be monitored and the results extrapolated to a larger area.

- Probabilistic monitoring yields statistically valid results if properly designed. There is no question of biased results.

- Probabilistic monitoring can be used to standardize monitoring between multiple sites and regional offices. In place of biological screening which is often the only feasible way to cover a large number of sites, more sensitive biological methods along with chemical monitoring and pathogen monitoring can be done at every site in the subsample. This allows for equal comparison between sites, greater sensitivity in measuring biological response, more definitive assessment of pollutants impacting multiple uses (recreation as well as fish and aquatic life).

- Probabilistic monitoring may produce more accurate assessments over a larger scale for statewide 305(b) reporting. Targeted monitoring generally addresses only the problems at the point selected for monitoring. Sites are not randomly selected and the number of sites in each monitoring area may vary due to staffing levels, expertise, accessibility, historical monitoring and driving distances.

- Probabilistic monitoring can be used for trend analyses since an equal effort is expended at an equal number of sites over time.

However, probabilistic monitoring alone is not adequate for a comprehensive program. Weaknesses of probabilistic monitoring include:

- Potential magnification of errors. In order to extrapolate accurately, assessments must be accurate.

- Water quality issues are generally local, not global.

- Probabilistic monitoring does not provide background data necessary for permit limit calculations.

- Probabilistic monitoring does not address sites that have already been assessed as impaired. It is not useful for determining extent of impairment along specific stream reaches. Therefore it is not practical for 303(d) assessments of streams that are considered impaired by pollution and not fully meeting designated uses or for those that are considered threatened.

c. Study Objectives

- Establish 30 randomly-selected stations in each of the three divisions of Tennessee based on aggregated Level III ecoregions for a total of 90 stations. (Minimum necessary for statistical confidence).

- Collect chemical, physical, bacteriological and biological data over a period of one year at each station. (Four seasons of chemical, one season bacteriological and chemical).

- Compile data within each division to calculate exceedence rates, establish support for designated uses, determine causes of impairments and identify possible sources of pollutants impacting uses.

- Analyze data from each division to compare and contrast water quality in each of the three grand divisions (east, middle and west).

- Compile assessment information from all stations in order to extrapolate results to the entire state of Tennessee.

- Establish stations that can periodically be monitored for statewide and regional trend analyses.

d. Report Format

A series of reports is being published to convey the results of the study. Each report will have general study information as well as details of different aspects of the project. Appendices will provide raw data specific to the report.

Volume 1: Executive Summary.

This report will summarize the entire study. It will also provide information on designated use support as well as causes and sources of pollution. Information will be extrapolated for each of the three regions and for the entire state.

Volume 2: Study Design and Stream Characterization

This report provides detail on the design and implementation of the project. It describes the site selection process. Information on drainage area, ecoregion, watersheds and land use is discussed to determine representativeness of the subsample to the entire population of Tennessee streams. This volume also provides information on sample collection, analyses and quality assurance. The appendices include site location and land use information.

Volume 3: Macroinvertebrates and Habitat

This report will provide detail on macroinvertebrate populations and habitat quality. Biometric and habitat assessment results will be presented and compared for each of the three divisions. A Tennessee Macroinvertebrate Index score will be calculated for the biological data at each site and compared to regional biocriteria goals. Habitat scores will be compared to regional guidelines. Statewide results will be compared to the 2004 National Wadeable Stream study as well as targeted monitoring over the last five years. Macroinvertebrate biometrics and habitat parameter scores for each site will be provided in the appendices.

Volume 4: Water Chemistry

This report will provide detail on field measurements and chemical data. Data will be presented and compared for each of the three divisions. Nutrient data from each site will be compared to regional goals. Field parameters (dissolved oxygen, temperature and pH) will be compared to numeric criteria. Statewide results will be compared to the 2004 National Wadeable Stream Study as well as targeted monitoring over the last five years. Field measurements and chemical data for each site will be provided in the appendices.

Volume 5: Pathogens

This report will provide detail on bacteriological data using the indicator organism *E. coli*. Data will be presented and compared for each of the three divisions. Statewide results will be compared to state water quality criteria and the 2008 305(b) report. Raw data for each site will be provided in the appendices.

Volume 6: Periphyton

This report will provide detail on periphyton data processed using indices developed by the state of Kentucky. Individual metrics and indices will be presented and compared for each of the three divisions and for the state. Possible correlations between nutrient data and periphyton will be explored. Raw data for each site will be provided in the appendices.

2. PROBABILISTIC SURVEY DESIGN

Probabilistic survey sampling is intended to characterize the entire population of interest; therefore, all members of the target population must have a known chance of being included in the sample. Simple random selection ensures that the sample is representative because all members of the population have an equal chance of being selected.

a. Randomized Site Selection

A key component of a properly designed probabilistic survey is the site selection process. The randomization design for this study was the same as the national study implemented by Tony Olsen with the USEPA Western Ecology Division in Corvallis, Oregon (USEPA, 2006). Barbara Rosenbaum, INDUS Corporation, contractor for EPA, provided the list of randomized streams.

The target population was all perennial wadeable streams and rivers within the state of Tennessee. To identify the target population streams, USGS/US EPA's National Hydrography Database-Plus (NHDPlus) was used as the sampling frame. This is a comprehensive set of digital spatial data on surface waters. The total stream length in the sample frame for Tennessee was 57, 721 miles.

The target population was 1st through 4th Strahler order streams (Strahler, 1957). Information about stream order was obtained from the River Reach File, a series of hydrographic databases that provide attributes about stream reaches. When a stream changed order, it was considered another reach with equal probability of selection.

Sample sites were identified using a probability-based sample design in which every element in the population has a known probability of being selected for sampling. Rules for site selection included weighting to provide balance in the number of stream sites from each of the first through fourth order size classes and controlled spatial distribution to ensure the sample sites were distributed across the state.

The state was divided into three divisions based on level 3 ecoregions (Figure 3). The base design was 30 sites per division (90 sites statewide). A sample size of 90 was recommended by EPA as the minimum number necessary to provide statistical confidence for both statewide estimates and comparison between three divisions. At 90% confidence interval statewide estimates would have +/- 9%, with +/- 15% for comparisons between divisions.

An additional 90 reserve replacement sites were generated for each division. The replacement sites were used when site reconnaissance documented that one of the original sites could not be sampled.

East: Ecoregions 66, 67, 68 and 69
Middle: Ecoregion 71
West: Ecoregions 65, 73 and 74

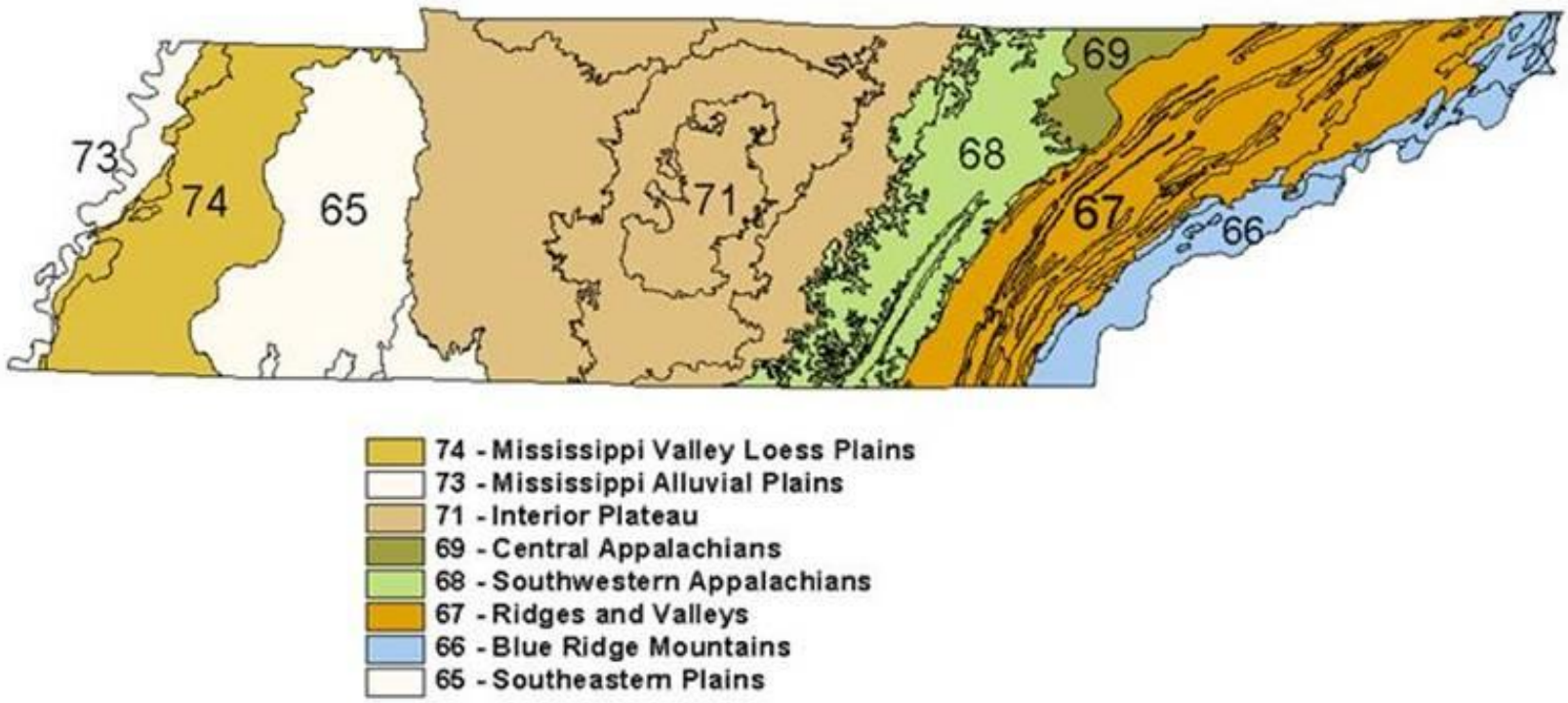


Figure 3: Level 3 ecoregions of Tennessee.

b. Site Reconnaissance

A total of 120 potential sample sites were randomly selected in each of the three divisions. Eighteen of the twenty sites randomly selected in Tennessee for the 2004 national study were incorporated in the design. (One site in middle Tennessee was dropped because it lacked the targeted riffle habitat and a site in east Tennessee had been impounded by beaver since 2004). New sites were then evaluated, in order of random selection, until thirty sites in each division met study objectives. All sites that occurred prior to the last site selected were evaluated for use and either sampled or replaced by the next randomly selected site. If a site was not used, the reason was documented (Table 2).

In order for a site to be sampled, it had to be within one-hour access from a road, to be wadeable, to have riffle habitat (middle and east only) and to have summer flow in 2007 (unless previously included in the 2004 study). Out of the primary draw of 90 sites, only 46 were assessed as being sampleable after field reconnaissance of sites was completed. A total of 248 random drawings were needed to get the required number of suitable sites.

The greatest factor for disqualifying sites statewide was lack of flow (dry, intermittent or old channel), which accounted for almost one third of the rejections (Figure 4). Severe drought conditions during the study period were probably responsible for many of the streams being dry although headwater streams in some ecoregions are typically dry during summer months. Inaccessibility was the biggest issue in west Tennessee and required the most replacement sites (Figure 5). The final 90 sites that met study requirements are presented in Figure 6.

Lack of flow accounted for 20% of randomly selected streams being rejected for inclusion in the study.

Photo of Little Goose Creek in Trousdale County provided by Nashville Environmental Field Office.

Table 2: Field reconnaissance of randomly selected wadeable stream sites.

Recon Results	West		Middle		East		Total	
	No. Drawn	% of Draw	No. Drawn	% of Draw	No. Drawn	% of Draw	No. Drawn	% of Draw
Sampleable	30	24.2	30	52.6	30	44.8	90	36.3
Dry	23	18.5	20	35.1	10	14.9	53	21.4
Inaccessible	33	26.6	2	3.5	13	19.4	48	19.4
Non-wadeable	8	6.4	2	3.5	8	11.9	18	7.2
Intermittent	13	10.5	0	0	1	1.5	14	5.6
Old Channel	10	8.1	0	0	0	0	10	4.0
No Defined Channel	2	1.6	2	3.5	0	0	4	1.6
Map Error	3	2.4	0	0	1	1.5	4	1.6
Access Denied	2	1.6	1	1.8	0	0	3	1.2
Underground	0	0	0	0	2	3.0	2	0.8
No Riffles	0	0	0	0	1	1.5	1	0.4
Duplicate Draw	0	0	0	0	1	1.5	1	0.4
Total	**124**		**57**		**67**		**248**	

Some randomly selected streams in middle and west Tennessee did not have a clearly defined channel and were not included in the project.

Photo provided by Nashville Enviornmental Field Office

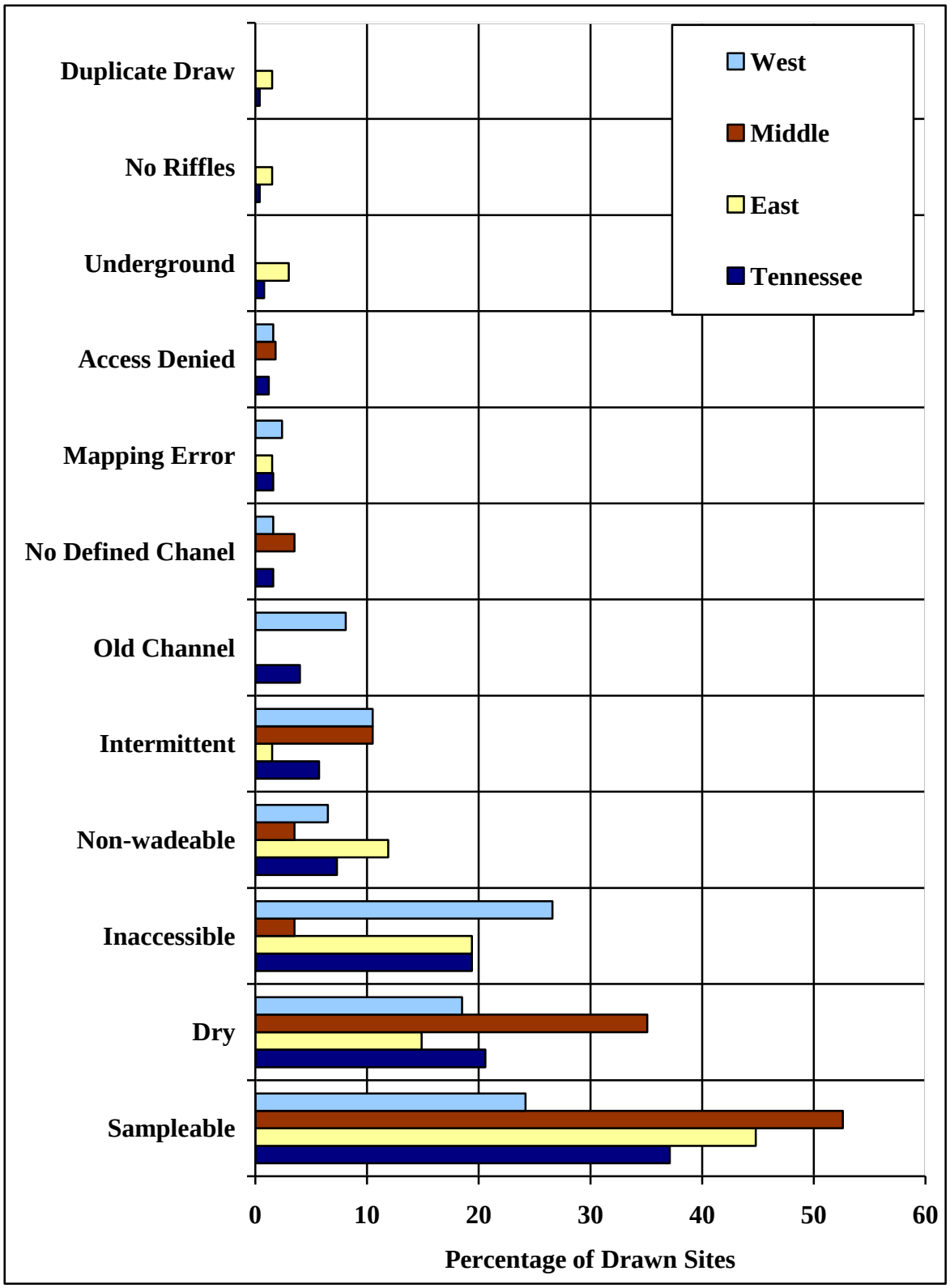


Figure 4: Status of randomly selected sites in each division.

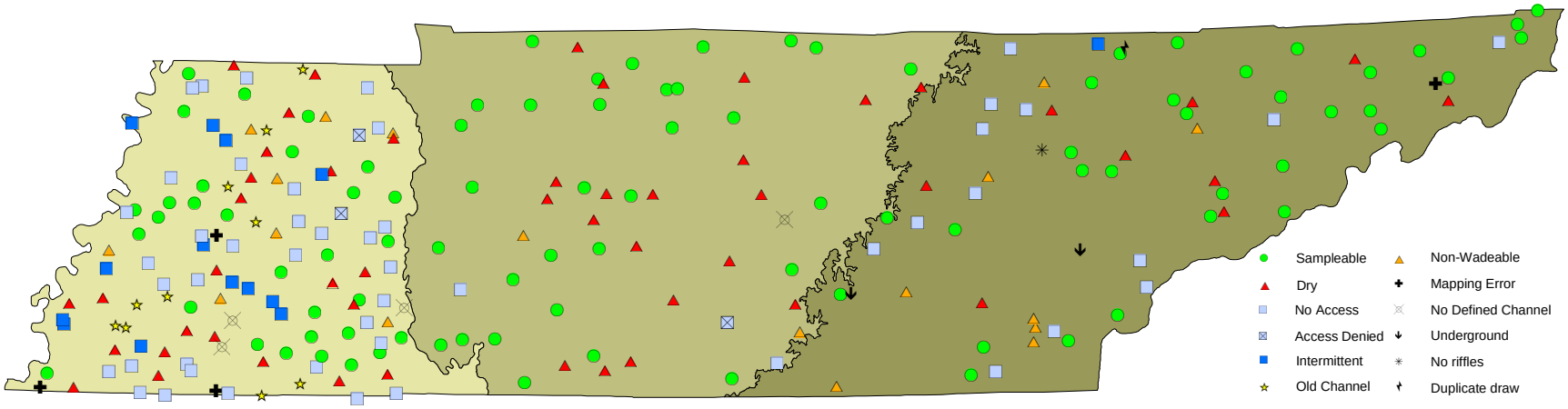


Figure 5: Location of primary and over-draw sites (All 248).

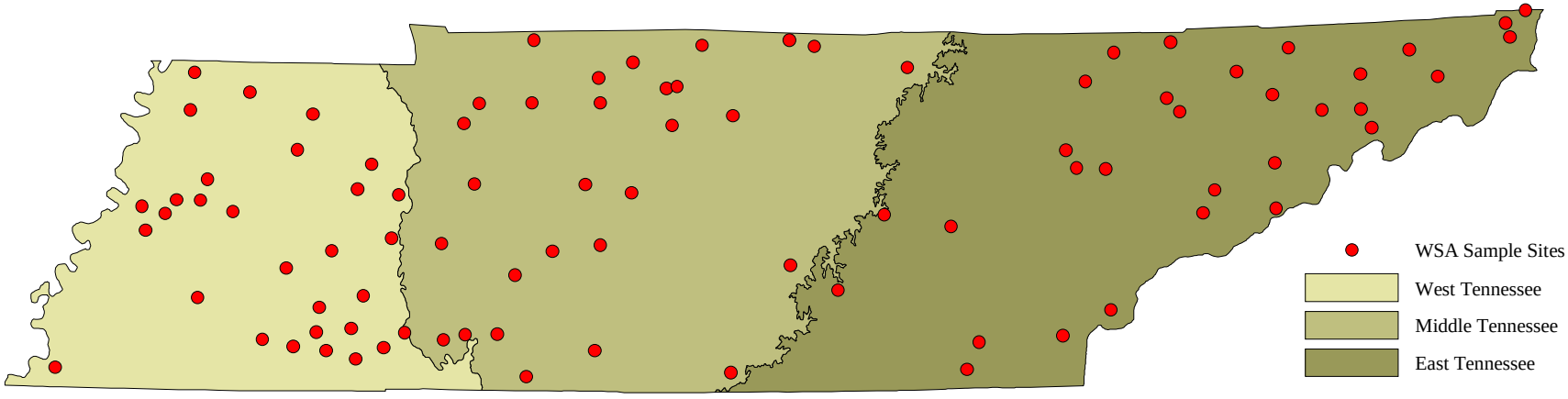


Figure 6: Location of final sample sites.

3. REPRESENTATIVENESS OF PROBABILISTIC SITES

a. Stream Order

Two thirds of the stream miles included in the sample frame (66-67%) were first order meaning they did not have any tributaries (Table 3). Stream order was determined by USGS/EPA's National Hydropgraphy Database Plus. During reconnaissance, many of these headwater streams did not meet study design (Figure 7). They were either intermittent or were dry due to drought conditions. According to the National Climatic Data Center, drought began in February 2007 in middle and east Tennessee. By the time monitoring began in July 2007, the entire state was in extreme to severe drought conditions (Figure 8). This affected the availability of smaller streams for monitoring.

Table 3: Stream length (miles) in Tennessee sample frame by stream order and division. Strahler order determined by USGS/EPA's National Hydropgraphy Database-Plus (NHDPlus).

Division	Strahler Order					
	Unknown	1	2	3	4	Total
East	367	14298	3599	2153	966	21383
Middle	296	13290	3467	2062	1020	20135
West	516	10906	2765	1327	688	16202
Total	1179	38494	9831	5542	2674	57720

The probabilistic study targeted 1st through 4th order wadeable streams. First order streams do not have tributaries. Second order streams have at least two first order tribrutaries. Third order streams have at least two second order tributaries and fourth order streams have at least two third order tributaries.

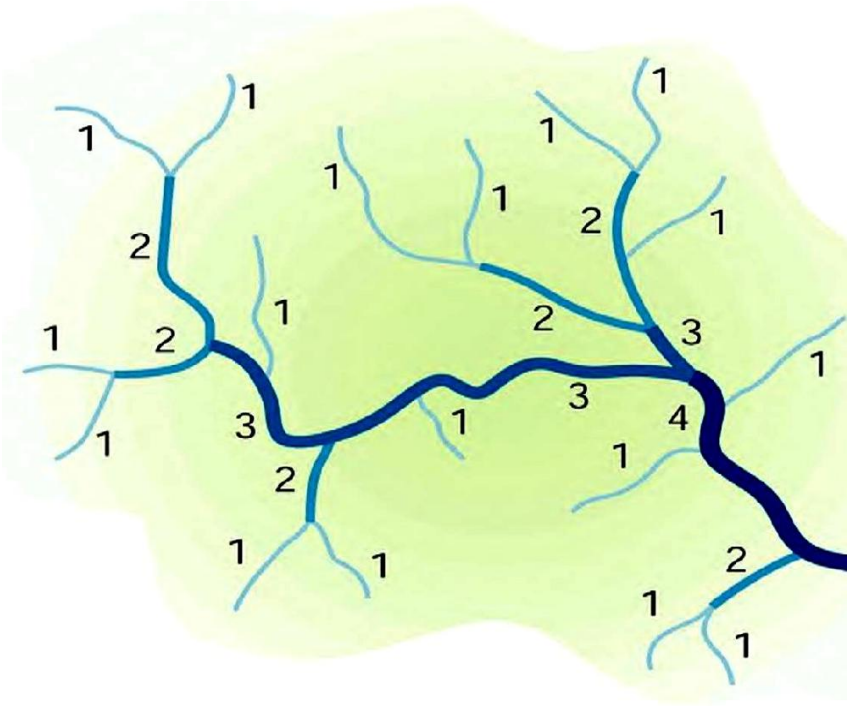


Diagram provided by North Carolina State University.

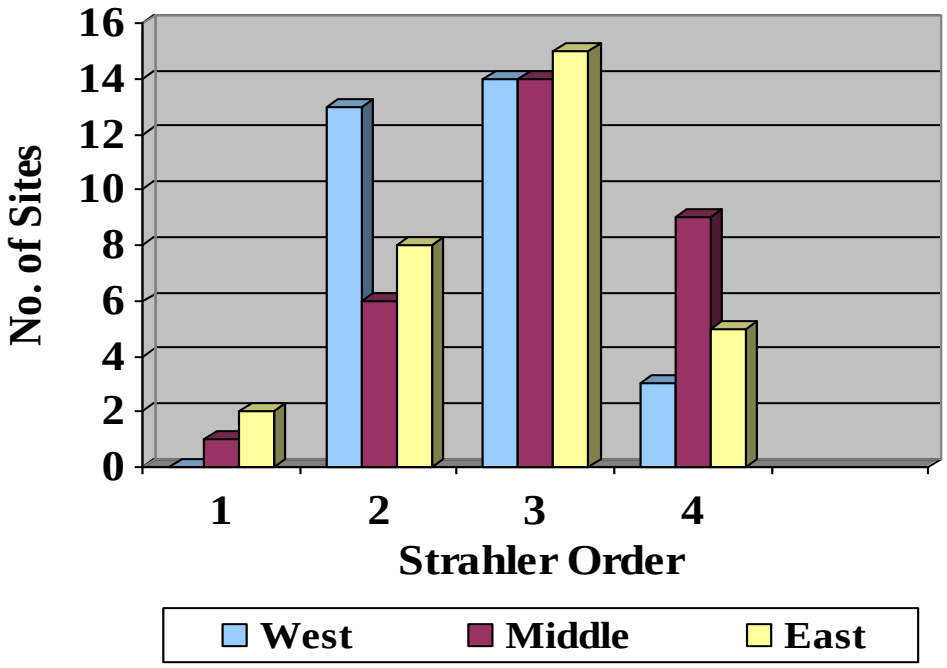


Figure 7: Number of sample sites by size class in each of the three divisions.

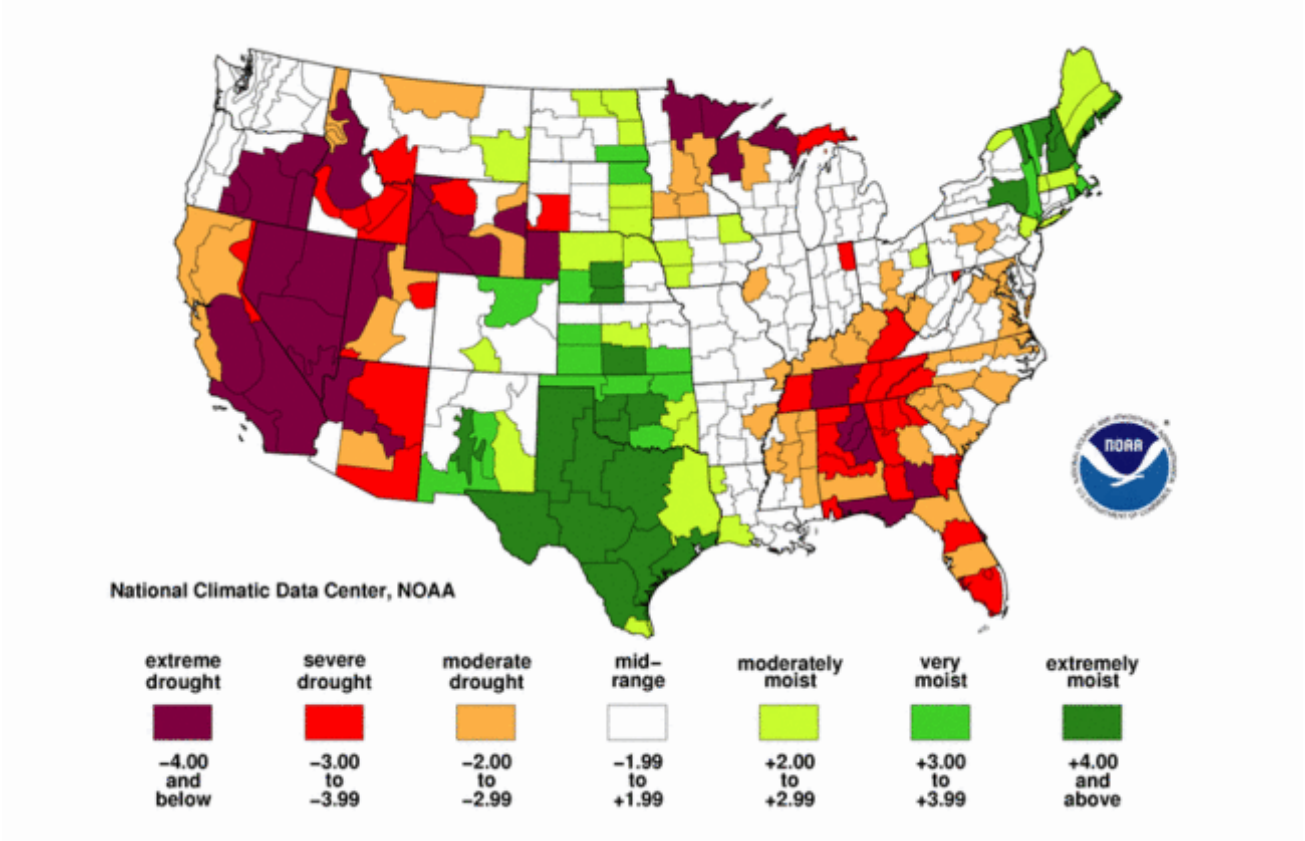


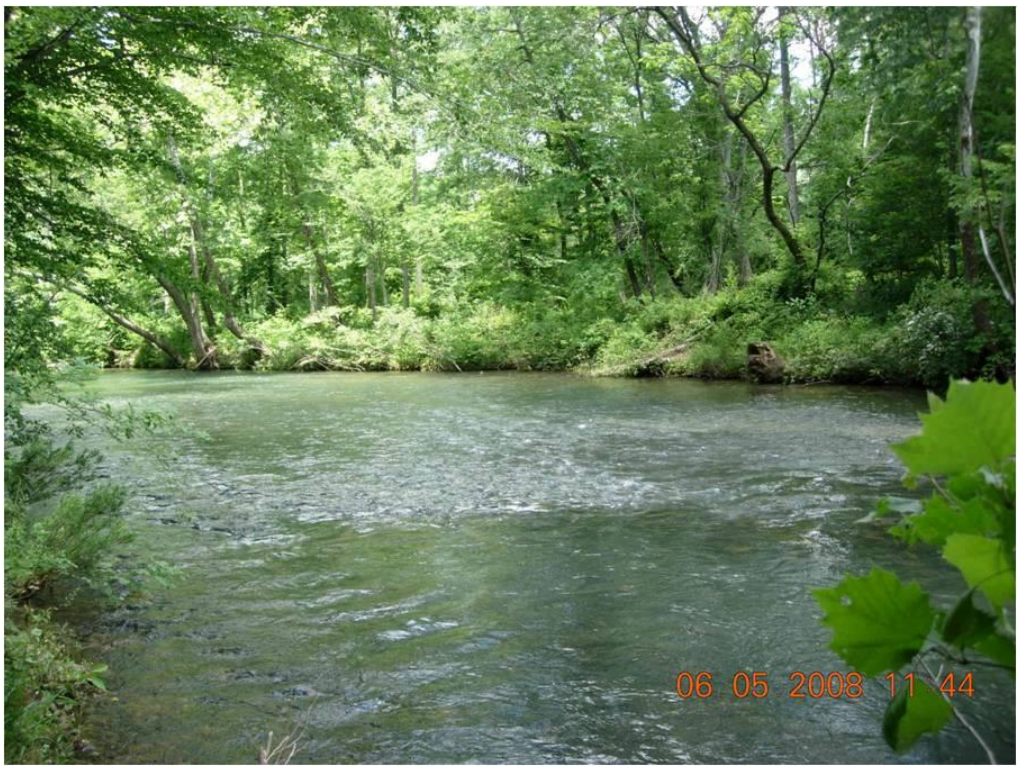
Figure 8: Palmer Drought Severity Index map, July 2007.

b. Drainage Area

Once the final sites were selected, drainage areas were determined using GIS (Figure 9). To determine the land areas that are hydrologically connected to each site, only portions of the watersheds that were upstream from the sample site were used. These drainage areas were delineated using a USGS topographic map layered over a National Land Cover Database (NLCD) map with 30 meter resolution (created in 2001).

Statewide, 1,747 square miles of watershed drainage area were included in the wadeable stream assessment project. This represents 4.1% of the state's total land area and 4.2% of the total stream miles in the state. The drainage area represented by the study sites closely approximated the percent of that region to the state (Table 4).

The drainage areas upstream of the test sites ranged from 0.1 to 159 square miles averaging 19 square miles. Some of the watershed areas are split between divisions, ecoregions and/or state boundaries. These areas are included in the same division as their corresponding station, even if the majority of that watershed was in a different division.



Cane Creek in Van Buren County (middle division) was the largest stream sampled in the probabilistic study with a drainage area of 159 square miles.
Photo provided by Cookeville Environmental Field Office.

Table 4: Upstream drainage area and stream miles represented by sample sites.

Total Land Area	**Square Miles**	**Percent of Area**
West Tennessee	10,472.3	24.8%
Middle Tennessee	15,843.7	37.5%
East Tennessee	15,886.8	37.6%
Total	**42,202.8**	
WSA Drainage Area		
West Tennessee	424.1	24.3%
Middle Tennessee*	838.8	48.0%
East Tennessee	484.1	27.7%
Total	**1,747.0**/42,202.8 =	**4.1% of State**

Total Stream Miles	**Miles**	**Percent of Miles**
West Tennessee	17,630.4	27.9%
Middle Tennessee	22,280.4	35.4%
East Tennessee	23,085.6	36.6%
Total	**62,996.4**	
WSA Stream Miles		
West Tennessee	724.8	27.2%
Middle Tennessee*	1,154.5	42.1%
East Tennessee	781.9	30.7%
Total	**2,661.2**/62,996.4 =	**4.2% of State**

Note: Some watershed areas and stream miles are divided between two regions or states but are placed in the same region of Tennessee as the corresponding station. Approximately 119 miles of streams and 120 square miles of area were within Kentucky rather than Tennessee.

*The Cane Creek watershed upstream of station CANE004.5VA has 158.6 out of 159.2 square miles in East Tennessee, as well as 216.1 out of 217.1 miles of East Tennessee streams, but is included in Middle Tennessee because of the WSA site location.

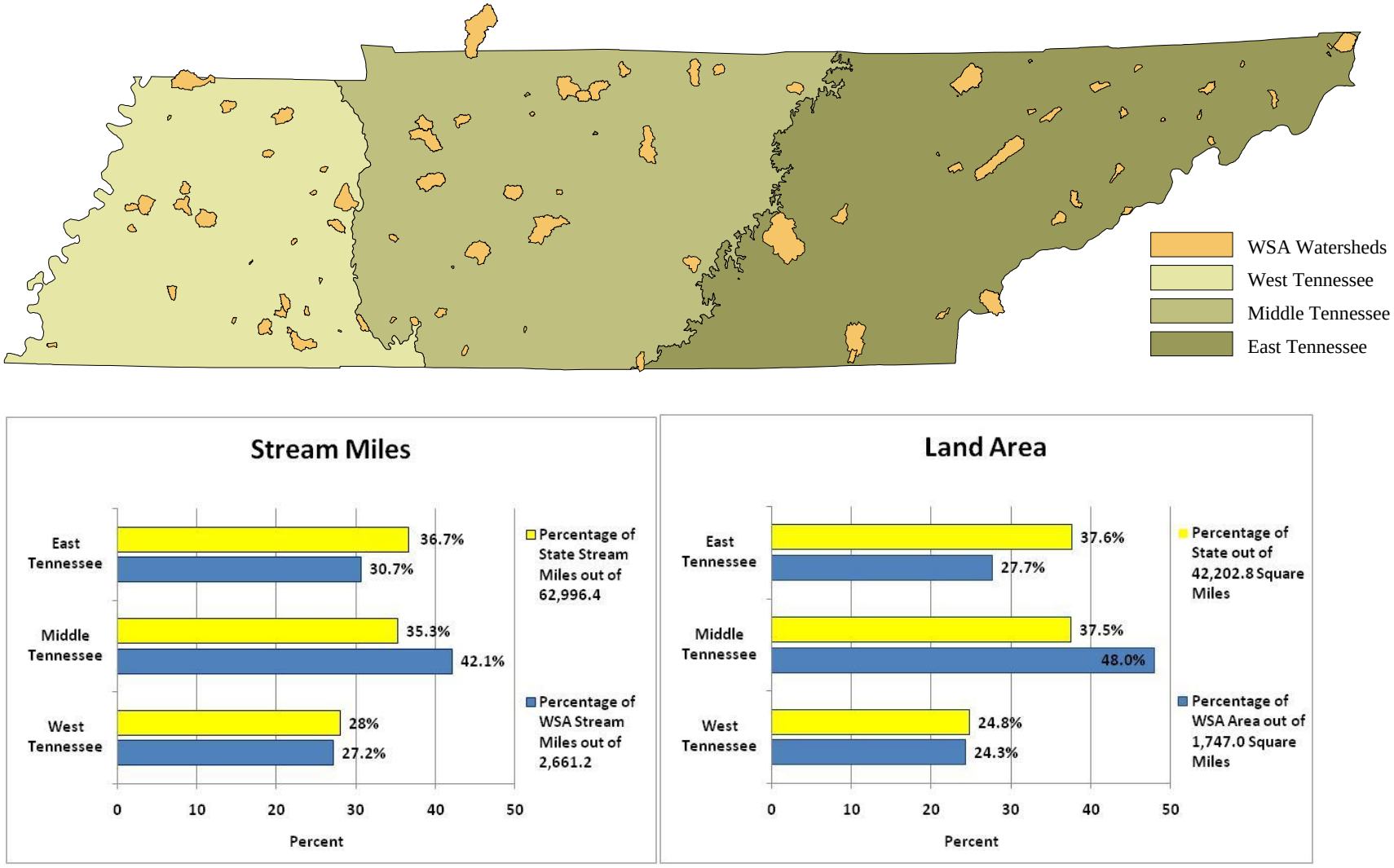


Figure 9: Drainage area upstream of sample sites.

c. Ecoregions

An ecoregion is a relatively homogenous area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology and other ecologically relevant variables (Griffith et al, 1977). Tennessee has eight Level III ecoregions which are subdivided into 31 Level IV subregions (Figure 10). Randomly selected test sites fell in 7 of the Level III ecoregions and 18 of the level IV ecoregions (Table 5). These 18 subregions represent 91.6% of the state. Generally, the study sites are distributed in proportion to the ecoregion size.

- **West Tennessee**

There are three Level III ecoregions in west Tennessee. The **Mississippi Alluvial Plain** (73) is the only one not represented in the study. This is a small and narrow ecoregion that lies on the western border of Tennessee along the Mississippi River. Only 8% of the western division of the state falls in this region. Two of the 124 potential west Tennessee test sites were in the random selection for this region. However, one stream was intermittent and the other was inaccessible.

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The other two Level III ecoregions found in west Tennessee are roughly equal in area. The **Southeastern Plains** (65) is 49% of west Tennessee and had 18 sample sites. There are four subregions. The largest subregion is the Southeastern Plains and Hills (65e) where most of the sites were located. The Southeastern Plains are a mixture of cropland, pasture, woodland, and oak-hickory-pine forest. Streams are relatively low-gradient and sandy-bottomed. The three other subregions were not represented but are very small and together account for less than 1% of the western division.

The **Mississippi Valley Loess Plains** (74) is 43% of the western division. Twelve test sites were randomly selected in this ecoregion representing both subregions. Streams generally have a lower gradient than the Southeastern Plains with a more silty substrate although streams in the Bluff Hills subregion are higher gradient with a gravel substrate. In Tennessee, row crops are the dominant land use.

- **Middle Tennessee**

The **Interior Plateau** (71) is the only level III ecoregion in middle Tennessee. The Interior Plateau is a diverse ecoregion with five distinct Level IV subregions. Rock substrates are distinctly different from the coastal plain sands of western Tennessee ecoregions, and elevations are lower than the Appalachian ecoregions to the east. All five of the subregions were represented by randomly selected sites. The number in each subregion was roughly proportional to the land area with the exception of the Inner Nashville Basin (71i). Only one site was sampleable in 71i although it is 11% of the middle division. Two other sites were selected but were dry. Many of the smaller streams in this region go dry even during normal summer conditions.

- **East Tennessee**

East Tennessee is the most diverse of the three divisions with four Level III ecoregions and 17 Level IV subregions. All of the level III ecoregions were represented in the study. The **Blue Ridge Mountains** (66) of Tennessee are characterized by cool, clear high gradient streams. Much of the ecoregion falls in the Cherokee National Forest or Great Smoky Mountains National Park. This ecoregion is one of the richest centers of biodiversity in the eastern U.S. There are seven Level IV subregions in the Blue Ridge Mountains. Six stations were located in the larger three subregions. None of the sample sites fell in the four smaller subregions, however, they comprise less than one percent of the state.

The **Ridge and Valley** (67) is a relatively low-lying region between the Blue Ridge Mountains to the east and the Cumberland Plateau on the west. Springs and caves are relatively numerous. Over half of the eastern division study sites fell in this ecoregion. There are four Level IV subregions, two of which were represented in the study. The Southern Limestone Dolomite Valleys and Low Rolling Hills (67f) is the largest subregion, comprising 33.5% of the eastern division. It has 12 sites, the most for east Tennessee.

The **Southwestern Appalachians** (68) stretch from Kentucky to Alabama; these open low mountains contain a mosaic of forest and woodland with some cropland and pasture. Coal strip mines are common. Streams generally originate on the plateau before dropping off the escarpment. The numerous first and second order headwater streams are often dry or subterranean during the summer months. There are four Level IV subregions. The Cumberland Plateau (68a) is the largest subregion and comprises 20% of the land area in the eastern division. However, most of the streams selected in this region were inaccessible headwater streams that were most likely dry. Only one randomly selected site met study conditions. Another site was located in the smaller Sequatchie Valley (68b). There were no acceptable sites in the Plateau Escarpment (68c). Of the three randomly selected, one was dry, one was inaccessible due to steep terrain and one was subterranean. The recently delineated Southern Table Plateau (68d) did not have any randomly selected sites but comprises less than 0.1% of the state.

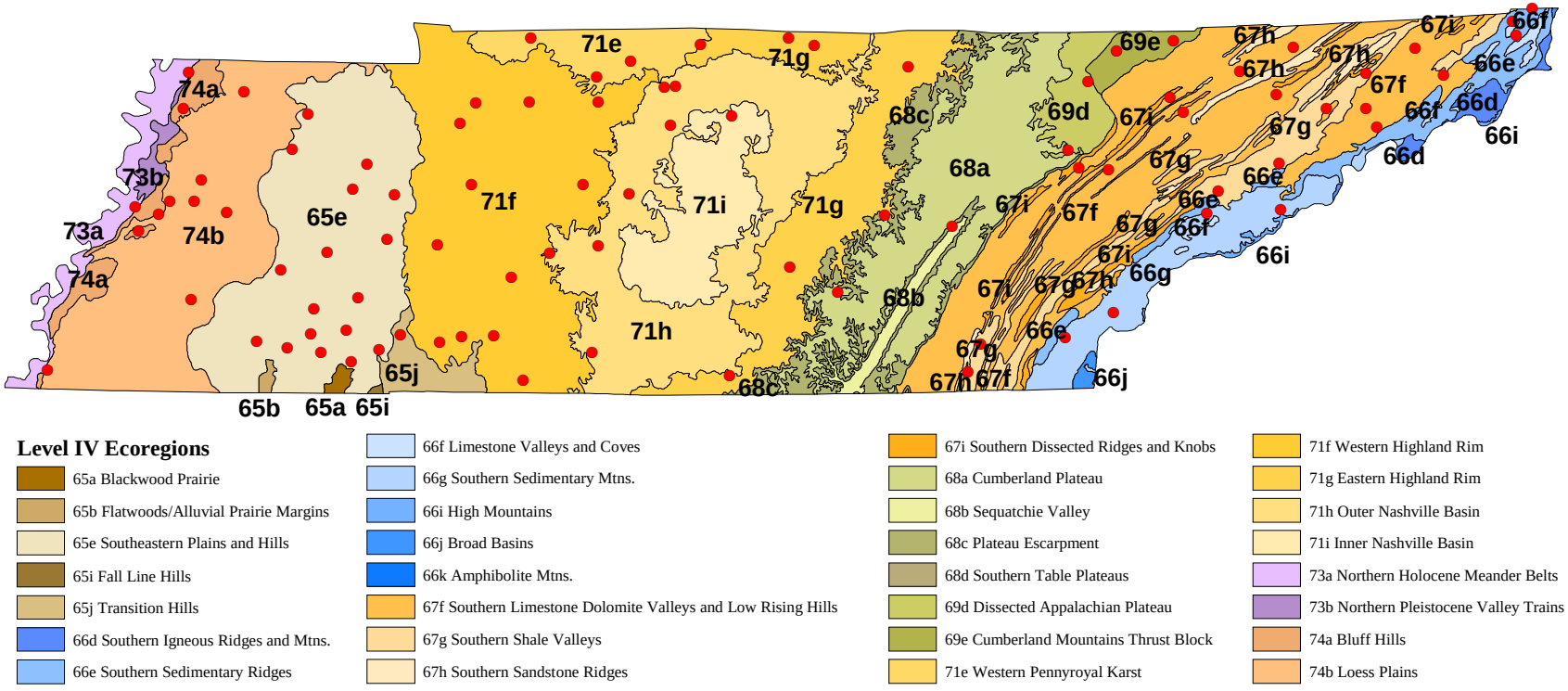
The **Central Appalachians** (69) stretch from northern Tennessee to central Pennsylvania. The rugged terrain, cool climate, and infertile soils limit agriculture resulting in a mostly forested land cover. Bituminous coal mines are common, and have caused siltation and acidification of streams. There are two Level IV subregions within Tennessee. Although it is a relatively small subregion, three sample sites were randomly selected in the Cumberland Mountain Thrust Block (69e). All three stations were selected randomly during the primary draw. Of the 17 subregions in east Tennessee, 69e ranks fourth in the number of sites, third in the WSA drainage area, and tenth in size.

Table 5: Distribution of randomly selected sites within each ecoregion.

Division	Ecoregion (Level III)	Subregion (Level IV)	Subregion % of State	Subregion % of Division	# of Sites	% of Sites in Division
West	65 Southeastern Plains	65a Blackland Prairie	0.1%	0.5%	0	0%
		65b Flatwoods/ Alluvial Prairie Margins	0.1%	0.3%	0	0%
		65e Southeastern Plains and Hills	10.9%	43.9%	16	53.3%
		65i Fall Line Hills	0.02%	0.1%	0	0%
		65j Transition Hills	1.0%	3.9%	2	6.7%
	74 Mississippi Valley Loess Plains	74a Bluff Hills	1.1%	4.7%	3	10.0%
		74b Loess Plains	9.6%	38.5%	9	30.0%
	73 Mississippi Alluvial Plain	73a Northern Holocene Meander Belts	1.7%	6.6%	0	0%
		73b Northern Pleistocene Valley Trains	0.3%	1.4%	0	0%
Middle	71 Interior Plateau	71e Western Pennyroyal Karst	2.0%	5.4%	3	10.0%
		71f Western Highland Rim	13.9%	37.3%	12	40.0%
		71g Eastern Highland Rim	6.9%	18.6%	6	20.0%
		71h Outer Nashville Basin	10.5%	28.1%	8	26.7%
		71i Inner Nashville Basin	4.0%	10.6%	1	3.3%
East	66 Blue Ridge Mtns	66d Southern Igneous Ridges and Mtns.	0.6%	1.4%	0	0%
		66e Southern Sedimentary Ridges	1.9%	5.0%	2	6.7%
		66f Limestone Valleys and Coves	0.3%	0.9%	1	3.3%
		66g Southern Metasedimentary Mtns.	3.2%	7.8%	4	13.3%

Table 5: cont.

Division	Ecoregion (Level III)	Subregion (Level IV)	Subregion % of State	Subregion % of Division	# of Sites	% of Sites in Division
		66i High Mountains	0.1%	0.4%	0	0%
		66j Broad Basins	0.0%	0.07%	0	0%
		66k Amphibolite Mountains	0.0%	0.01%	0	0%
	67 Ridge and Valley	67f Southern Limestone Dolomite Valleys and Low Rolling Hills	12.6%	33.5%	12	13.33%
		67g Southern Shale Valleys	3.4%	9.0%	5	5.6%
		67h Southern Sandstone Ridges	0.8%	2.1%	0	0%
		67i Southern Dissected Ridges and Knobs	1.4%	3.7%	0	0%
	68 Southwestern Appalachians	68a Cumberland Plateau	7.6%	20.0%	1	1.1%
		68b Sequatchie Valley	0.6%	1.6%	1	1.1%
		68c Plateau Escarpment	3.3%	8.7%	0	0%
		68d Southern Table Plateaus	0.0%	0.02%	0	0%
	69 Central Appalachians	69d Dissected Appalachian Plateau	1.4%	3.7%	1	1.11%
		69e Cumberland Mountain Thrust Block	0.7%	1.9%	3	3.3%



Level IV Ecoregions

- 65a Blackwood Prairie
- 65b Flatwoods/Alluvial Prairie Margins
- 65e Southeastern Plains and Hills
- 65i Fall Line Hills
- 65j Transition Hills
- 66d Southern Igneous Ridges and Mtns.
- 66e Southern Sedimentary Ridges
- 66f Limestone Valleys and Coves
- 66g Southern Sedimentary Mtns.
- 66i High Mountains
- 66j Broad Basins
- 66k Amphibolite Mtns.
- 67f Southern Limestone Dolomite Valleys and Low Rising Hills
- 67g Southern Shale Valleys
- 67h Southern Sandstone Ridges
- 67i Southern Dissected Ridges and Knobs
- 68a Cumberland Plateau
- 68b Sequatchie Valley
- 68c Plateau Escarpment
- 68d Southern Table Plateaus
- 69d Dissected Appalachian Plateau
- 69e Cumberland Mountains Thrust Block
- 71e Western Pennyroyal Karst
- 71f Western Highland Rim
- 71g Eastern Highland Rim
- 71h Outer Nashville Basin
- 71i Inner Nashville Basin
- 73a Northern Holocene Meander Belts
- 73b Northern Pleistocene Valley Trains
- 74a Bluff Hills
- 74b Loess Plains

Figure 10: Sample sites by Ecoregions.

d. Watersheds

There are 55 HUC 8 watersheds in Tennessee. Randomly selected sample sites were located in 38 watersheds which covered almost 79% of the state. (Figure 11). Generally, the larger watersheds tended to have more sites than the smaller ones, but this was not always the case (Table 6).

Some of the larger watersheds had few or no sites selected possibly due to fewer numbers of streams draining larger areas or a large portion of the watershed being impounded. This was especially true in the eastern division. For example, the Chickamauga watershed, which is 7.7% of eastern Tennessee did not have any sites in the random selection. The Watts Barr and Ft. Loudoun watersheds (8.3% of East Tennessee) also had no sites selected.

Other watersheds had more sites rejected during reconnaissance as drought conditions appeared more severe in these watersheds. Three sites were selected in the Upper Duck watershed but they were found to be dry. Nine sites selected in the Loosahatchie watershed were dry or no longer followed the original stream channel.

Other watersheds were not represented because of inaccessibility. In southwestern Tennessee, none of the randomly selected sites in the Loosahatchie and the Wolf River watersheds met study conditions. Between the two they had 18 sites drawn and none met study conditions. The majority of the drawn sites were disqualified because they were either dry or inaccessible.

The largest watershed in Tennessee did have the most sites. The Tennessee Western Valley (06040001) drains 2,087 square miles, 98% within the state boundaries. It covers nearly 5% of the entire state, draining both the western and middle division. Eight sites were sampled in this watershed.

South Fork Cub Creek in the Tennessee Western Valley. *Photo provided by Jackson Environmental Field Office.*

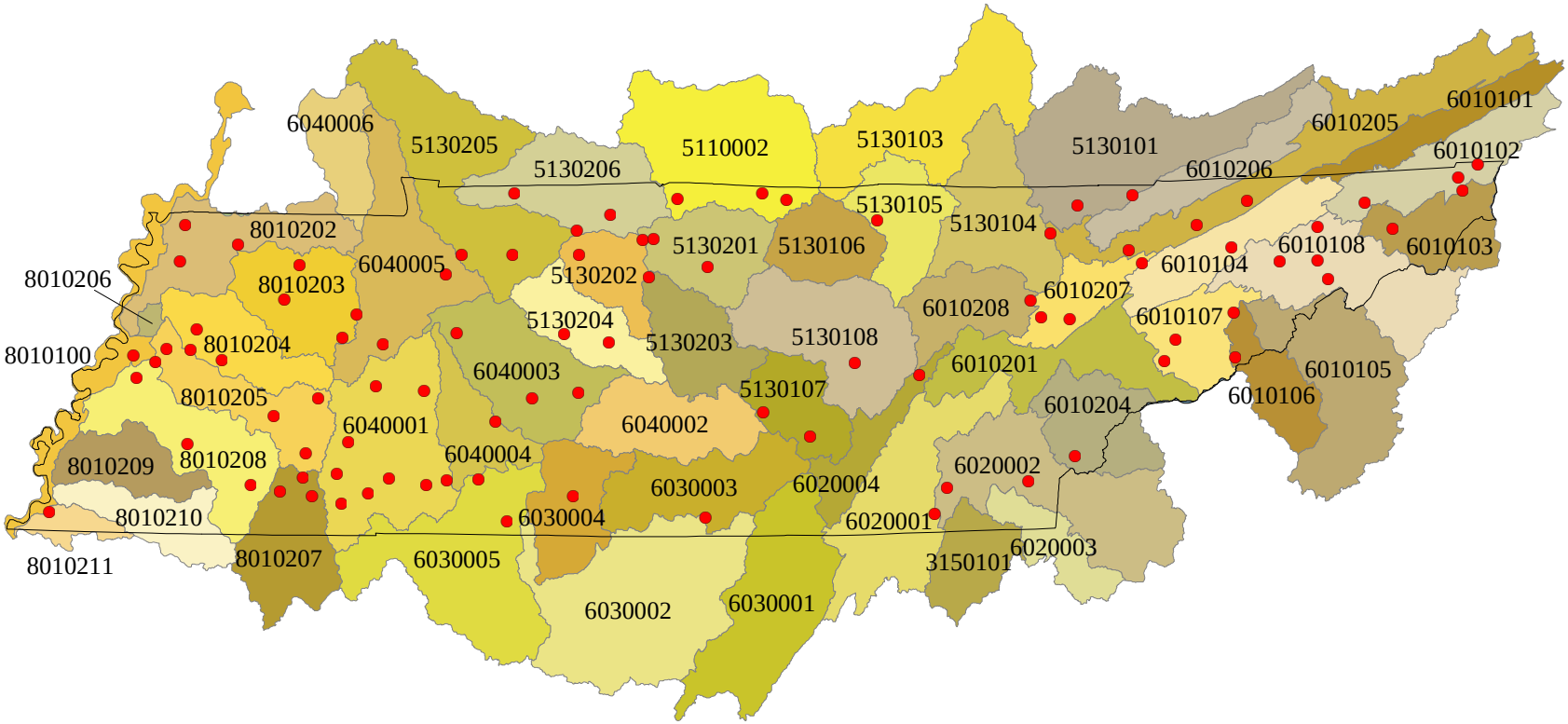


Figure 11: Sample sites by watershed.

Table 6: Number of study sites by watershed. Table sorted by HUC with the largest drainage area in TN.

HUC	Name	# Sites	HUC Area Total (mi^2)	HUC Area in TN (mi^2)	HUC % of TN
6040001	TN Western Valley (Beech)	8	2087	2048	4.9
5130108	Caney Fork	1	1790	1790	4.2
6040003	Lower Duck	4	1548	1548	3.7
6040005	TN Western Valley (KY Lake)	3	1809	1451	3.4
8010208	Hatchie	3	1461	1449	3.4
6010201	Watts Barr	0	684	684	3.2
6030003	Upper Elk	1	1289	1289	3.1
6020001	TN Chickamauga	0	1870	1216	2.9
6040002	Upper Duck	0	1182	1182	2.8
8010202	Obion	3	1313	1167	2.8
8010203	Obion, South Fork	3	1159	1159	2.8
6010108	Nolichucky	4	1744	1124	2.7
8010205	South Fork Forked Deer	5	1065	1065	2.5
5130201	Cumberland (Old Hickory)	3	994	994	2.4
5130205	Lower Cumberland (Lake Barkely)	2	2344	989	2.4
6010104	Holston	2	1000	1000	2.4
6020002	Hiwassee	3	2070	1018	2.4
5130104	South Fork Cumberland	0	1375	976	2.3
8010204	North Fork Forked Deer	3	956	956	2.3
5130203	Stones	1	944	944	2.2
5130204	Harpeth	2	868	868	2.1
6010208	Emory	0	870	879	2.1
5130106	Upper Cumberland (Cordell Hull)	0	794	794	1.9
5130107	Collins	2	797	797	1.9
6010107	Lower French Broad	2	800	800	1.9
5130105	Obey	1	945	781	1.8
5130206	Red	3	1451	761	1.8
6010204	Little TN	1	1050	774	1.8

Table 6 cont.

HUC	Name	# Sites	HUC Area Total (mi^2)	HUC Area in TN (mi^2)	HUC % of TN
6040004	Buffalo	1	763	763	1.8
8010209	Loosahatchie	0	741	741	1.8
6010205	Upper Clinch	4	1979	718	1.7
6030004	Lower Elk	1	964	713	1.7
6010103	Watauga	2	869	660	1.6
5130202	Lower Cumberland (Cheatham Lake)	1	645	645	1.5
6010201	Ft. Loudoun	0	638	638	1.5
6010207	Lower Clinch	3	631	631	1.5
6030005	Pickwick Lake	2	2276	636	1.5
6010102	South Fork Holston	3	1179	577	1.4
6020004	Sequatchie	1	605	605	1.4
8010100	Mississippi	1	1087	579	1.4
8010210	Wolf	0	819	575	1.4
5110002	Barren	3	2259	409	1.0
6010206	Powell	1	940	400	1.0
8010207	Little Hatchie	3	1139	419	1.0
5130101	Clear	1	2330	336	0.8
6030001	Guntersville Lake	0	1984	331	0.8
6010105	Upper French Broad	0	1860	218	0.5
6020003	Ocoee	0	637	199	0.5
6030002	Wheeler Lake	0	2886	224	0.5
8010211	Nonconnah	1	277	196	0.5
6010106	Pigeon	2	705	152	0.4
3150101	Conasauga	0	729	126	0.3
8010206	Forked Deer	0	69	69	0.2
5130103	Upper Cumberland (Lake Cumberland)	0	1883	35	0.1
6010101	North Fork Holston	0	721	24	0.1
6040006	Lower TN	0	704	21	0.1

e. Land Use

National Land Cover Data (NLCD) from 2001 satellite imagery were used to determine land use (Figures 12, 13 and 14). The NLCD land usages were grouped into nine categories, which include cultivated crops, forest, developed land, wetlands, open water, pasture, shrub, barren land, and undefined. Land use in drainages upstream of the sample sites closely approximated land use for each division (Figures 14, 15 and 16) indicating sites were representative.

The four most prevalent land uses in the state are cultivated crops, forest, pasture, and development. In west Tennessee, the largest land use category is cultivated crops followed by forest (Figure 15). The dominant land use in middle and east Tennessee is forest then pasture which includes both animal grazing and hayfields (Figures 16 and 17). It should be noted in all three divisions that some of the forested area is planted pine plantations. The smallest of the four major land uses in all three divisions is developed land (Figure 18). However this has probably increased since the 2001 imagery. East Tennessee had both the most forest and the most developed land of the three divisions.

Development is the fastest growing land use in many parts of the state. *Photo provided by Nashville Environmental Field Office.*

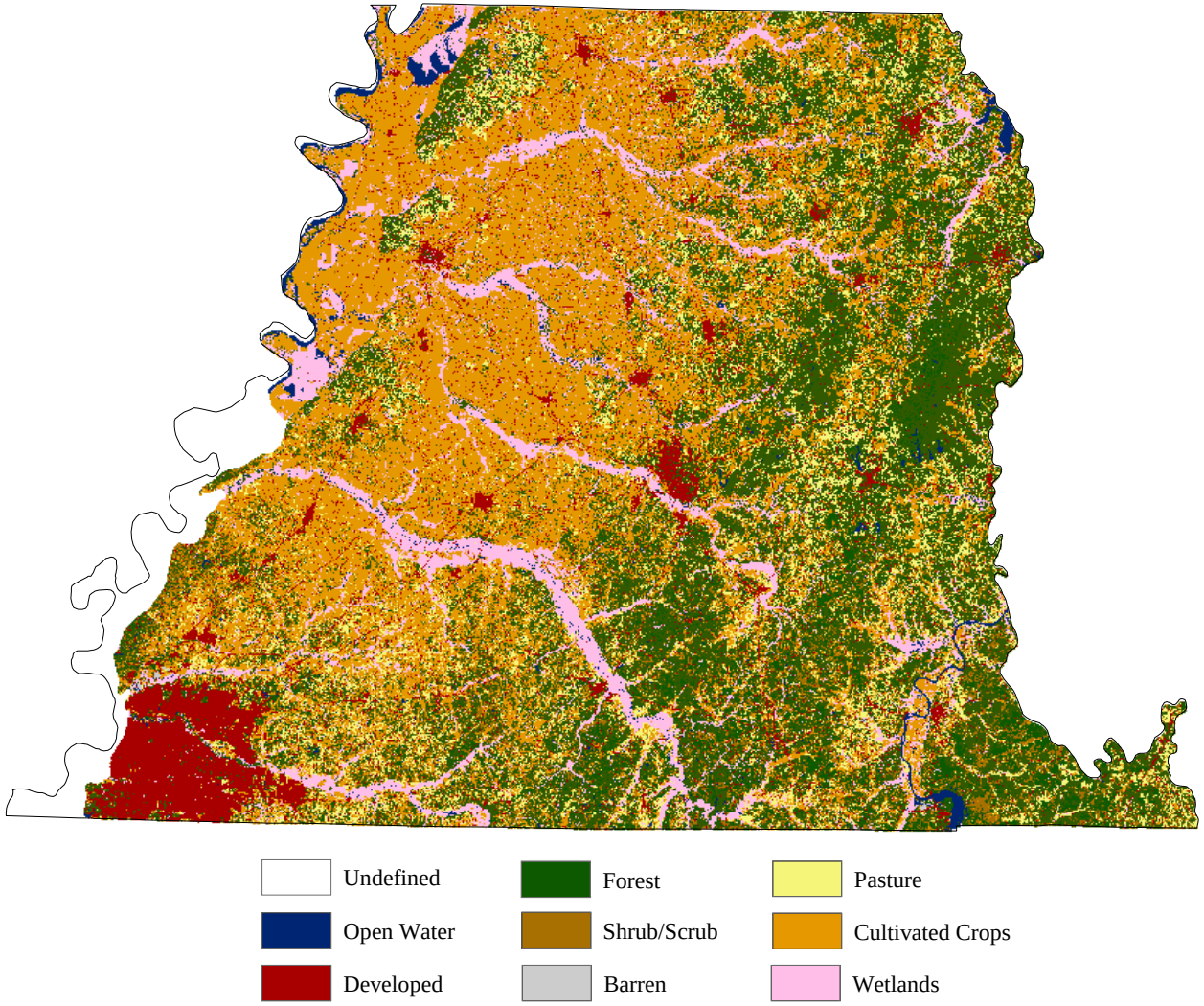


Figure 12: Land use in west Tennessee based on National Land Cover Data (NLCD) imagery from 2001.

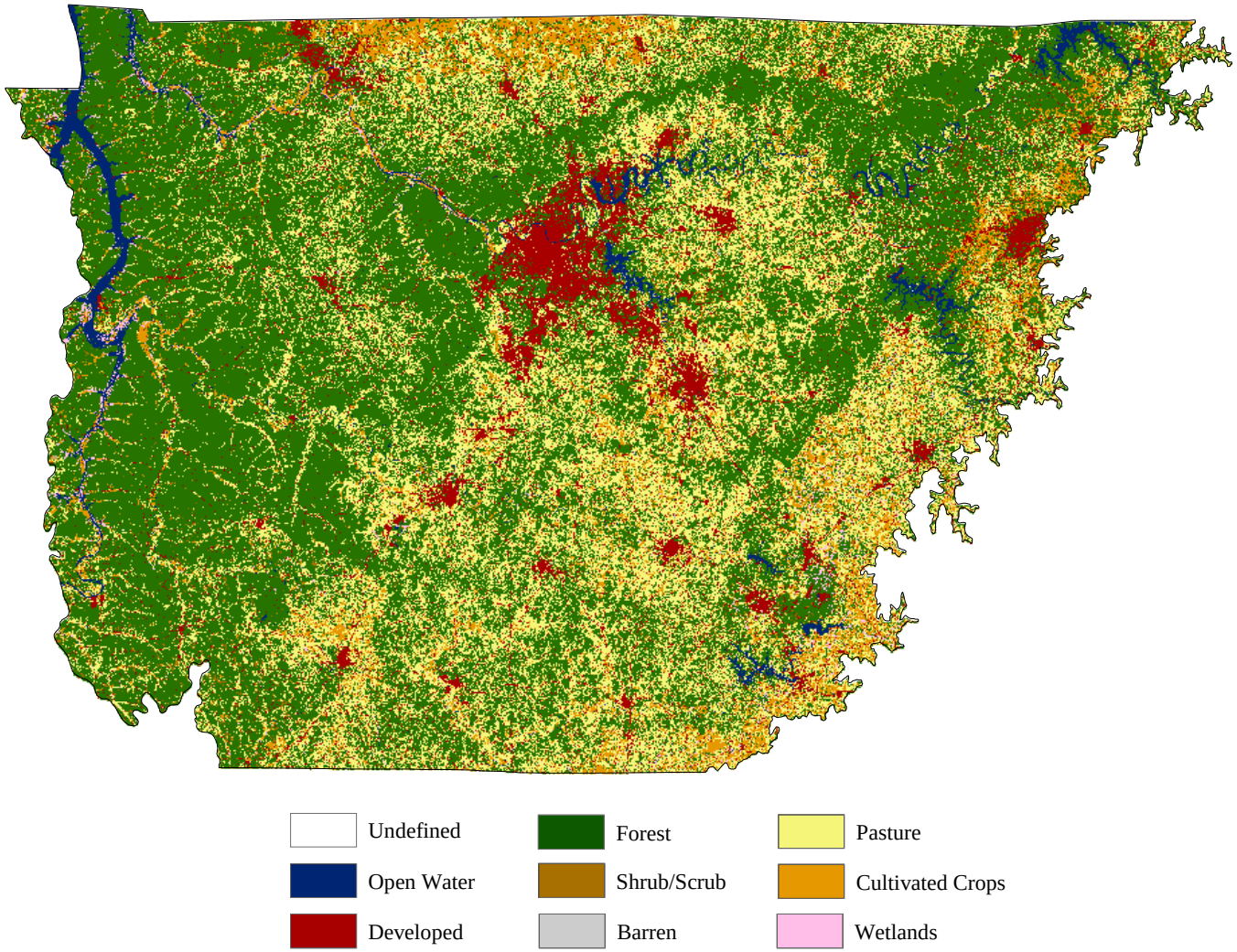


Figure 13: Land use in middle Tennessee based on National Land Cover Data (NLCD) imagery from 2001.

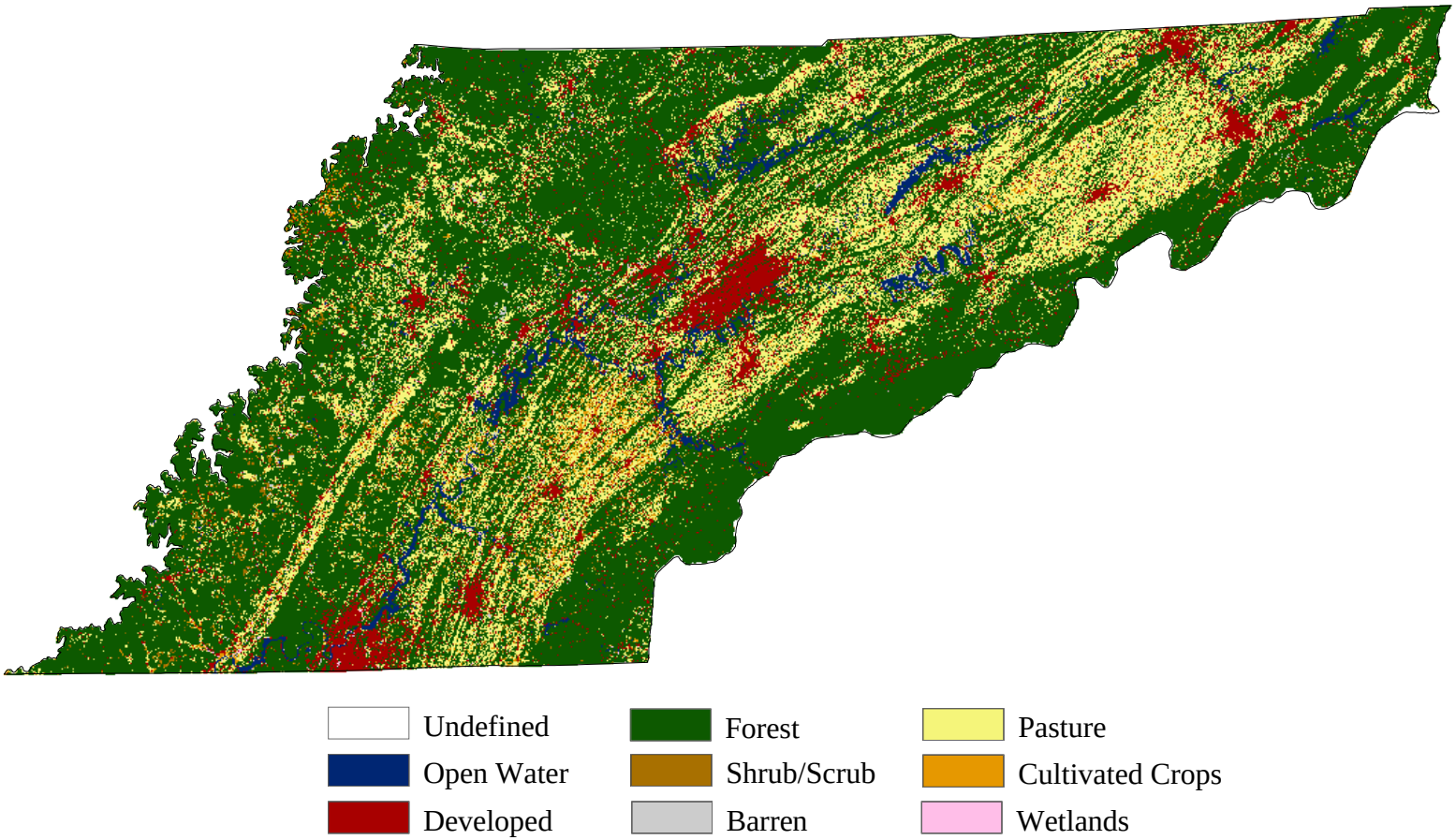


Figure 14: Land use in east Tennessee based on National Land Cover Data (NLCD) imagery from 2001.

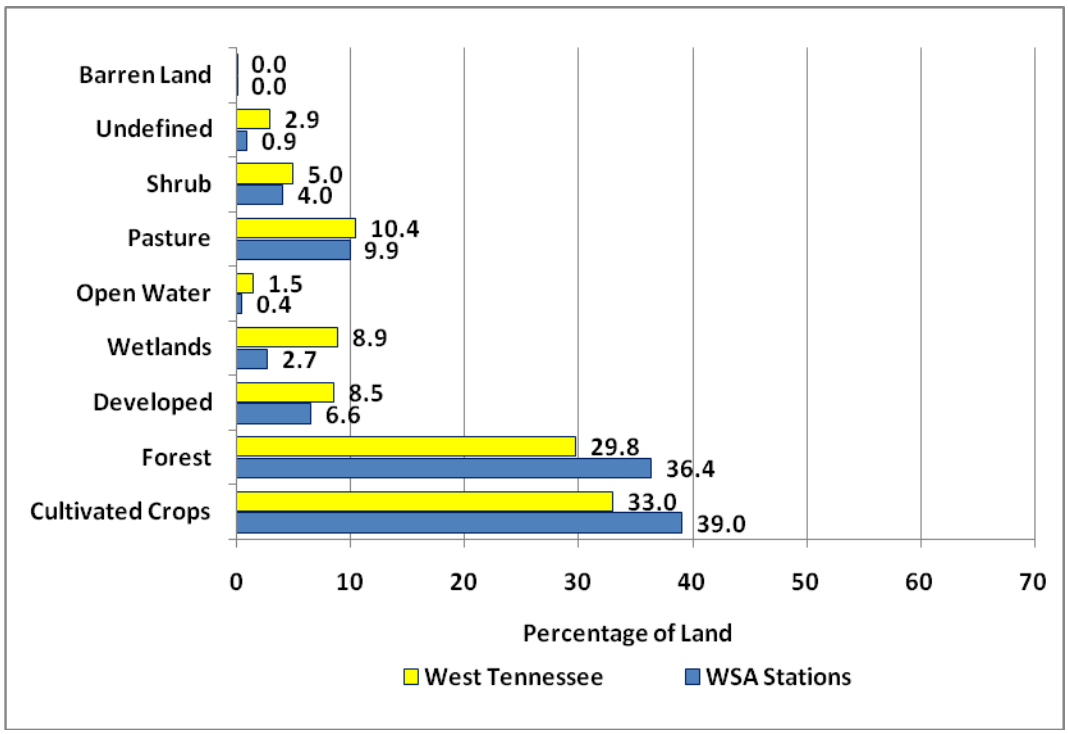


Figure 15: Land use in west Tennessee compared to study sites in that division.

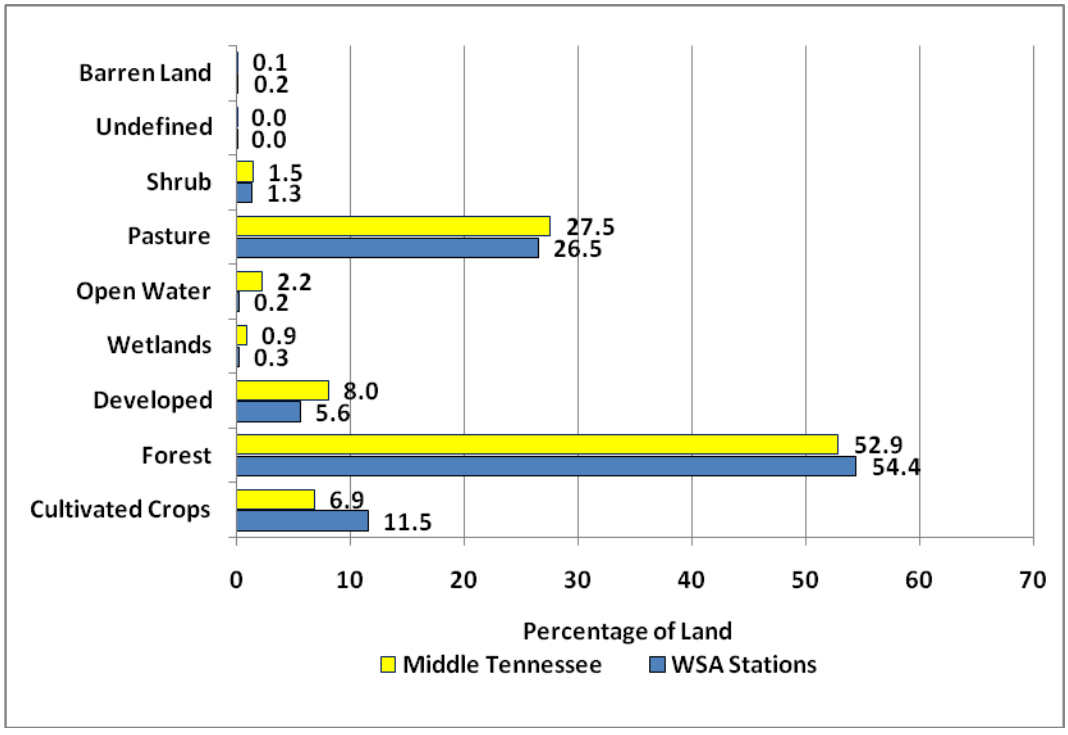


Figure 16: Land use in middle Tennessee compared to study sites in that division.

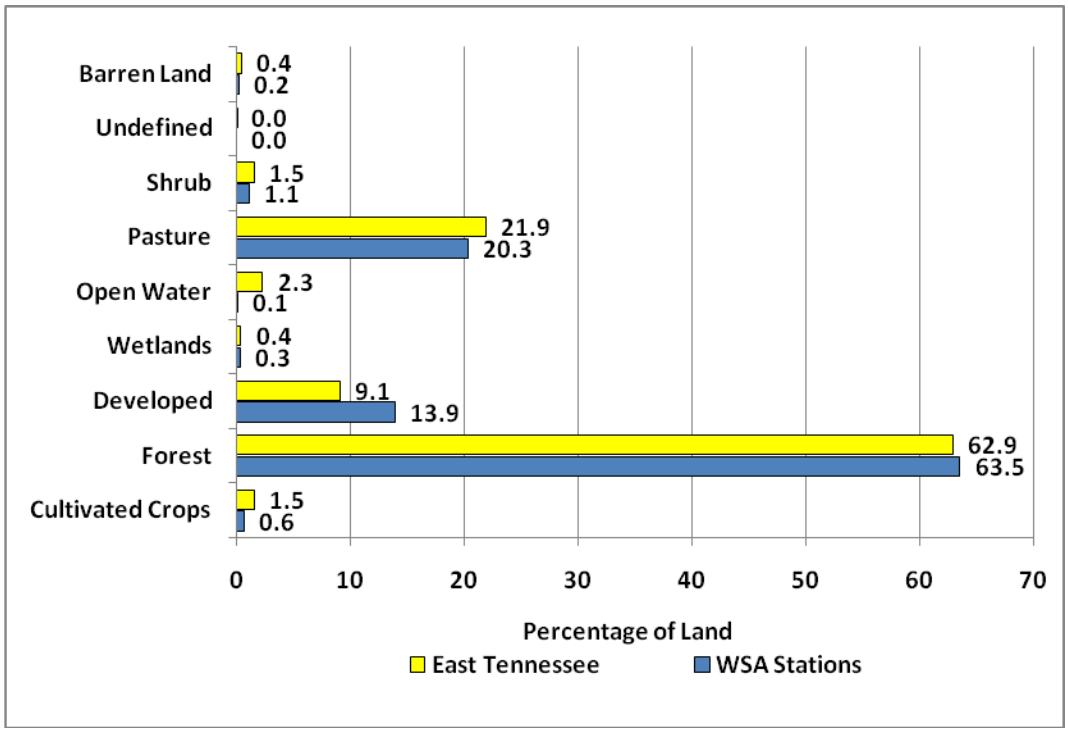


Figure 17: Land use in east Tennessee compared to study sites in that division.

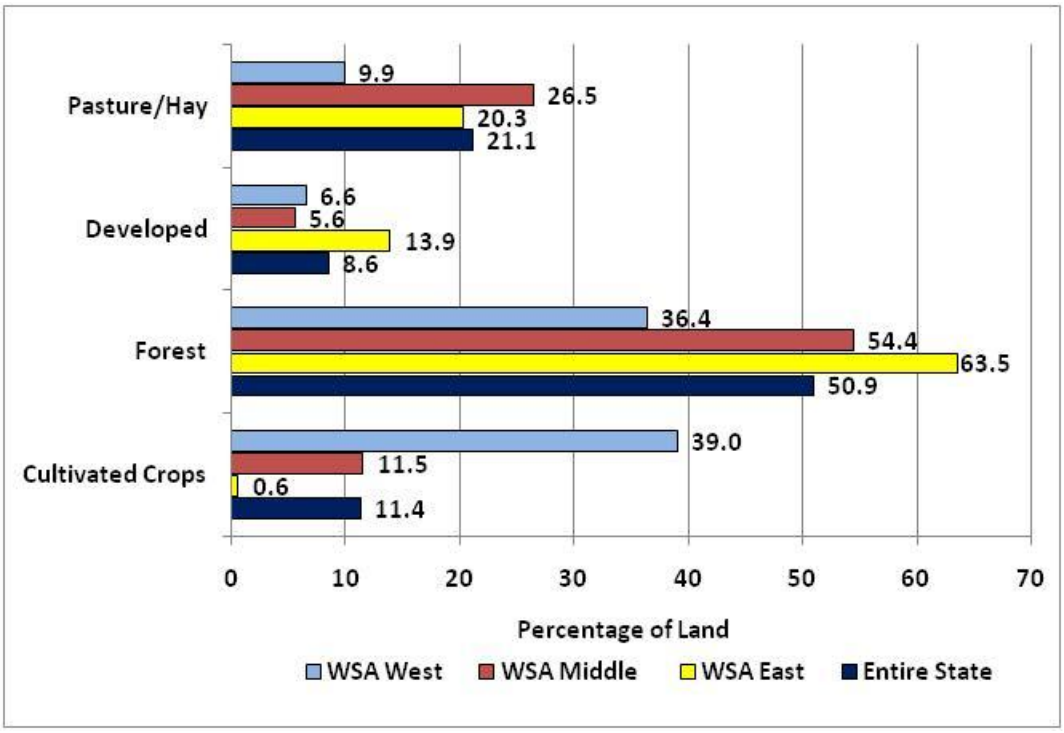


Figure 18: Comparison of dominant land use between divisions upstream of sample sites.

4. DATA COLLECTION AND ANALYSES

The randomly selected location, within latitude and longitude of +/- 0.002778, was designated the middle of the stream sample reach. Field parameters, chemical, bacteriological and flow samples were collected at this location. In accordance with the 2004 national study, reach length for biological and habitat surveys varied depending on stream size. In streams with a wetted width less than four meters, the sample reach was 150 meters. Streams with a wetted width four meters or more, the sample reach was 40 times the wetted width. The wetted width was calculated by averaging five typical channel widths within the sample reach.

a. Macroinvertebrates

The macroinvertebrate community was sampled once at each site between July and October. Eighteen sites were previously sampled in 2004 as part of the national probabilistic survey. The rest were sampled in 2007. Three sites in middle Tennessee were sampled both years since it appeared stream conditions had changed. A single habitat semi-quantitative approach was used to determine the health of the aquatic community (TDEC, 2006). Riffles were sampled in middle and east Tennessee. Undercut rooted banks were sampled in low gradient west Tennessee streams. The advantages of using macroinvertebrates as indicator organisms include:

- Sensitivity to nutrients and metals.
- Sensitivity to physical changes.
- Dependency on stable habitat.
- Limited mobility to avoid sources of pollution.
- Abundance and diversity.
- Vital position in the food chain.
- Short life cycle.

Samples were collected by experienced stream biologists and delivered to the Aquatic Biology Lab, Tennessee Department of Health for sorting and identification. The majority of samples were contracted to the Aquatic Resources Center. Taxa were identified to genus level within a 200 organism subsample.

Macroinvertebrate samples were assessed using the Tennessee Macroinvertebrate Index (TMI) developed for interpretation of narrative biological criteria (Arnwine and Denton 2001). The TMI is a multi-metric index composed of seven biometrics. The index ranges from 0 to 42 with a score of 32 meeting expectations. Scoring criteria are calibrated for 13 bioregions. The individual biometrics measure different aspects of the macroinvertebrate population including richness, community composition, pollution tolerance and habit. Macroinvertebrate results will be presented in Volume 3 of this report series. Designated use assessments are presented in Volume 1.

b. Habitat

Habitat assessments were conducted concurrently with the macroinvertebrate sampling using EPA's Rapid Bioassessment technique (Barbour et al, 1999). This method uses qualitative assessments of ten parameters that varied depending on stream gradient (Table 7). High gradient forms were used in east and middle Tennessee. Low gradient forms were used in west Tennessee.

Table 7: Habitat assessment parameters.

High Gradient Streams	Low Gradient Streams
Epifaunal Substrate/Available Cover	Epifaunal Substrate/Available Cover
Embeddedness	Pool Substrate Characterization
Velocity/Depth Regime	Pool Variability
Sediment Deposition	Sediment Deposition
Channel Flow Status	Channel Flow Status
Channel Alteration	Channel Alteration
Frequency of Riffles or bends	Channel Sinuosity
Bank Stability	Bank Stability
Vegetative Protective Score	Vegetative Protective Score
Riparian Vegetative Zone Width	Riparian Vegetative Zone Width

Assessments were conducted by two experienced stream biologists with scores arbitrated in the field. The entire reach was evaluated for each parameter.

Total habitat scores can range from 0 to 200 and have been calibrated for each bioregion. Total habitat scores and values for each parameter were compared to regional expectations (TDEC, 2006). Habitat results will be presented in Volume 3 of this report series. Designated use assessments are presented in Volume 1.

c. Water Chemistry and Field Measurements

Water chemistry samples were collected seasonally within a two month window at each sample location following TDEC protocols (TDEC, 2004). Samples were analyzed for ammonia (NH_3), nitrate+nitrite (NO_2+NO_3), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), total phosphorus (TP) and total suspended solids (TSS). Samples were delivered to the nearest state environmental laboratory (Knoxville, Nashville or Jackson) for analyses. Dissolved oxygen, conductivity, temperature, pH and flow measurements were made quarterly in conjunction with water chemistry samples.

Summer: July – August 2007
Fall: October – November 2007
Winter: January – February 2008
Spring: April – May 2008

Nitrate+nitrite and total phosphorus data were compared to ecoregional guidelines developed for interpretation of narrative criteria (Denton et al, 2001). Dissolved oxygen, temperature and pH measurements were compared to Tennessee Water Quality Criteria for fish and aquatic life (Tennessee Water Quality Control Board, 2007). Water quality data, as well as statistical interpretation of results will be presented in Volume 4 of this report series. Designated use assessments are presented in Volume 1.

d. Pathogens

Pathogen samples were collected five times within a 30 day period at each sample site following TDEC protocols (TDEC, 2004). The primary window for sample collection was July – October, 2007. A few sites were collected in November due to drought conditions during the summer and early fall. Samples were delivered to the state lab for analyses within six hours of collection. *E coli* were analyzed as an indicator for the presence of pathogens.

The geometric mean, as well as the highest single measurement, were compared to Tennessee Water Quality Criteria for recreation. Pathogen data and statistical interpretation of results will be presented in Volume 5 of this report series. Designated use assessments are presented in Volume 1.

e. Periphyton

The periphyton community is comprised of sessile algae that inhabit the surfaces of underwater rocks and other stable substrates. A periphyton survey was conducted at each site between July and October 2007. Each survey consisted of a field-based rapid survey of periphyton biomass and collection of a multihabitat sample for taxonomic analyses in the lab (Barbour et al, 1999). Both soft algae and diatoms were collected.

Samples were preserved and delivered to the state laboratory. Sample processing and taxonomic analyses were contracted to Dr. Kalina Manoylov with Georgia College and State University. Three hundred algal cell counts were identified to the lowest possible taxonomic level for both soft algae and diatoms.

Water Pollution Control is still in the preliminary stages of developing a regional periphyton index. In the meantime, the diatom bioassessment index from the state of Kentucky (KDEP, 2002) will be used to assess the diatom community. Since an index has not been developed for soft algae, these data will be presented and summarized. Periphyton data and analyses of results will be presented in Volume 6 of this report series.

f. Quality Assurance

Stream surveys and field sampling were conducted in accordance with TDEC Quality System Standard Operating Procedures and Quality Assurance Project Plan (TDEC 2004, 2006 and 2007). Chain of custody was maintained on all samples.

Duplicate samples of macroinvertebrates and periphyton were collected at ten percent of the sites. Duplicate measurements of field parameters and flow were made at a minimum of ten percent of the stations. Duplicate samples and field blanks were collected at ten percent of the chemical and bacteriological collections. Field blanks were collected every tenth trip.

Macroinvertebrate samples processed and identified by the state laboratory and Aquatic Resources Inc. were conducted by experienced taxonomists. The TDEC Quality System Standard Operating Procedure was followed (TDEC, 2006). Ten percent of the samples were re-sorted by a second taxonomist with a target of 90% recovery of organisms. Identification of ten percent of samples was verified by a second taxonomist. All samples met sorting and taxonomic requirements. One hundred percent of data reduction and data entry was verified.

Chemical and bacteriological samples were analyzed by the Tennessee Department of Health environmental laboratory. Minimum detection limits and quality assurance met laboratory standards as approved by EPA. Ten percent of data entry was verified.

Ten percent of periphyton samples analyses were duplicated by an independent contractor. One hundred percent of data entry and data reduction was verified.

Courtney Brame collects a periphyton sample at South Harpeth River in Williamson County (middle division).

Photo provided by Nashville Environmental Field Office

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Jonathon Burr looks conducts a habitat assessment at Fall Creek in Union County (east division). *Photo provided by Knoxville Environmental Field Office.*

APPENDIX A

PROBABILISTIC STUDY SITES

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
BEAGL008.3OV	TNW07657-081	Big Eagle Creek	0.4 mi d/s Monroe Branch Rd	Overton	05130105	3	71g	Middle	Cookeville	-85.25816	36.4614
BEAR002.1WY	TNW07657-199	Bear Creek	100 yds d/s bridge on Staffords Store Rd.	Weakley	08010203	2	65e	West	Jackson	-88.697892	36.102302
BEAVE008.9KN		Beaver Creek	Across bend from ford on Rather Rd	Knox	06010207	3	67f	East	Knoxville	-84.15841	35.97385
BFLAT018.0UN	OWW04440-1006	Big Flat Creek	Hwy 131 just SE of Davis Rd at quarry.	Union	06010104	3	67f	East	Knoxville	-83.72875	36.22177
BIRCH000.6JO	OWWO4440-1412	Birch Branch	In Birch Branch Sanctuary approx. 0.7 mile u/s HWY 133	Johnson	06010102	2	66e	East	Johnson City	-81.869055	36.555368
BIRDS012.3BN	TNW07657-175	Birdsong Creek	400 yds d/s old USGS gaging station end of Billy Malin Rd	Benton	06040005	4	65e	West	Jackson	-88.126225	35.901204
BRUSH01.1LS	TNW07657-031	Brush Creek	Off Springer Church House Rd	Lewis	06040004	1	71f	Middle	Columbia	-87.4767	35.5353
BSPRI003.9CH	TNW07657-015	Blue Spring Creek	Off Bennett Rd (0.2 mi east of Blue Springs Rd).	Cheatham	05130202	2	71f	Middle	Nashville	-86.99175	36.32115
BUNDR000.6WE	TNW07657-076	Bundrant Branch	Off Bundrant Hollow Rd 0.4 mi from Indian Creek Rd	Wayne	0604001	2	71f	Middle	Columbia	-87.87223	35.23977
BYRD001.5HS	TNW07657-030	Byrd Creek	0.5 mile d/s Clinch Valley (East Lee Valley) Rd	Hawkins	06010205	3	67f	East	Johnson City	-83.101288	36.492893
CANDI017.1BR	TNW07657-098	Candies Creek	Off Eveningside drive in Cleveland.	Bradley	06020002	4	67f	East	Chattanooga	-84.894725	35.201631
CANDI033.1BR	TNW07657-034	Candies Creek	0.2 mile upstream Kelly Lane	Bradley	06020002	3	67f	East	Chattanooga	-84.966891	35.078203
CANE001.4SH	TNW07657-196	Cane Creek	U/S Mallory Ave in Pine Hills Municipal Golf Course, Memphis	Shelby	08010211	2	74b	West	Memphis	-90.028979	35.087933

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
CANE004.5VA	TNW07657-117	Cane Creek	Jeep trail off Wheelbarrow Rd near Sweetgum	VanBuren	05130108	4	71h	Middle	Cookeville	-85.406	35.7932
CATHE001.5MY	TNW07657-095	Catheys Creek	Off Booker Farm Rd.	Maury	06040003	4	71h	Middle	Columbia	-87.26633	35.64281
CFORK003.4SR	TNW07657-093	Caney Fork Creek	U/S Butler Bridge Rd in Corinth	Sumner	05110002	3	71g	Middle	Nashville	-86.4167	36.57831
CHISH015.4LW	TNW07657-104	Chisholm Creek	Off West Point Rd.	Lawrence	06030005	3	71f	Middle	Columbia	-87.574999	35.26657
CLEAR001.3GE	OWW04440-0420	Clear Creek	Just upstream I-81 at Jearoldstown	Greene	06010108	3	67f	East	Johnson City	-82.70291	36.35725
CLOVE1T0.5OB	TNW07657-276	Clover Creek tributary	200 yards upstream Clover Creek Rd	Obion	08010202	2	74b/74a	West	Jackson	-89.306272	36.277750
COLD006.3LE	TNW07657-152	Cold Creek	200 yards upstream Jeff Webb Rd.	Lauderdale	08010100	3	74a	West	Jackson	-89.565169	35.832373
CORN002.5JO	TNW07657-067	Corn Creek	0.3 mile u/s hwy 421 near Mtn City.	Johnson	06010103	3	66f	East	Johnson City	-81.850858	36.490415
COSBY012.2CO	OWW04440-0164	Cosby Creek	GSMNP off Cosby Creek Campground Rd, approx 0.5 mi d/s campground.	Cocke	06010106	3	66g	East	Knoxville	-83.21176	35.76356
COVE003.8SR	OWW04440-1134	Cove Creek	Off Hwy 321 0.5 mile u/s Cove Creek Cascades (Bonny Brook B&B).	Sevier	06010107	3	66g	East	Knoxville	-83.622529	35.756537
CROOK005.0MC	TNW07657-252	Crooked Creek	Off Hwy 64 just u/s of Emmons Rd.	McNairy	8010207	2	65e	West	Jackson	-88.526052	35.185199
CYPRE002.1CK	TNW07657-283	Cypress Creek	100 yards d/s Emmerson Rd.	Crockett	8010204	3	74b	West	Jackson	-89.055177	35.815156
CYPRE005.9OB	TNW07657-183	Cypress Creek	300 yards u/s North Herman Carter Rd	Obion	8010202	3	74b	West	Jackson	-88.970482	36.361246
CYPRE023.8MC	TNW07657-016	Cypress Creek	400 yards upstream Limon Gage Rd	McNairy	8010207	3	65e	West	Jackson	-88.581726	35.271332

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
DIXON000.4LW	OWW04440-0142	Dixon Branch	U/S Johnson Lake	Lawrence	06030005	2	71f	Middle	Columbia	-87.41366	35.07039
DRAKE011.8SR	OWW04440-0286	Drake Creek	Off Hwy 258 0.25 mi d/s Latimer Rd at ford.	Sumner	05130201	3	71h	Middle	Nashville	-86.62148	36.38653
EFPOP007.3RO	TNW07657-058	East Fork Poplar Creek	0.4 mile u/s Gum Hollow Rd	Roane	6010207	3	67I	East	Knoxville	-84.322	35.9821
FALL001.5UN	OWW04440-1028	Fall Creek	Hwy 170 and old HWY 33 at Lickskillet.	Union	06010205	3	67f	East	Knoxville	-83.80029	36.2873
FALL003.2HA	TNW07657-046	Fall Creek	Off Fall Creek Rd approx. 0.5 mi d/s Three Springs Rd	Hamblen	06010104	2	67f	East	Knoxville	-83.206001	36.282823
GAMMO000.7SU	OWW04440-0132	Gammon Creek	Off Minga Rd approx. 0.25 mile u/s embayment crossing.	Sullivan	06010102	2	67f	East	Johnson City	-82.42138	36.45862
GAP000.1CT	OWW04440-1476	Gap Creek	In Watauga Point between Hwy 321 and W.G. Street.	Carter	06010103	2	67f	East	Johnson City	-82.268516	36.329873
GRASS005.1GE	TNW07657-062	Grassy Creek	Off Henard (Cox) Rd u/s Grassy Creek crossroad.	Greene	6010108	2	67f	East	Johnson City	-82.930724	36.203883
GREEN016.2WE	TNW07657-012	Green River	112 Green River Rd approx 3 mi south of Waynesboro.	Wayne	06040004	3	71f	East	Columbia	-87.75263	35.26443
HALLS001.7LE	TNW07657-040	Halls Creek	Off Espy Park Rd, 200 ys d/s Lawrence Rd near Halls	Lauderdale	08010205	4	74b	West	Jackson	-89.374177	35.864196
HAWKI002.1CR	TNW07657-091	Hawkins Creek	Just upstream Westport Rd	Carroll	08010203	2	65e	West	Jackson	-88.3582	35.9268
HAYES003.3HR	TNW07657-048	Hayes Branch	400 yds downstream Hwy 64	Hardeman	08010208	2	65e	West	Jackson	-88.879565	35.233594

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
HICKO008.4CA	OWWO4440-1374	Hickory Creek	Off Stinking Creek Rd approx. 0.5 u/s Hwy 25W bridge.	Campbell	05130101	4	69d	East	Knoxville	-84.088862	36.503498
HORSE007.0GE	TNW07657-126	Horse Creek	D/S Horse Creek Recreation Area	Greene	60108006	3	66e	East	Johnson City	-82.65643	36.11197
HROCK002.4CR	TNW07657-323	Hollow Rock Branch	D/S bridge Hollow Rock Branch Lane in Hollow Rock.	Carroll	06040005	2	65e	West	Jackson	-88.280422	36.038374
HURRI007.4HE	OWW04440-0334	Hurricane Creek	Approx 100 yards d/s McBride Cemetary Rd	Henderson	06040001	2	65e	West	Jackson	-88.3222	35.43981
HYDE002.7LE	TNW07657-308	Hyde Creek	D/S RR tracks and impoundmnent in Ripley.	Lauderdale	08010208	3	74b	West	Jackson	-89.5444	35.7235
INDIA003.7GR	TNW07657-110	Indian Creek	Off Indian Creek Rd, approx 1 mi u/s Joe Mill Creek	Grainger	60100205	3	67f	East	Knoxville	-83.40339	36.39519
KERR000.4HD	OWW04440-0910	Kerr Branch	Off Wildflower Lane, approx. 100 yards d/s HWY 226	Hardin	6040001	2	65j	West	Jackson	-88.20614	35.20273
LAURE002.5GY	OWW04440-0886	Laurel Creek	Hunters Mill Rd at Shady Grove Nursery	Grundy	05130108	1	68a	East	Chattanooga	-85.67326	35.45178
LAURE006.3JO	TNW07657-131	Laurel Creek	Off Hwy 91 approx. 0.4 mi d/s Owens Br near VA/TN line	Johnson	06010102	4	66e (drains 66f)	East	Johnson City	-81.75358	36.61095
LBART006.5DI	TNW07657-079	Little Bartons Creek	Off Little Bartons Ck Rd. near Dickson-Montgomery Co Line	Dickson	05130205	3	71f	Middle	Nashville	-87.3775	36.32072
LONG004.9MA	TNW07657-045	Long Fork	U/S Galen Rd (Hwy 261)	Macon	05110002	4	71g	Middle	Cookeville	-85.92298	36.5988
MIDDL001.2SV	OWW04440-0238	Middle Creek	Just u/s bridge crossing on Burden Hill Rd	Sevier	06010107	2	67g	East	Knoxville	-83.55145	35.8579

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
MILLE007.3RN	OWW04440-0846	Millers Creek	Off Henry Grove Rd (field behind 2571)	Robertson	05130206	2	71e	Middle	Nashville	-87.00219	36.43528
NFFDE1T1.5HE	TNW07657-075	North Fork Forked Deer Tributary	200 yds upstream McCaney Mill Rd	Henderson	08010205	2	65e	West	Jackson	-88.497718	35.641134
NFLICK002.0PE	TNW07657-063	North Fork Lick Creek	Off Stickland (North Fork) Rd approx. 1.6 miles from Lick Creek (Linden-Pineview) Rd.	Perry	06040001	4	71f	Middle	Columbia	-87.886	35.6789
NREEL000.4OB	TNW07657-200	North Reelfoot Creek	Off Bob McCann Rd 0.8 mile u/s USGS gauging station at Hwy 22.	Obion	08010202	3	74a	West	Jackson	-89.283069	36.446742
OTOWN008.9CL	OWW04440-0516	Old Town Creek	End of Colm Rd.	Claiborne	06010206	2	69d	East	Knoxville	-83.76789	36.54249
OWL003.7HD	TNW07657-188	Owl Creek	0.5 mile d/s Hwy 142.	Hardin	06040001	4	65e	West	Jackson	-88.360956	35.148435
POND013.8CK	TNW07657-099	Pond Creek	100 yards d/s Old Mounds Rd	Crockett	08010204	3	74b	West	Jackson	-89.237133	35.865760
POPLA000.1MG	OWW04440-0750	Poplar Creek	60 yds u/s ford on Big Mtn Hollow Rd	Morgan	06010207	2	69d	East	Knoxville	-84.37868	36.06558
POPLA014.7HY	TNW07657-256	Poplar Creek	200 yards u/s Dancyville-Eukaton Road	Haywood	06010020	3	74b	West	Jackson	-89.2459	35.4191
PRUN000.1GS	TNW07657-082	Pleasant Run Creek	D/S Hwy 31	Giles	06030004	2	71h	Middle	Columbia	-87.03429	35.18977
RIPLE001.5GE	OWW04440-0612	Ripley Creek	Ripley Island Rd adjacent to Twin Creeks Golf Course.	Greene	06010108	3	67f	East	Johnson City	-82.71205	36.1998
ROBIN000.6FR	TNW07657-066	Robinson Creek	Ford off Hill Medley LN (off Robinson Creek Rd)	Franklin	06030003	3	71h	Middle	Columbia	-86.27853	35.08427

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
ROSE001.3MC	TNW07657-280	Rose Creek	400 yards d/s HWY 64 u/s Keith Branch	McNairy	08010207	3	65e	West	Jackson	-88.7102	35.2054
RUTHE007.4MY	TNW07657-137	Rutherford Creek	Near junction Double Branch Rd and Hwy 31	Maury	06040003	4	71h	Middle	Columbia	-86.998418	35.672127
SCAMP008.3SR	TNW07657-029	Station Camp Creek	U/S Liberty Rd Bridge	Sumner	05130201	4	71h	Middle	Nashville	-86.55863	36.39175
SCOTT000.9DA	TNW07657-089	Scotts Creek	Hwy 70 and Tulip Grove Rd in Nashville	Davidson	05130203	2	71h	Middle	Nashville	-86.58972	36.2143
SEQUA101.2BL	TNW07657-005	Sequatchie River	300 yds u/s driveway @ 12943 Upper East Valley Rd (0.5 mi d/s Lowes Gap Mtn Rd)	Bledsoe	06020004	4	68b	East	Chattanooga	-85.034733	35.733589
SFCUB009.5DE	TNW07657-295	Sulphur Fork Cub Creek	Off Sulpher Spring (Adrienne Wallace) Rd approx. 0.5 miles u/s Sulphur Spring	Decatur	06040001	3	65e	West	Jackson	-88.165402	35.703482
SFFDE1T0.7MN	TNW07657-144	South Fork Forked Deer tributary	U/S Perry Switch Rd.	Madison	08010205	2	65e	West	Jackson	-88.753529	35.560731
SFMUD003.8MC		South Fork Mud Creek	400 yds downstream HWY 22.	McNairy	06040001	2	65e	West	Jackson	-88.3872	35.288
SHARP014.4WI	TNW07657-059	South Harpeth River	U/S confluence with Caney Fork Creek	Williamson	05130204	4	71f	Middle	Nashville	-87.08038	35.94889
SINKI003.0CO	OWW04440-0292	Sinking creek	70W near 5 Rivers Plaza in Newport	Cocke	06010106	3	67g	East	Knoxville	-83.20963	35.97017
SMITH003.5HD	TNW07657-204	Smith Fork	Off Smith Fork Rd d/s ford approx. 2 miles d/s Hwy 64.	Hardin	06040001	3	65j	West	Jackson	-88.088686	35.272589
SPRIN009.0WS	TNW07657-077	Srping Creek	0.5 mile d/s Hwy 141	Wilson	05130201	3	71i	Middle	Nashville	-86.24856	36.2558
STOKE004.9CK	TNW07657-227	Stokes Creek	Just u/s Elizabeth Road.	Crockett	08010204	3	74b	West	Jackson	-89.20155	35.96116

Table A-1: Location of Study Sites.

TN Station ID	EPA ID	Stream	Location	County	HUC	Order	ECO	Division	EFO	LONG	LAT
SULPH036.0RN	TNW07657-157	Suphur Fork Red River	4-wheel drive trail behind barn at 4316 Armstrong east of Springfield	Robertson	05130206	3	71e	Middle	Nashville	-86.80929	36.50636
TAR003.0CS	TNW07657-328	Tar Creek	U/S Braund (Brunz) Rd	Chester	08010205	3	65e	West	Jackson	-88.566176	35.384102
TELLI040.5MO	TNW07657-138	Tellico River	Off River Rd just u/s Buckhorn Creek	Monroe	60100204	4	66g	East	Knoxville	-84.155916	35.328391
THOMP000.2WY	TNW07657-007	Thompson Creek	0.3 mile d/s bridge on Thompson Creek Rd (Jeans Rd)	Weakley	08010203	3	65e	West	Jackson	-88.613667	36.264116
TISDA1T1.2LE	TNW07657-088	Tisdale Creek tributary	Off John White Rd 300 yds d/s Curve-Concord Rd.	Lauderdale	08010205	2	74b	West	Jackson	-89.436158	35.801288
TITUS1T0.1CA	OWW04440-0862	Titus Creek Trib	Royal Blue Wildlife Management Area	Campbell	06010205	1	69d	East	Knoxville	-84.25564	36.3755
TOWEE005.9PO	OWWO4440-1486	Towee Creek	Off Fingerboard Rd	Polk	06020002	3	66g	East	Chattanooga	-84.427915	35.219717
TRACE003.6CY	TNW07657-145	Trace Creek	Off Trace Creek Rd approx. 0.5 mile u/s Hermitage Springs	Clay	05110002	3	71g	Middle	Cookeville	-85.782	36.566950
TUMBL003.8HU	TNW07657-107	Tumbling Creek	Tumbling Creek Rd just east of Wills Ln	Humphreys	06040003	4	71f	Middle	Nashville	-87.7017	35.95078
WATSO002.3WI	OWWO4440-1358	Watson Branch	Off South Courthers in Franklin	Williamson	05130204	3	71h	Middle	Nashville	-86.822236	35.90802
WELLS007.6HO	OWW04440-0078	Wells Creek	Just D/S of Hwy 49 bridge at first island.	Houston	05130205	3	71f	Middle	Nashville	-87.6749	36.31962
WFHICK007.0CE	TNW07657-121	West Fork Hickory Creek	Off Tic Tac Mill Rd 0.4 mi d/s Bryan Mill	Coffee	05130107	3	71g	Middle	Cookeville	-85.938501	35.570990
WFRED010.7MT	TNW07657-004	West Fork Red River	Off Boy Scout Rd in Billy Dunlop Park	Montgomery	05130206	3	71e	Middle	Nashville	-87.36663	36.60839
WHITE013.5HU	TNW07657-043	Whiteoak Creek	U/S bridge on Tennessee Ridge Rd.	Humphreys	06040005	4	71f	Middle	Nashville	-87.76439	36.2266

APPENDIX B

LAND USE UPSTREAM OF PROBABILISTIC MONITORING SITES

Table B-1: Land use in drainage area upstream of Probabilistic Monitoring Stations. Based on GIS 2001 National Land Cover Data.

STATION ID	Drainage sq mi	% Barren	% Crops	% Forest	% Developed	% Wetland	% Pasture	% Open Water	% Scrub	% Undefined	Total
BEAGL008.3OV	17.7	0.1	21.1	54.2	9.4	0	15.0	0	0.1	0	99.9
BEAR002.1WY	8.1	0	39.2	33.3	5.5	4.9	16.3	0.1	0.6	0	99.9
BEAVE008.9KN	83.8	0.5	0.3	26.7	41.7	0.9	29.9	0	0	0	100
BFLAT018.0UN	15.3	1.1	0	54.7	6.8	0	37.3	0.1	0	0	100
BIRCH000.6JO	1.9	0	0	99.7	0	0	0.1	0	0.1	0	99.9
BIRDS012.3BN	45.7	0.4	9.8	77.6	2.4	0.6	8.4	0.1	0.7	0	100
BRUSH001.1LS	0.6	0	0	83.4	3.2	0	11.2	0	2.0	0	99.8
BSPRI003.9CH	2.0	0	4.3	48.6	5.9	0	40.7	0.4	0.1	0	100
BUNDR000.6WE	2.6	0	0.1	89.0	0.7	0	7.9	0	2.2	0	99.9
BYRD001.5HS	4.2	0.4	0	68.5	5	0	26.0	0	0	0	99.9
CANDI017.1BR	67.1	0	2.4	53.8	13.8	0.3	25.3	0.2	4.3	0	100.1
CANDI033.1BR	8.8	0	3.1	55.9	3.3	0.1	30.7	0.2	6.5	0	99.8
CANE001.4SH	4.5	0	0.7	1.2	97.2	0.2	0.5	0	0.2	0	100
CANE004.5VA	159.2	0.5	1.1	76.4	3.3	0.3	14.8	0.4	3.2	0	100
CATHE001.5MY	46.1	0	2.2	65.6	3.0	0.1	27.7	0	1.0	0.2	99.8
CFORK003.4SR	13.4	0	4.7	43.4	6.2	0	45.4	0.1	0.2	0	100
CHISH015.4LW	9.4	3.8	53.9	1.2	4.4	0	34.6	0	2.1	0	100
CLEAR001.3GE	13.6	0	4.6	27.5	5.7	0	61.8	0	0.3	0	99.9
CLOVE1T0.5OB	1.4	0	11.0	37.2	3.5	4.2	43	0	1.1	0	100
COLD006.3LE	9.6	0	30.6	44.3	4.2	1.8	18.7	0.1	0.2	0	99.9
CORN002.5JO	1.0	0	0	96.9	1.5	0	1.4	0	0.2	0	100
COSBY012.2CO	6.8	0	0	99.9	0.1	0	0	0	0	0	100
COVE003.8SV	15.8	0	0.4	65.2	8.4	0.4	24.8	0	0.7	0	99.9
CROOK005.0MC	2.6	0	9.3	65.6	7.5	0.8	5.9	1.8	9.0	0	99.9
CYPRE002.1CK	35.2	0	70.8	8.9	9.0	2.9	8.0	0.2	0.1	0	99.9
CYPRE005.9OB	17	0	73.1	4.8	9.7	8.4	3.9	0.1	0.1	0	100.1
CYPRE023.8MC	9.5	0	9.5	58.2	4.1	2.9	4.8	1.8	18.7	0	100
DIXON000.4LW	5.4	0	4.9	36.8	8.9	0.2	42.9	0.1	6.2	0	100

Table B-1 cont.:

STATION ID	Drainage sq mi	% Barren	% Crops	% Forest	% Developed	% Wetland	% Pasture	% Open Water	% Scrub	% Undefined	Total
DRAKE011.8SR	16.7	0	0.3	82.1	3.5	0	13.8	0	0	0	99.7
EFPOP007.3RO	11.5	0.1	0.2	34.1	59.0	2.1	4.3	0.1	0	0	99.9
FALL001.5UN	3.7	0.4	0	63.5	8.6	0.1	27.2	0	0	0	99.8
FALL003.2HA	6.7	0	0.8	25.6	20.8	0.1	51.3	0	1.3	0	99.9
GAMMO000.7SU	2.2	0	1.2	15.7	25.3	0	57.6	0	0.2	0	100
GAP000.1CT	11.2	0.2	0.2	69.9	6.9	0	22.3	0	0.5	0	100
GRASS005.1GE	1.5	0	2.2	13.6	6.6	0	77.2	0	0.4	0	100
GREEN016.2WE	7.0	0.3	1.7	56.0	5.4	0.1	27.1	0.1	9.4	0	100.1
HALLS001.7LE	28.4	0	61.0	15.6	7.8	3.5	11.9	0.3	0	0	100.1
HAWKI002.1CR	2.7	0	17.8	69.3	4.0	0.8	6.2	0.2	1.8	0	100.1
HAYES003.3HR	2.3	0	4.0	61.3	4.3	1.1	10.5	0.3	18.6	0	100.1
HICKO008.4CA	69.4	0.3	0	87.8	3.8	0.1	7.8	0.1	0.1	0	100
HORSE007.0GE	5.5	0	0	97.8	0.4	0	0	1.8	0		100
HROCK002.4CR	3.9	0	23.2	50.7	8.0	0.4	16.7	0	0.9	0	99.9
HURRI007.4HE	1.5	0	13.1	57.9	1.6	1.2	17.0	0	9.2	0	100
HYDE002.7LE	5.6	0	58.7	11.7	8.3	1.8	11.6	0.7	7.2	0	100
INDIA003.7GR	15.7	0.4	0	69.4	5.4	0.1	24.7	0	0	0	100
KERR000.4HD	0.6	0	11.0	50.1	11.5	1.3	11.4	0.6	14.1	0	100
LAURE002.5GY	0.2	0	8.1	38.0	7.2	0	45.1	0	1.7	0	100.1
LAURE006.3JO	38.9	0	0.1	82.0	3.6	0	13.5	0	0.8	0	100
LBART006.5DI	15.8	0	1.5	68.4	3.3	0	26.7	0	0	0	99.9
LONG004.9MA	29.0	0	4.3	61.5	4.6	0	29.4	0	0	0	99.8
MIDDL001.2SV	14.5	0.1	0.3	55.5	13.7	0.1	29.1	0	1.3	0	100.1
MILLE007.3RN	1.5	0	1.8	59.8	5.7	0	32.7	0	0	0	100
NFFDE1T1.5HE	3.0	0	15.4	43.0	4.0	0.1	36.6	0.1	0.8	0	100
NFLIC002.0PE	5.6	0	2.8	93.7	1.0	0	2.4	0	0.1	0	100
NREEL000.4OB	62.4	0	58.9	16.7	5.4	0.1	11.6	0.8	0.3	6.2	100
OTOWN008.9CL	1.0	0.4	0	80.1	5.6	0	13.8	0	0.2	0	100.1

Table B-1 cont.:

STATION ID	Drainage sq mi	% Barren	% Crops	% Forest	% Developed	% Wetland	% Pasture	% Open Water	% Scrub	% Undefined	Total
OWL003.7HD	34.2	0	18.0	39.8	4.7	5.8	17.4	0.3	14.1	0	100.1
POND013.8CK	22.8	0	83.6	1.7	9.2	3.3	2.1	0.1	0	0	100
POPLA000.1MG	0.9	0	0	89.7	8.8	0	0.5	0	1	0	100
POPLA014.7HY	11.4	0	50.9	20.0	4.6	2.8	10.9	0.6	10.1	0	99.9
PRUN000.1GS	1.5	0	0.1	33.0	58.5	0	7.3	0.3	0.8	0	100
RIPLE001.5GE	2.8	0	0.7	26.2	14.1	0	58.9	0	0.1	0	100
ROBIN000.6FR	14.8	0	30.3	21.1	5.3	3.6	36.9	0.7	2.0	0	99.9
ROSE001.3MC	20.8	0	8.9	58.4	6.1	5.8	7.0	0.5	13.3	0	100
RUTHE007.4MY	73.2	0.2	6.7	31.1	12.1	0.1	47.7	0.2	1.7	0	99.8
SCAMP008.3SR	30.8	0	0.8	67.7	3.8	0	27.7	0.1	0	0	100.1
SCOTT000.9DA	1.2	0	0.4	18.2	69.5	0	10.0	0	1.9	0	100
SEQUA101.2BL	20.4	0.2	0	69.6	5.0	0.7	22.0	0	2.5	0	100
SFCUB009.5DE	16.4	0	12.7	77.8	2.4	0.5	5.9	0.2	0.6	0	100.1
SFFDE1T0.7MN	0.7	0	17.1	57.8	4	2.3	3.8	1.9	13.0	0	99.9
SFMUD003.8MC	4.4	0	12.7	65.5	3.7	0	7.1	0.1	9.4	1.4	99.9
SHARP014.4WI	27.4	0	0.6	80.4	1.7	0	17.2	0	0	0	99.9
SINKI003.0CO	11.2	0.2	0	73.9	14.2	0.1	10.8	0	0.8	0	100
SMITH003.5HD	13.2	0.1	3.2	68.9	2.4	0.4	14.0	0.1	10.9	0	100
SPRIN009.0WS	49.7	0	3.6	32.1	5.6	0.3	55.0	0.1	3.3	0	100
STOKE004.9CK	11.7	0	89.1	1.3	5.8	3.2	0.6	0	0	0	100
SULPH036.0RN	44.9	0	2.7	43.2	9.1	0	44.8	0.2	0	0	100
TAR003.0CS	14.5	0	11.1	58.0	5.0	3.8	6.2	0.2	15.6	0	99.9
TELLI040.5MO	49.2	0	0	98.5	1.0	0	0	0	0.4	0	99.9
THOMP000.2WY	29.1	0	28.6	49.5	4.8	4.1	10.7	1.6	0.7	0	100
TISDA1T1.2LE	0.9	0	38.4	19.6	7.0	0.8	33.9	0.2	0.2	0	100.1
TITUS1T0.1CA	0.1	0	0	92.6	2.7	0	4.7	0	0	0	100
TOWEE005.9PO	8.7	0	0	93.8	3.0	0	2.2	0	0.7	0	99.7
TRACE003.5CY	12.0	0	4.0	58.7	4.2	0	32.5	0	0.5	0	99.9

Table B-1 cont.:

STATION ID	Drainage sq mi	% Barren	% Crops	% Forest	% Developed	% Wetland	% Pasture	% Open Water	% Scrub	% Undefined	Total
TUMBL003.8HU	43.5	0	0.7	85.2	1.6	0	12.4	0	0	0	99.9
WATSO002.3WI	3.0	0.1	3.0	21.9	27.2	0	42.8	0	4.8	0	99.8
WELLS007.6HO	20.0	0	1.3	84.4	2.8	0	11.2	0	0.2	0	99.9
WFHIC007.0CE	22.0	0	13.3	19.6	8.7	3.4	51.1	0.1	3.6	0	99.8
WFRED010.7MT	115.2	0.1	56.5	18.4	6.6	0.2	17.5	0.5	0	0	99.8
WHITE013.5HU	48.6	0	0.8	80.8	2.9	0	15.3	0	0.1	0	99.9