PROBABILISTIC MONITORING IN THE INNER NASHVILLE BASIN WITH EMPHASIS ON NUTRIENT AND MACROINVERTEBRATE RELATIONSHIPS

Tennessee Department of Environment and Conservation
Division of Water Pollution Control
7th Floor L&C Annex
401 Church Street
Nashville, TN 37243-1534

PROBABILISTIC MONITORING IN THE INNER NASHVILLE BASIN WITH EMPHASIS ON NUTRIENT AND MACROINVERTEBRATE RELATIONSHIPS

by

Deborah H. Arnwine

Kimberly J. Sparks

Gregory M. Denton

December 2003

Tennessee Department of Environment and Conservation
Division of Water Pollution Control
7th Floor L&C Annex
401 Church Street
Nashville, TN 37243-1534

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

TABLE OF CONTENTS

PAGE

LIST OF FIGURES

ACKNOWLEDGMENTS

This document was prepared by the Planning and Standards Section of the Division of Water Pollution Control. This study was partially funded by a federal 104(b) (3) grant administered by EPA. This document was prepared in partial fulfillment of the requirement of that grant.

The Aquatic Biology Staff of the Department of Health Environmental Laboratories performed all monitoring and sample collections for this study. The manager of that office is David Stucki.

The Water Pollution Control staff of TDEC's Nashville Environmental Assistance Centers (EAC) staff collected the majority of data used in development of regional guidelines for the Inner Nashville Basin. The WPC manager of the Nashville EAC is Joe Holland.

Ann Hoos, Hydrologist with the Water Resources Division of the United States Geological Survey (USGS) reviewed the section on relationships between nutrient levels and macroinvertebrate populations and provided many insightful comments and recommendations.

EXECUTIVE SUMMARY

The Inner Nashville Basin (71i) is one of five ecological subregions in the Interior Plateau. All or part of nine middle Tennessee counties are in the subregion, which represents four percent of Tennessee and does not extend into any other state. Portions of six major watersheds are included in the subregion: Upper Duck River, Lower Duck River, Stones River, Old Hickory and Cheatham Reservoirs on the Cumberland River and the Harpeth River.

In 2000, Tennessee was awarded federal 104(b)(3) grant funding to conduct a probabilistic monitoring study of water quality in this subregion. Monitoring was conducted seasonally for one year and results were published in March 2002 (Arnwine and Denton, 2002). The preliminary study indicated the possibility of a direct correlation between nutrient levels and the health of the macroinvertebrate community. The study was extended through June 2002 to further explore this relationship.

The project was designed to test the general feasibility of the probabilistic monitoring approach. Additionally, data were specifically analyzed to meet the following objectives:

1. Characterize water quality at each probabilistic monitoring station.

2. Extrapolate probabilistic data to the entire subecoregion, providing data for the development of the statewide assessment report.

3. Determine if a direct correlation between macroinvertebrate populations and nutrient levels can be measured in this subregion.

4. Compare water quality assessment information extrapolated from probabilistic sampling to historical assessments within 71i to provide a sense of the accuracy of historical targeted monitoring efforts.

5. Determine if the probabilistic sampling would identify additional and perhaps superior reference steams in ecoregion 71i.

6. Develop assessment methodologies to help distinguish naturally occurring environmental stresses in the Inner Nashville Basin from those caused by pollutants, land use and/or outside factors.

To accomplish these goals, 50 probabilistic monitoring sites were randomly selected on streams in the Inner Nashville Basin. Chemical, bacteriological and macroinvertebrate samples were collected seasonally between January 2000 and June 2001. Habitat assessments, flow readings, canopy estimates and geomorphologic analyses were performed in the field during sample collection.

The first objective of the study was to characterize water quality at each station. Fifty-four percent of the sites were assessed as impaired. This information was included in the 2002 305(b) report and the proposed final 2002 303(d) list. Despite the increased urbanization of this subregion, the majority of impaired sites (77%) were impacted, at least in part, by agriculture activities, specifically grazing, livestock access and riparian removal. Siltation was the primary cause of pollution affecting 68% of the impaired sites. Elevated pathogens, habitat loss and nutrients were also significant pollutants in this subregion.

A second objective of the study was to extrapolate data to the entire subregion. Based on the 2002 303(d) report, 31 segments were assessed as impaired. These segments represent 57% of the assessed miles in the subregion. Three additional sites failed to meet biological guidelines but were not part of this assessment cycle. The addition of these segments would raise overall stream impairment to 64% in the Inner Nashville Basin.

Another objective of the study was to compare water quality assessment information extrapolated from the probabilistic sampling to historic assessments within 71i. Based on probabilistic data alone, 43% of the sampled stream segments were assessed as fully supporting. Historic targeted monitoring assessed 64% of the streams as fully supporting. A combination of both probabilistic and targeted monitoring data was used to determine use support for streams in the Inner Nashville Basin.

When both data were combined, 57% of the stream miles in this subregion were assessed as fully supporting. Assessments that combined both types of data provided the most extensive and accurate evaluation of the streams in this subregion. A large portion of the streams in the Inner Nashville Basin, approximately 70%, has been assessed through these efforts.

The fourth objective of the study (and the basis for the 2002 grant extension) was to determine the relationship between the biological community and nutrient levels. Based on multiple regression analyses, a relationship was identified between percent canopy cover, nitrate+nitrite, total phosphorus and macroinvertebrate populations. Data showed that the absence of canopy played a significant role in the response of macroinvertebrates to elevated nutrient levels in the Inner Nashville Basin. This is most apparent in the fall when flows are down and temperatures are up providing an environment conducive to algal growth.

Another objective of the study was to determine if the ecoregion reference streams in the Inner Nashville Basin were appropriately selected. It was especially difficult to locate acceptable reference streams in this region during the ecoregion project. Only three streams were selected for monitoring. Of these, one was subsequently degraded by highway construction and dropped for reference consideration. This left two streams, with observable agricultural impacts, to define reference condition for this stressed subregion. Four additional reference quality streams were identified during the probabilistic monitoring study and added to the reference database.

The final objective of this project was to develop assessment methodologies to distinguish naturally occurring environmental stresses in the Inner Nashville Basin. The methodologies developed for the ecoregion reference project and used in biocriteria development proved suitable for this purpose. This method has been included in the Division's Quality Systems Standard Operating Procedure published in March 2002. Based on data analyses, it appears that assessments conducted in the late winter through early summer period (February through June) provide the most accurate picture of the benthic population health.

Good quality streams, such as Cedar Creek in Wilson County were located during the probabilistic monitoring project. Data from these sites were included in the ecoregion reference database to use in setting guidelines for similar size streams in the Inner Nashville Basin. *Photo provided by Aquatic Biology Section, TDH.*

1. INTRODUCTION

In 2000, Tennessee was awarded federal 104(b)(3) grant funding to conduct a probabilistic monitoring study of water quality in ecological subregion 71i (Inner Nashville Basin). Monitoring was conducted seasonally for one year and initial results were published in March 2002 (Arnwine and Denton, 2002). The preliminary study indicated the possibility of a direct correlation between nutrient levels and the health of the macroinvertebrate community. A special nutrient criteria development grant was obtained in 2001 and the study was extended through June 2002 to further explore this relationship.

The project was designed to meet the following objectives:

1. Characterize water quality at each of the probabilistic monitoring stations. Document violations of water quality standards and determine the degree of support of designated uses. Determine likely sources of pollutants in impacted streams.

2. Extrapolate probabilistic data to the entire subecoregion, providing data for the development of the statewide assessment report. (However, it should be noted that extrapolated data were not used for 303(d) listing purposes, except for the specific sites monitored.)

3. Compare water quality assessment information extrapolated from probabilistic sampling to historical assessments within 71i to provide a sense of the accuracy of historical targeted monitoring efforts.

4. Determine if a direct correlation between macroinvertebrate populations and nutrient levels can be measured in this subregion.

5. Determine if the division's reference streams in ecoregion 71i were appropriately selected. If superior sites were identified through random sampling, the data from those sites would augment or replace existing sites in the ecoregion reference database.

6. Develop assessment methodologies to distinguish naturally occurring environmental stresses in the Inner Nashville Basin from those caused by pollutants, land use and/or outside factors.

2. CHARACTERIZATION OF THE INNER NASHVILLE BASIN

2.0 Watersheds in the Inner Nashville Basin

The Inner Nashville Basin (71i) is one of five ecological subregions in the Interior Plateau. The subregion includes all or part of nine counties in middle Tennessee and does not extend into any other state. The Inner Nashville Basin represents four percent (1670 square miles) of the state (Griffith et al, 1997). The terrain is less hilly and lower in elevation than the Outer Nashville Basin, ecological subregion 71h, which completely surrounds it. Soils are shallow, usually a few inches deep, and overlay limestone rock.

As illustrated in Figure 1, there are portions of six major watersheds draining the subregion: Upper Duck River (TN06040002), Lower Duck River (TN06040003), Stones River (TN05130203), Old Hickory (TN05130201) and Cheatham (TN05130202) Reservoirs on the Cumberland River and the Harpeth River (TN05130204). The Stones River has the largest number of river miles in this subregion, 768 miles representing 83% of the watershed's drainage. The Upper Duck has a similar number of stream miles in 71i, 690 miles, but this represents only 43% of the total stream miles in this larger watershed. The Old Hickory watershed has approximately half as many river miles in the subregion (280 miles). Comparatively, few river miles in the Inner Nashville Basin are in the Harpeth (92 miles), Cheatham (30 miles) and Lower Duck (24 miles) drainages.

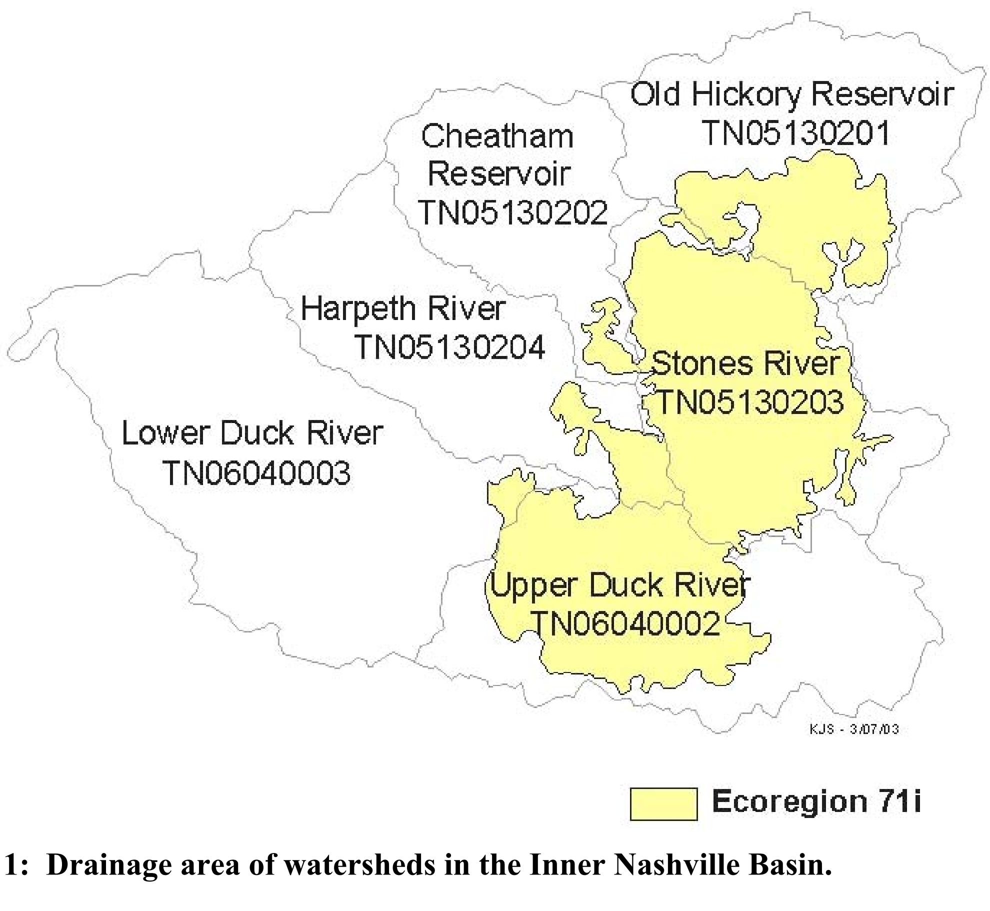


Figure 1: Drainage area of watersheds in the Inner Nashville Basin.

Streams in the Inner Nashville Basin are typically low gradient with elevations ranging from 480 to 785 feet. The majority of streams flow over large expanses of bedrock. Many streams are dry, reduced to isolated pools or are subterranean during the late summer and fall.

Alexander Creek with normal spring flow, April 2000.

Photo by Kim Sparks, WPC, TDEC.

Alexander Creek at the same location 6 months later in October 2000.

Photo by Pat Alicea, Aquatic Biology, TDH.

2.1 Land use in the Inner Nashville Basin

The land in this subregion has long been used for agriculture. Cattle pasture and hay are most common, with small areas of row crops. Due to the generally shallow soils, productive cropland is generally in small tracts on terraces or narrow bottoms. Many streams run through pasture. Stream banks are often cleared of riparian with cattle having full access to the water. Satellite imagery from 1992 (most recent available) shows 55% of the land cleared for agriculture with 44% undeveloped (Figure 2). Less than two percent of the land use was non-agricultural development (labeled as urban).

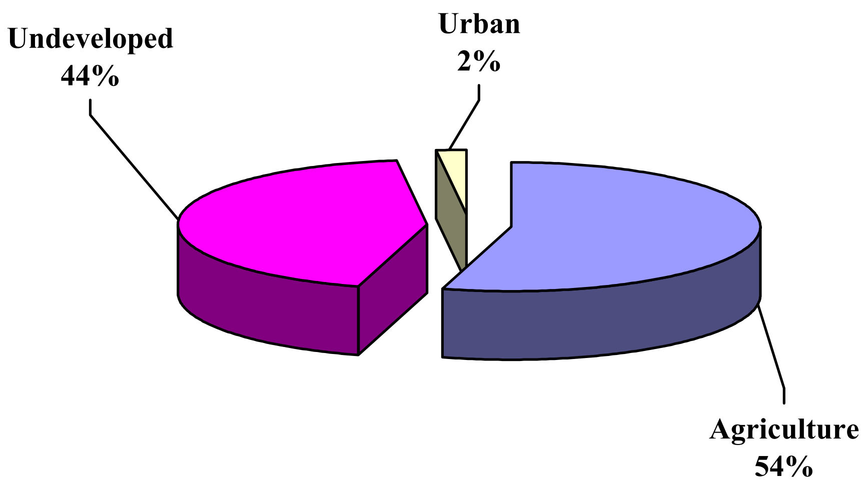


Figure 2: Distribution of land use in 1992 upstream of 50 probabilistic monitoring sites in the Inner Nashville Basin. Land use based on satellite imagery. All non-agricultural development including residential and industrial are grouped as urban.

The land use upstream of the probabilistic sites was similar to that of the Inner Nashville Basin as a whole. Undeveloped land in the entire subregion was slightly lower (36%) with 61% of the land used for agriculture and 3% urban.

Recently, this region has seen rapid population growth with increasing demands on the land for development. Census bureau statistics show a 20% increase in population across the nine counties included in this subregion between 1990 and 2000. This is higher than the overall population growth in the state (17%) or nation (13%). The fastest population growth was seen in Rutherford (54%) and Williamson (56%) counties. This accelerated growth has the potential to adversely affect streams as more land is developed to handle the burgeoning population.

Based on field observations of the upstream watersheds of the same 50 sites conducted in 2000 and 2001, much of the undeveloped land has disappeared in the last eight years with urban uses increasing faster than agriculture (Figure 3). Although field observations are not directly comparable to satellite imagery, rough estimates based on broad categories of urban, agriculture and undeveloped can be made with some confidence. Urban includes all non-agricultural development such as cities, residential, industrial, and commercial. Undeveloped includes forest, scrub, wetlands and transitional areas. Agriculture includes pasture, livestock operations and croplands.

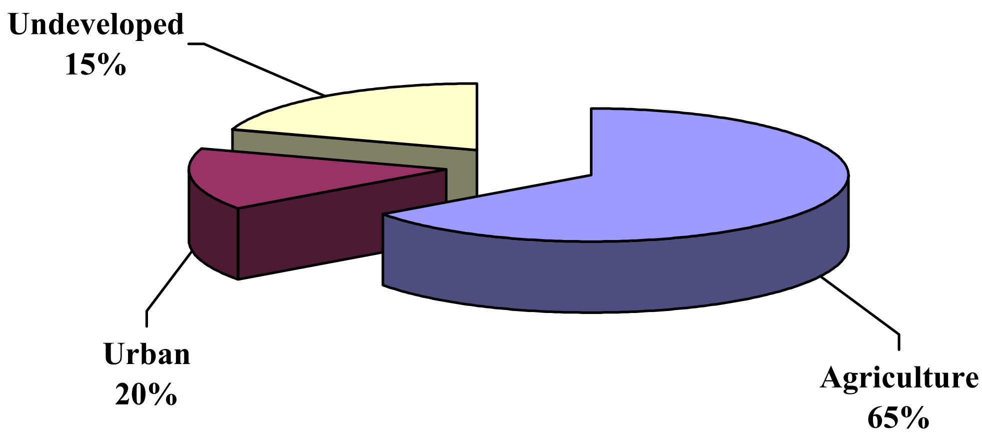


Figure 3: Distribution of land use in 2000 at 50 probabilistic monitoring sites in the Inner Nashville Basin. Land use based on field observations of watershed upstream of sites.

3. DATA COLLECTION

3.0 Site Selection

The 50 probabilistic monitoring sites included in this study were randomly selected in December 1999 and January 2000 from 1,675 potential sampling locations. The site selection process is detailed in the March 2002 report. The sites represent all six of the major watersheds draining the Inner Nashville Basin (Figure 4)

Upper Duck River (TN0604002):	19 stations
Stones River (TN05130203):	17 stations
Old Hickory Reservoir (TN05130201)	10 stations
Cheatham Reservoir (TN0513202)	2 stations
Lower Duck River (TN06040003)	1 station
Harpeth River (TN05130204)	1 station

Concurrent with the 50 randomly selected test sites, two established ecoregion reference sites were also sampled. The ecoregion reference sites are in the Stones and Upper Duck River drainages. A site list including location information is provided in Appendix A.

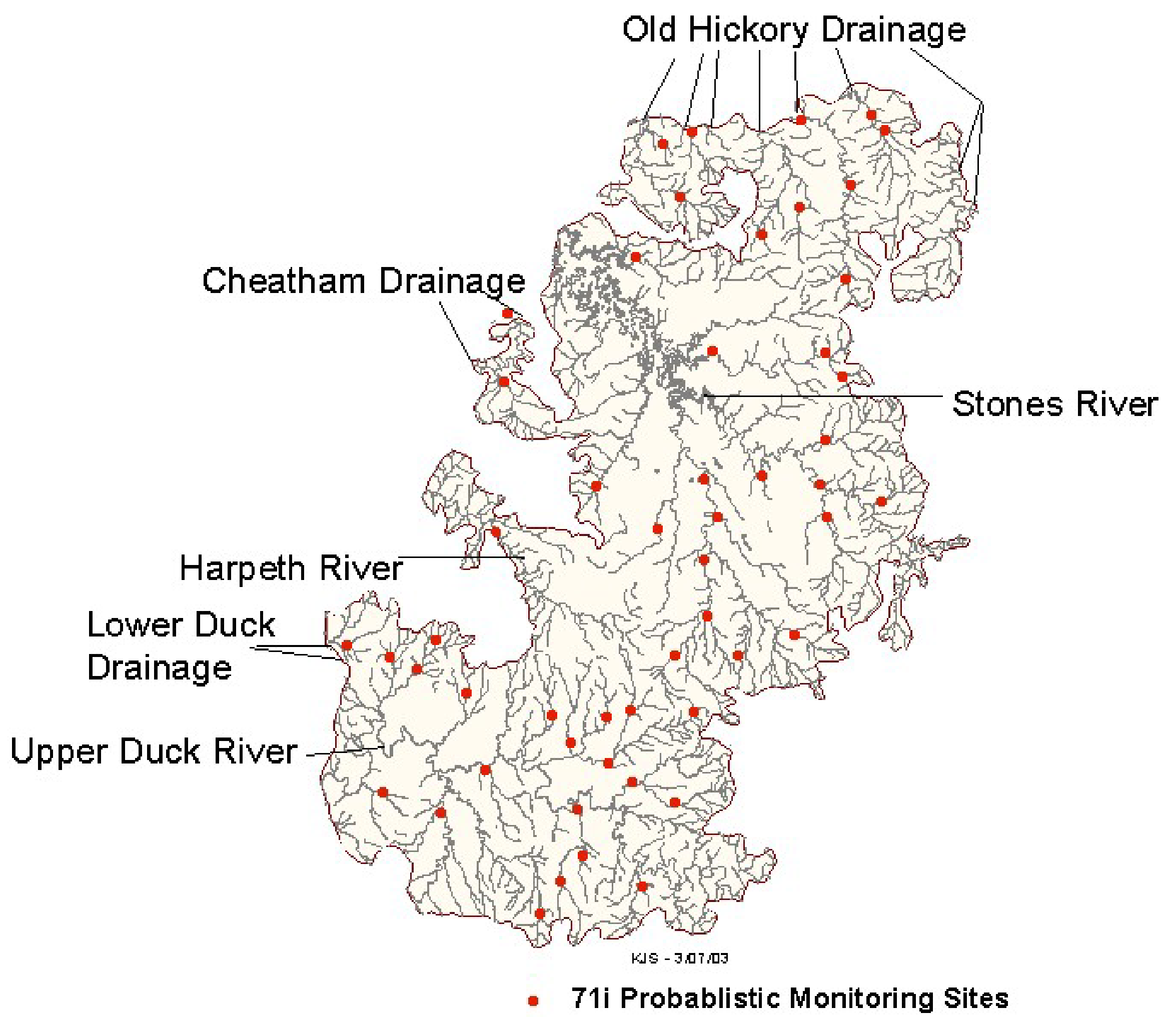


Figure 4: Location of 50 probabilistic monitoring sites in ecological subregion 71i (Inner Nashville Basin).

3.1 Sample Collection and Stream Monitoring

The Division of Water Pollution Control contracted with the Aquatic Biology Section, Tennessee Department of Health (TDH) to conduct all monitoring activities. During the first year of the study (January – December 2000) chemical and bacteriological samples were collected quarterly while macroinvertebrate samples were collected in spring and fall. Chemical and bacteriological samples were analyzed for the 22 parameters listed below. Data are presented in the 2002 report.

Alkalinity as $CaCO_3$	Manganese
Arsenic	Mercury
Cadmium	Nickel
Chromium	Nitrogen, Ammonia
Copper	Nitrogen, NO_3 & NO_2
E. coli	Nitrogen, Total Kjeldahl
Enterococcus	Phosphorous, Total
Fecal Coliform	Residue, Dissolved
Hardness, Total as $CaCO_3$	Residue, Suspended
Iron	Turbidity
Lead	Zinc

For the second phase of the study, nitrate+nitrite, total phosphorus, fecal coliform, *E. coli* and macroinvertebrate samples were collected between May 8 and June 12, 2001. These data were combined with the quarterly sampling conducted in 2000 and are included in Appendix B.

Chemical and bacteriological samples were collected using a modified clean hands technique established for the ecoregion monitoring project (Arnwine et al, 2000). Field personnel wore new disposable gloves while handling each sample. Samples were double bagged, iced and returned to the state laboratory for analysis within six hours of collection. Duplicates, field blanks and trip blanks were collected at 10 percent of the stations during each sampling period.

Macroinvertebrate samples were collected, processed and analyzed in accordance with WPC's macroinvertebrate SOP (TDEC, 2002). Consistent with guidelines for the Inner Nashville Basin, two methods were used to collect samples based on stream type and/or flow levels. In streams where riffle habitat was available, a semi-quantitative riffle kick (SQKICK) sample was collected. If riffles were not present, a semi-quantitative bank sample (SQBANK) was collected. The method selected would sometimes vary between seasons at the same site due to fluctuating water depths, which affected habitat availability. All samples were returned to the state lab for sorting and identification.

Percent canopy was measured seasonally using a spherical densiometer. Readings were taken mid-stream in the middle of the sampling reach. Measurements were taken facing four directions (upstream, downstream, right bank, left bank) at each site.

Flow measurements were taken in conjunction with nutrient collections each quarter. Flow was measured across each sample reach using a calibrated Marsh-McBirney flow meter. A minimum of 25 readings were taken on each transect.

Elevation readings were measured along the flow transect during the first sampling effort to calculate stream profile (cross section) information. Particle counts were measured seasonally along each transect. These data provided information for stream characterization (Rosgen, 1996).

Habitat assessments were conducted every quarter using the method developed by Barbour et al., EPA 841-B-99-002. This method numerically assesses the stream for the parameters listed below. A score of 1-20 was assigned to each parameter

Riffle Streams	Non-Riffle 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	Channel Sinuosity
Bank Stability	Bank Stability
Vegetative Protection	Vegetative Protection
Riparian Vegetative Zone Width	Riparian Vegetative Zone Width

4. RESULTS

4.0 Stream Characterization

4.0.0 Channel Profile

Cross section profiles measured in January or February 2000 at each site indicated that the majority of streams had one of two channel shapes. Forty-eight percent of the streams had a horizontally sloping channel (Figure 5), while 34% of the streams had a flat channel (Figure 6). The rest of the streams (18%) had either a flat channel with deep crevices between the bedrock or a double channel created by a side channel during high water.

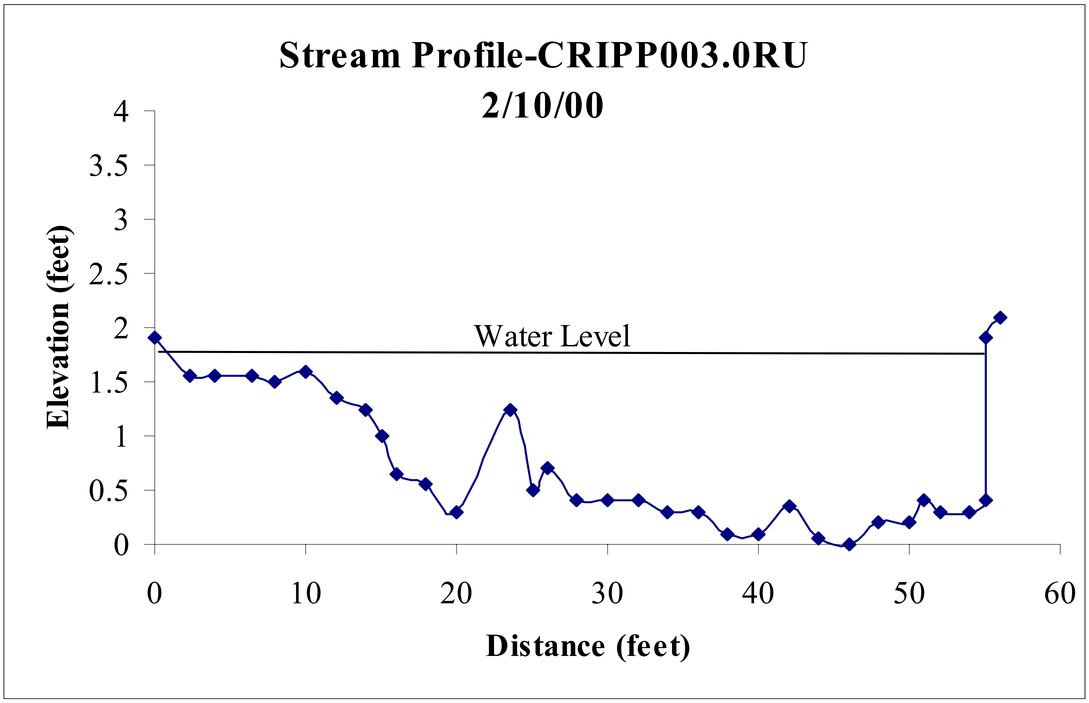


Figure 5: Streambed profile of Cripple Creek, a typical sloped channel stream in the Inner Nashville Basin.

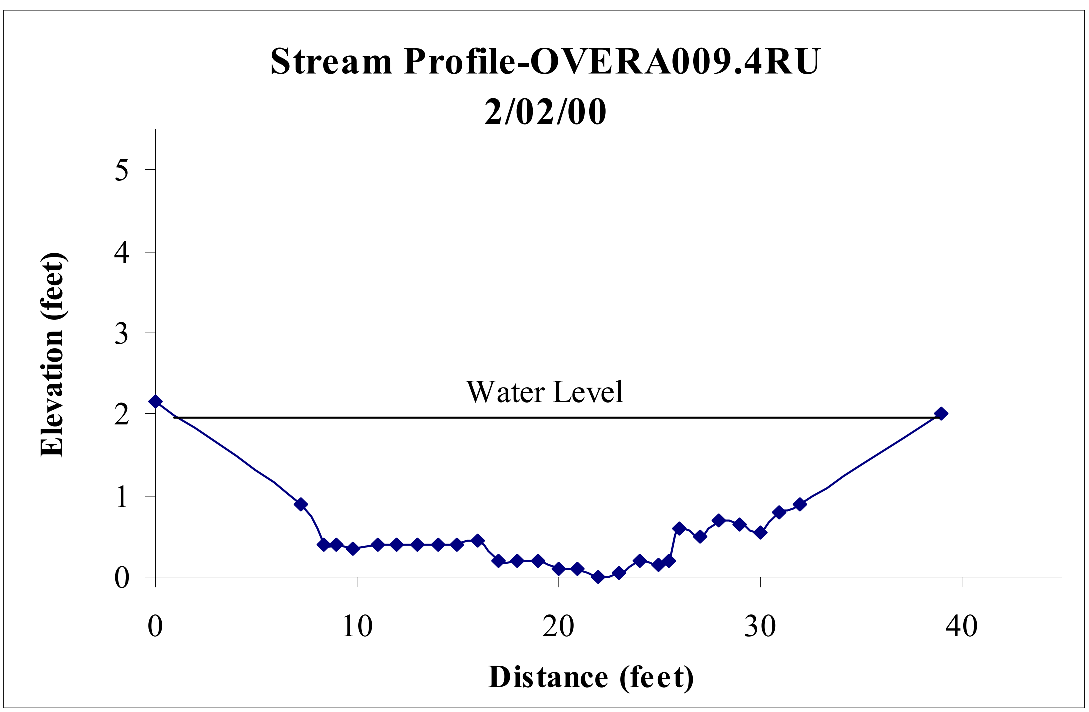


Figure 6: Streambed profile of Overall Creek, a typical flat channel stream in the Inner Nashville Basin.

4.0.1 Channel Material Size Distribution Analysis

Based on particle counts conducted seasonally, channel shape and flow influenced particle deposition. In sloped channel streams such as Cripple Creek, one side of the channel is deeper, resulting in less scouring during high flow and more long-term deposition of larger particles such as cobble, gravel and broken segments of bedrock (Figure 7). The relative distribution of these particles is relatively consistent year round.

On the other hand, the particle size distribution in flat channel streams, such as Overall Creek, varies with the seasonal flow (Figure 8). In winter, flows begin to rise and larger particles such as gravel and cobble as well as boulder size pieces of broken bedrock are washed from upstream and deposited on top the bedrock bottom. In spring, high flows cause scouring of the substrate and the mobile particles are washed downstream.

As flow decreases in summer, the larger particles begin to settle out. Periodic storms during the summer cause these particles to wash downstream so that bedrock once again is the dominant substrate in fall. The fine sands measured in the channel during fall were beyond the edge of water and were left as the water level receded. The periodic scouring makes the substrate unusable for colonization by most macroinvertebrates.

4.0.2 Habitat Assessments

Habitat is often a limiting factor to macroinvertebrate colonization in the Inner Nashville Basin. Even in relatively undisturbed areas, the natural stream conditions can create a stressful environment. Periods of low flow are especially harsh. Common habitat disturbances in this region include riparian loss and siltation.

Habitat scores were compared to habitat guidelines for ecoregion 71i that were based on regional reference data (Arnwine and Denton, 2001). A habitat score of 98 (out of a possible 200) is considered adequate for a healthy aquatic community in winter and spring while a score of 96 is considered supportive in summer and fall. Fifty-eight percent of the test sites fell below the minimum acceptable habitat scores during at least one season (Appendix B).

In the Inner Nashville Basin, habitat scores are most meaningful in the winter and spring when streams are at their highest flows. If only winter and spring scores are used, 26 percent of the sites fell below habitat guidelines. Approximately half of the sites failing to support a healthy macroinvertebrate community had adequate habitat. This indicates a water quality problem in these streams. Nutrients were elevated at all but one of these sites.

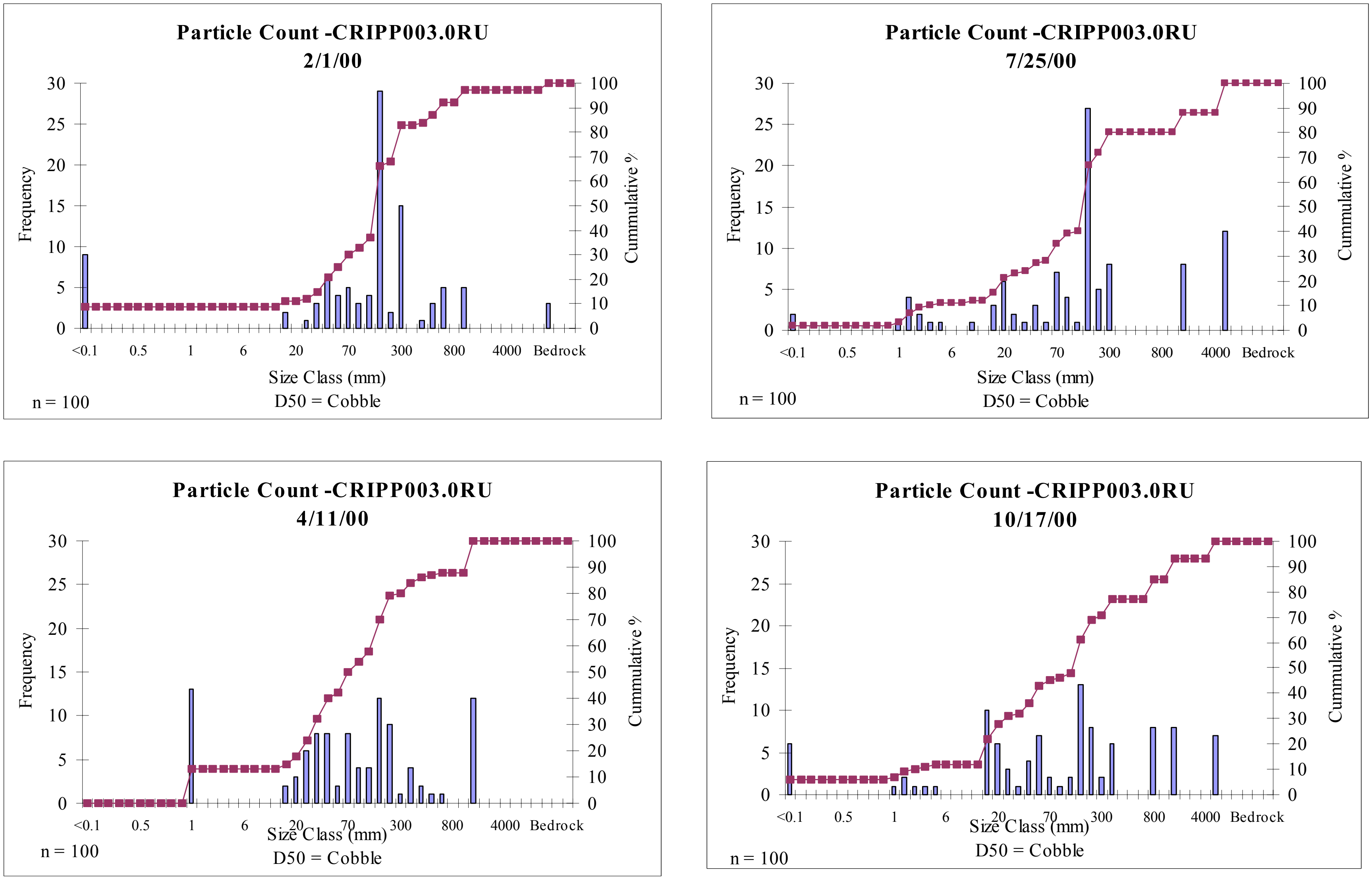


Figure 7: Seasonal channel particle size distribution at Cripple Creek.

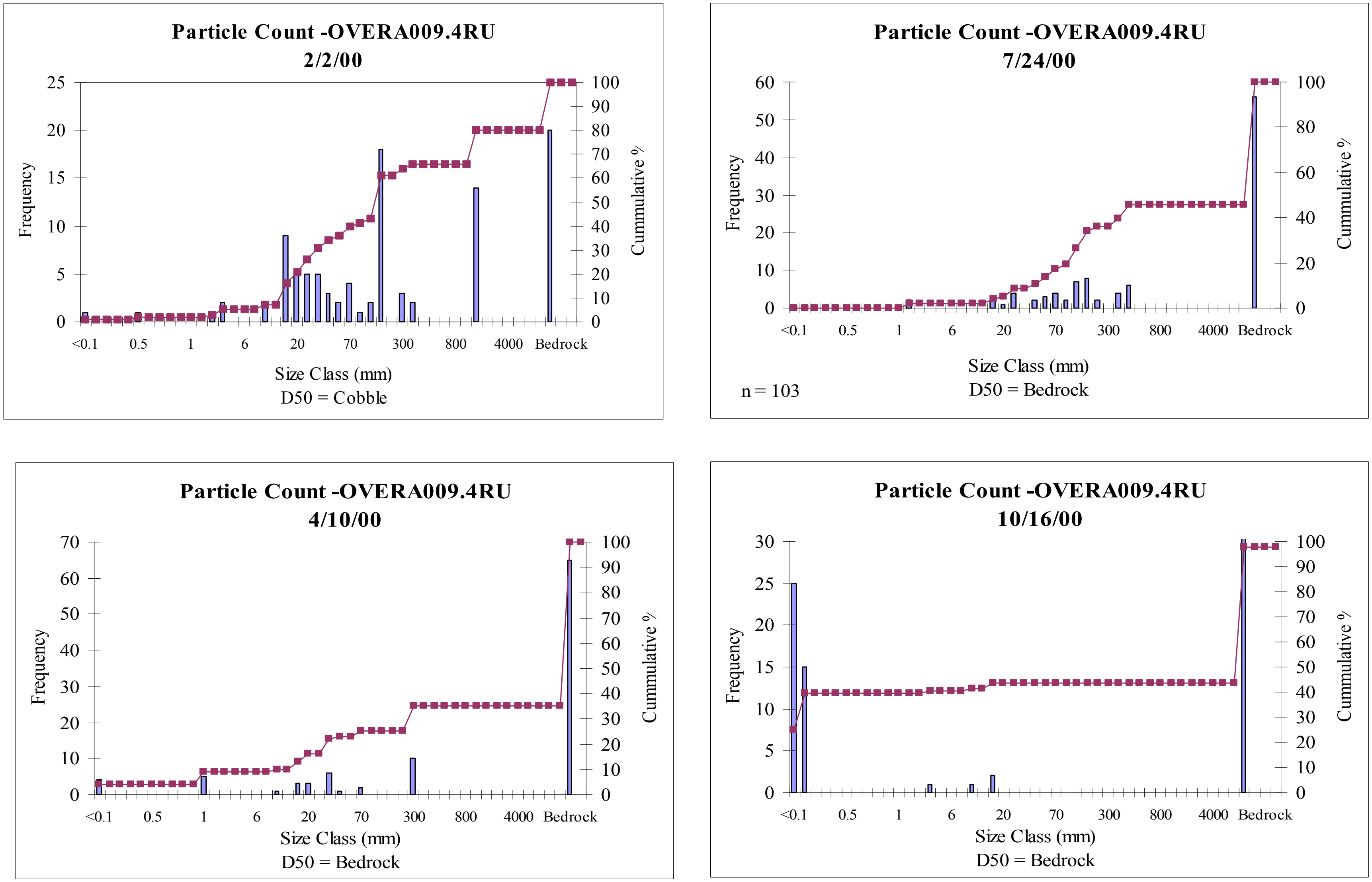


Figure 8: Seasonal channel particle size distribution at Overall Creek.

4.1 Water Quality Characterization

A primary objective of this study was to characterize water quality at each of the probabilistic monitoring stations. This was to include documenting violations of water quality standards, determining whether each site supported designated uses, and identifying the most likely source of pollutants. Preliminary results, based on probabilistic data alone, were presented in the March 2002 report. Assessments were later finalized and included in the proposed final 2002 303(d) list in September 2002 and the 2002 305(b) report in December 2002. Thirty stream segments (31 sites) were assessed as impaired (Appendix C).

Eighteen of the sites were assessed as impaired in both the 1998 and proposed 2002 303(d) reports. However probabilistic monitoring allowed several of the segments to be refined to more accurately reflect the extent and types of pollution. For example two tributaries, Clem Creek and Weakley Creek, were included with the entire North Fork Creek watershed in the 1998 assessment representing 98.4 miles. Results of the probabilistic monitoring facilitated assessing each of the tributaries separately as well as splitting North Fork Creek into two segments. Sources and causes were then refined to more accurately reflect conditions in each segment.

Thirteen sites were newly assessed as impaired in 2002. Eight of these streams had not previously been surveyed. The probabilistic approach often randomly selected streams that had not been targeted for monitoring. Due to limited resources, there is not time to monitor all of the streams in each watershed, therefore focus is generally on those where problems are known or expected. The probabilistic selection process resulted in identifying additional problem areas.

Two sites on Sinking Creek in Bedford County augmented a less intensive biorecon conducted at one of the sites in 1999 as well as bacteriological sampling conducted at the other site. The combination of all data resulted in the stream being assessed as partially supporting due to siltation and habitat loss.

A biological screening on Suggs Creek in 1996 yielded inconclusive results that were clarified by probabilistic monitoring. The more intensive biological survey combined with a habitat assessment resulted in the stream being assessed as impaired due to silt.

The probabilistic monitoring on Spencer Creek in Wilson County indicated this previously unassessed stream was impaired by nutrients and pathogens. This prompted a biorecon upstream to determine the extent of impairment. As a result, Spencer Creek was segmented to define the impaired section. In this way, probabilistic monitoring proved useful in providing focus for planning targeted monitoring needs.

Four streams were reassessed as fully supporting based on the probabilistic surveys. Fall Creek was removed from the 303(d) list. The more intensive monitoring that could be compared to regional biological and nutrient guidelines allowing a more accurate assessment process.

Florida Creek, which did not previously have data, had been included with Fall Creek as impaired in 1998. The probabilistic site on Florida Creek showed the biota met regional expectations. Likewise, Bradley Creek in Rutherford County was split from Jarman Creek and assessed as non-impaired. Overall Creek in Rutherford County had previously been included with Armstrong Creek as impaired. Probabilistic data demonstrated Overall Creek met guidelines for the region.

Despite the increased urbanization of this subregion, the majority of impaired sites (77%) were impacted by agriculture activities, specifically grazing, livestock access and riparian removal (Figure 9). Five sites were impaired due to urban runoff and land development. Two sites, Mill Creek in Davidson County and Hurricane Creek in Rutherford County had point sources contributing to the problems although other sources (agriculture and land development) were also listed.

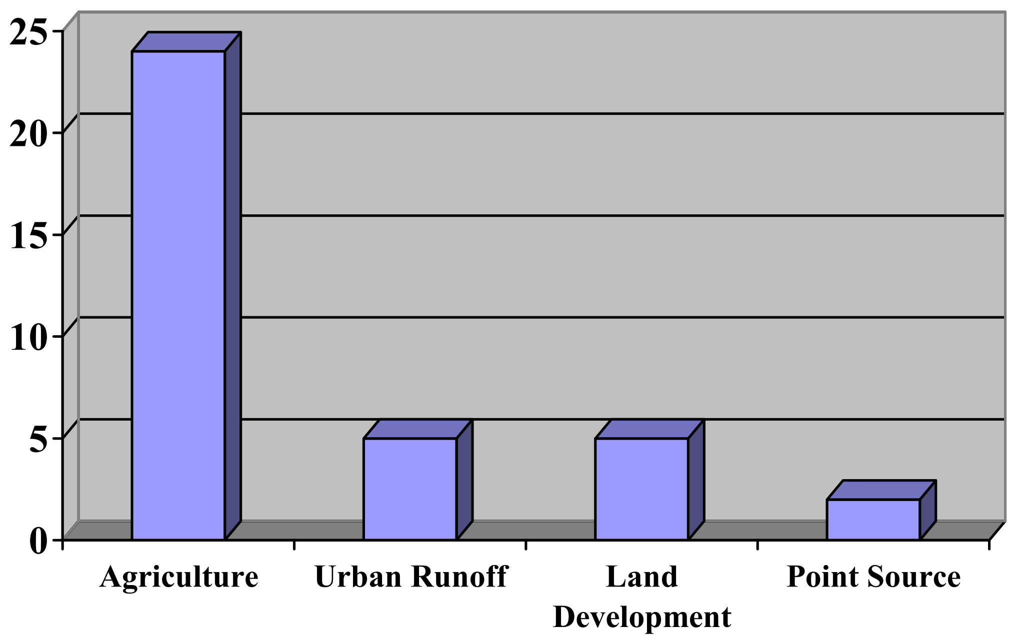


Figure 9: Sources of pollution at 31 impaired probabilistic monitoring sites in the Inner Nashville Basin. Note: data are not cumulative since sites may have more than one pollution source.

Siltation was the primary cause of pollution, affecting 68% of the 31 impaired sites (Figure 10). Excessive siltation was determined by the scored habitat parameters of embeddedness and sediment deposition. Embeddedness is an estimate of the percent that gravel, cobble and boulder particles are surrounded by fine sediment. Optimal conditions are defined by less than 25% sediment. Sediment deposition is determined by the increase in bar formation, deposition at obstructions, constrictions and bends as well as pool deposition. Both parameters are measured on a scale of 1 to 20.

Elevated pathogen levels were a problem at 58% of the impaired sites. Pathogen violations were determined by comparing fecal coliform and *E coli* results to the 1999 water quality criteria.

Based on comparisons to regional guidelines, habitat was inadequate to support a healthy benthic community at 35% of the impaired sites.

Nutrients were elevated at 26% of the impaired sites. Nutrients were listed as a cause if the biological community did not meet regional guidelines and either nitrate+nitrite or total phosphorus levels exceeded regional guidelines.

Bacteriological, habitat and nutrient data for each site are presented in Appendix B.

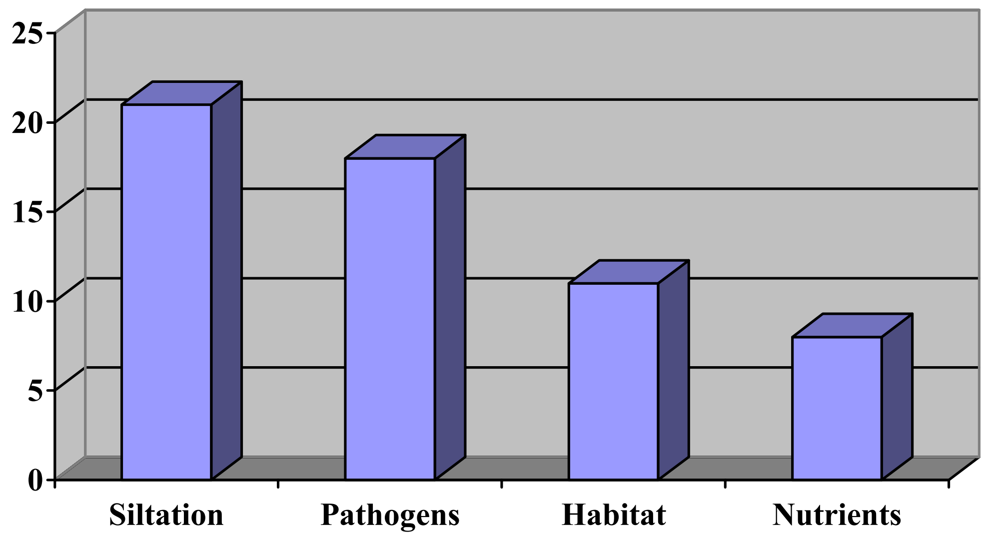


Figure 10: Number of probabilistic monitoring sites listed as impaired due to various causes of pollution. Data represents 31 sites. Data are not cumulative since most sites had multiple causes of pollution.

The Stones River was the only watershed that did not have a lower percentage of streams supporting designated uses in the Inner Nashville Basin than in the watershed as a whole (Figure 11). Most of the Stones River drainage (83%) is in the Inner Nashville Basin, so it is likely that most of the assessed stream miles are also in this region (Figure 12). The Lower Duck River had the largest discrepancy with none of the stream miles in the Inner Nashville Basin assessed as fully supporting. However, only 1% of the stream miles for the watershed are in this subregion.

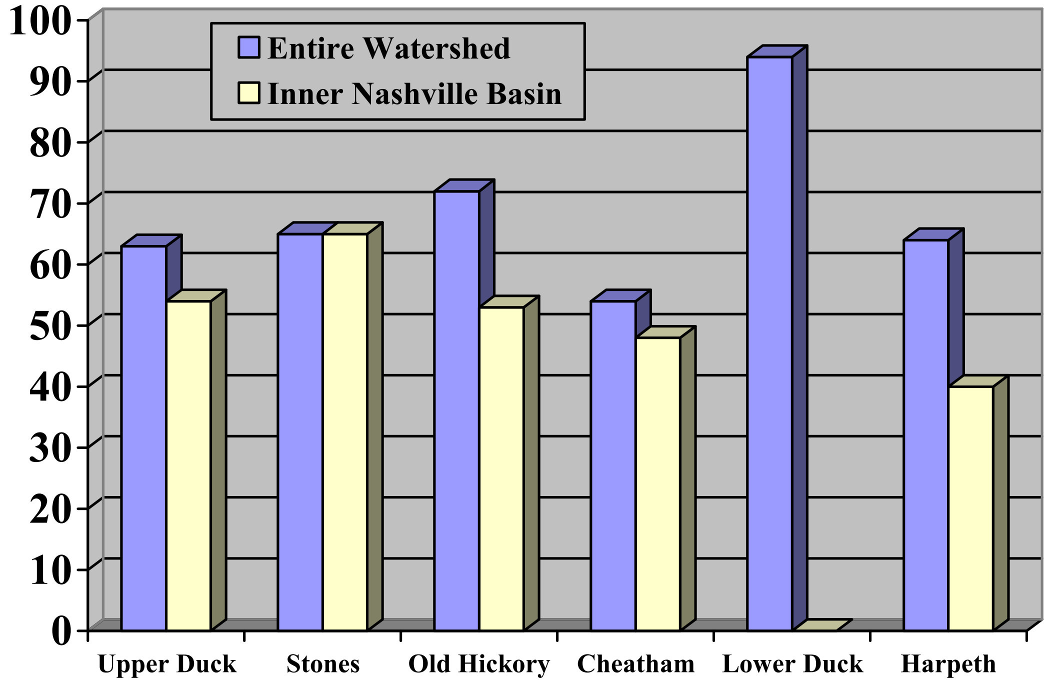


Figure 11: Percent of stream miles meeting designated uses by watershed and ecoregion in six watersheds.

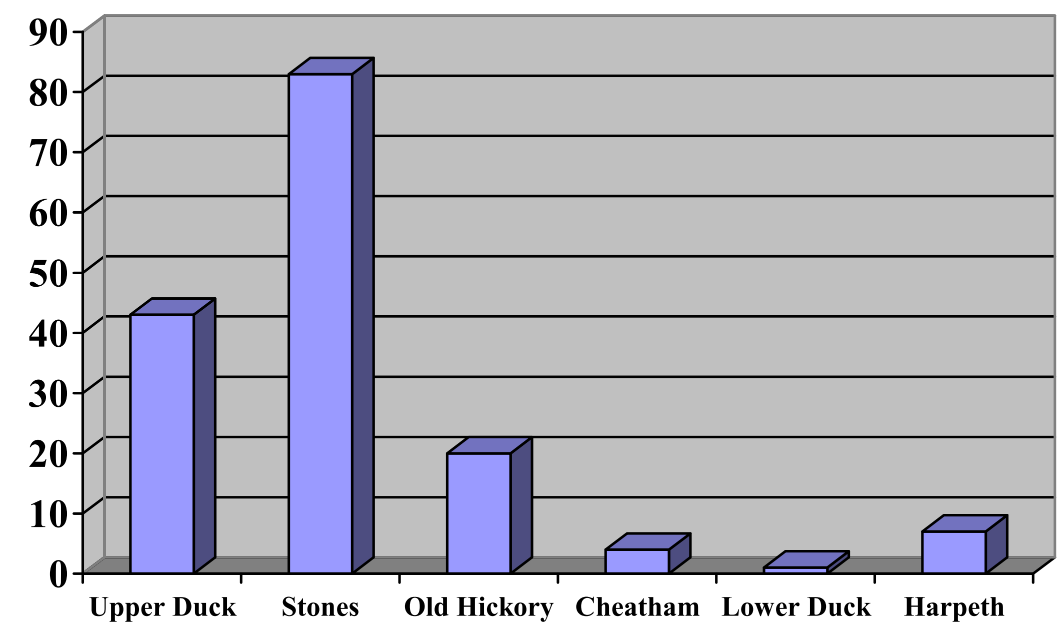


Figure 12: Percent of stream miles in six watersheds within the Inner Nashville Basin.

4.2 Subregion Extrapolation

Another objective of the probabilistic monitoring project was to extrapolate the data to the entire subecoregion. The 49 stream segments represented by the probabilistic monitoring sites represent 609.6 stream miles. (Only 49 segments are represented by the 50 stations since two sites on Cedar Creek in Wilson County were used to assess a single 11.9 mile segment.)

Based on probabilistic data, 31 segments were assessed as impaired. These segments represent 345.8 stream miles or 57% of the assessed stream miles. Three additional sites, Cedar and Rich Creeks in the Upper Duck watershed and Stewart Creek in the Stones River watershed, failed to meet biological guidelines for the region for any of the sampling efforts but were not part of the 2002 assessment cycle. The addition of these segments would add 43 impaired stream miles raising overall impairment to 64%.

4.3 Comparison to Historical Assessments

The fourth objective of the study was to compare water quality assessment information extrapolated from the probabilistic sampling to historic assessments within Inner Nashville Basin to provide a sense of the accuracy of targeted monitoring sites. It should be noted that with the watershed approach, more streams are assessed that are not targeted due to a known or suspected pollution source. However, these assessments are generally based on a single site that is usually selected due to habitat availability since biorecons are often performed. The potential problem with these assessments is the site may reflect refugia where the benthic populations are diverse due to habitat availability that may not be representative of the entire stream.

Probabilistic monitoring on the other hand is random. Therefore, if habitat is poor or the site is in the middle of a pollution source (such as a cow field) that is where the site is monitored. The idea is that if these types of sites are randomly selected, the probability is that this type of problem is prevalent in the watershed. On the other hand, if a non-impaired site with good habitat is randomly selected, it is likely that this is generally reflective of the stream as a whole.

There was a combination of biological, bacteriological and/or chemical data available from 200 targeted monitoring stations in the Inner Nashville Basin used for the 2002 305(b) assessment (Table 1). Any assessments made solely on probabilistic data from this study were removed from this data set. All watersheds have gone through one complete assessment cycle so the relative percentages of sites are reflective of monitoring activities in these watersheds.

Assessment information from the stream segments represented by these sites was compared to the stream segments represented by the 50 probabilistic monitoring sites (Figure 13). For this comparison, the segments represented by the probabilistic monitoring sites were called supporting if they passed spring biocriteria guidelines.

Table 1: Breakdown, by watershed, of assessed stream miles for targeted and randomly-selected (probabilistic) monitoring sites in the Inner Nashville Basin.

Watershed	Miles in 71i	Targeted Monitoring			Probabilistic Monitoring		
		# Sites	Assessed Miles	Miles Supporting	# Sites	Assessed Miles	Miles Supporting
Upper Duck	690	93	358	219	19	278	108
Stones	768	61	520	358	17	220	115
Old Hickory	280	21	80	66	10	90	34
Cheatham	30	6	15	3	2	14	0
Lower Duck	24	7	6.1	0	1	2.5	0
Harpeth	92	12	66	22	1	4.7	5
Total	1884	200	1045	668	50	609	261

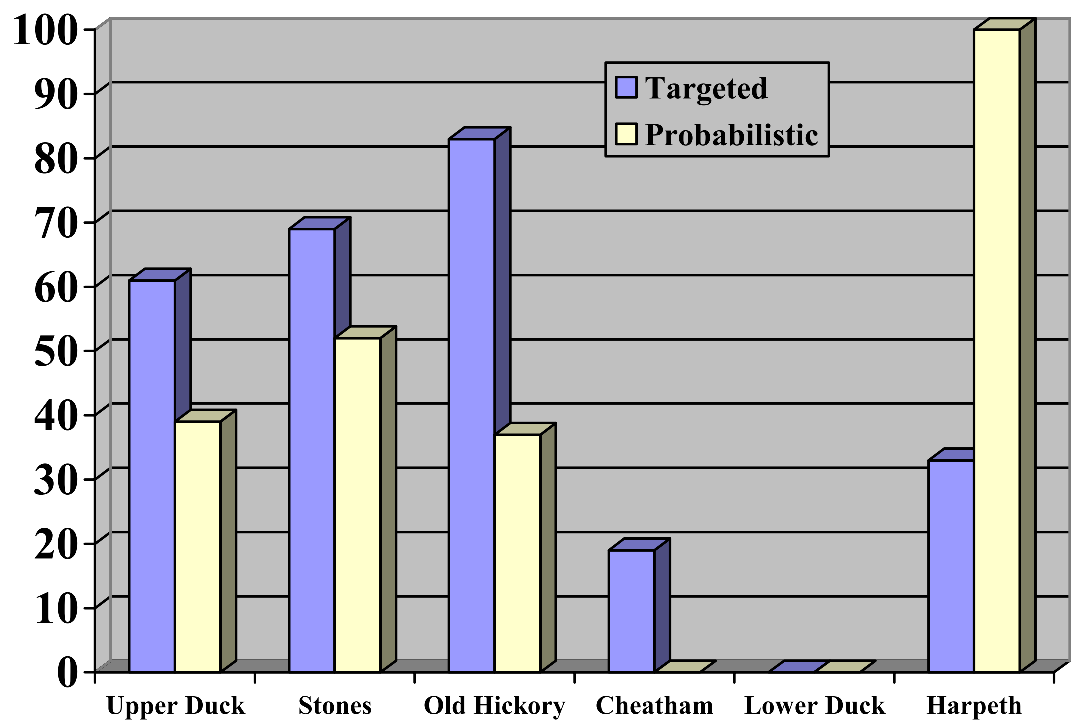


Figure 13: Percent of supporting stream miles based on targeted and probabilistic monitoring of six watersheds in the Inner Nashville Basin.

There are several possibilities for the discrepancies between assessments based on targeted monitoring alone and those using only probabilistic monitoring.

1. The assessment techniques most commonly used in targeted monitoring (primarily biorecons) are not as sensitive as the semi-quantitative assessment techniques used in the probabilistic monitoring study. The biorecon technique is a good screening tool but is relatively subjective. Extremely good sites or obviously impaired sites can be accurately assessed. However, moderate impairment cannot be determined with as much confidence especially if additional water quality data are not available.

2. Targeted assessments were often based on a single site visit, usually in late summer or fall. Probabilistic sites were assessed three times over two seasons, fall and spring. More than twice as many sites failed to meet biocriteria guidelines in the spring (57%) than in the fall (28%). Therefore, if sites were only assessed in the summer or fall, the proportion of sites assessed as having healthy year-round biological communities may be skewed. Another problem with targeted summer/fall sampling is that many streams in this subregion are dry or subterranean during low flow periods even though, based on reference streams that are dry during low flow, this stream type has the potential to support a diverse benthic community in the spring. If the stream was only visited in the summer/fall an assessment could not be made therefore this type of stream would be excluded from the overall assessment.

3. Sites for targeted monitoring (especially general watershed monitoring) were often selected to represent a large upstream segment. When collecting macroinvertebrates, sites were generally located in areas where habitat was most conducive to colonization. Habitat may not be as supportive of the benthic community in the rest of the stream segment. On the other hand, probabilistic monitoring sites were randomly selected. Often habitat quality would be very poor in the selected reach. This did not always represent a large portion of the stream but reflected a more localized problem. Conversely, if a localized problem was randomly selected, odds are that there are a high proportion of localized problems in the stream reach.

Probabilistic and targeted monitoring data were combined to determine use support for streams in the Inner Nashville Basin (Figure 14). When both data were combined, 57% of the stream miles in this subregion were assessed as fully supporting. This value falls between the assessments based on targeted monitoring alone (64%) and those based only on probabilistic monitoring (43%). The combined data were also used to determine use support by watershed in the 2002 305(b) report (Denton et al, 2002).

Assessments that used both sets of data provided the most extensive and probably the most accurate evaluation of the streams in this subregion. Approximately 70% of the streams in the Inner Nashville Basin have been assessed in this manner. One extremely useful purpose of the probabilistic monitoring was to provide guidance for additional targeted sites.

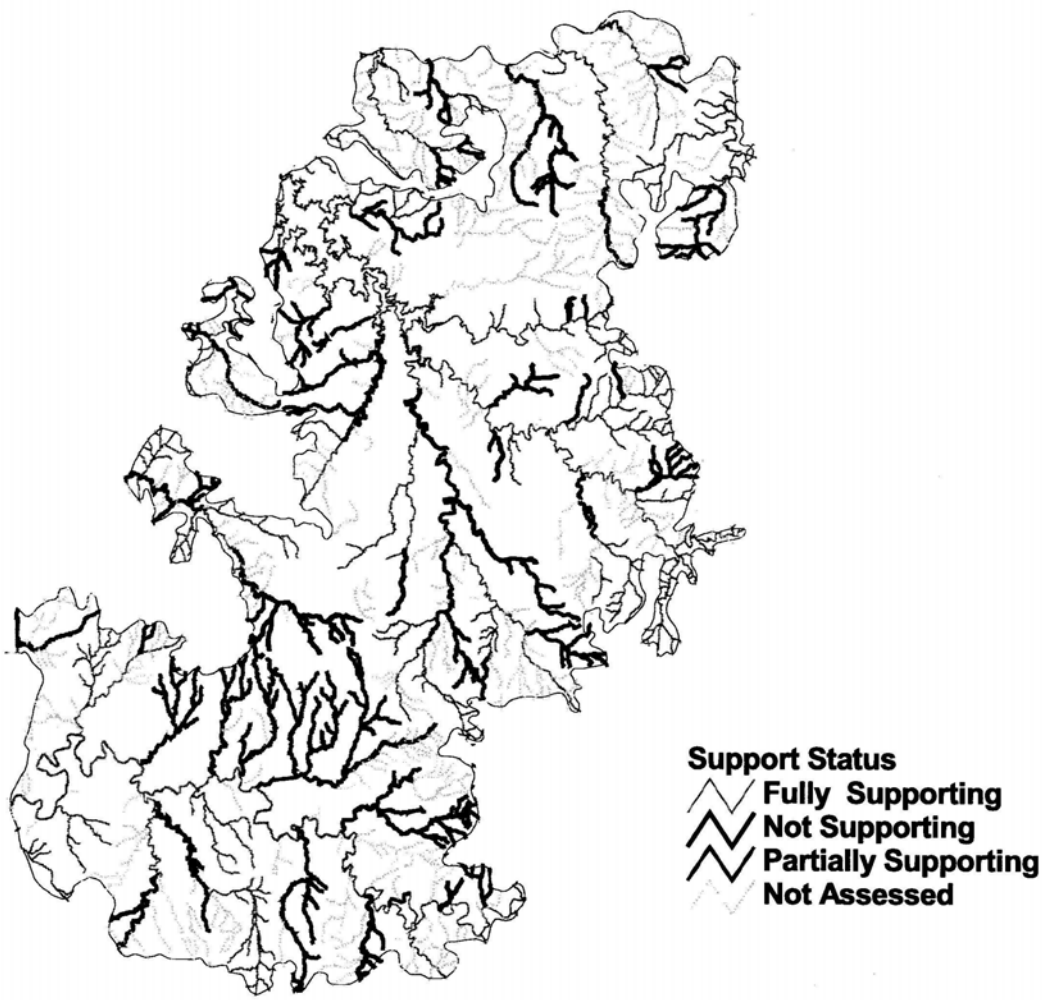


Figure 14: Use support of streams in the Inner Nashville Basin based on the 2002 305(b) assessment. Support status was assessed using a combination of targeted and probabilistic monitoring.

4.4 Relationships Between Nutrient Levels and Macroinvertebrate Populations

The primary goal of this phase of the 71i probabilistic study was to determine if a correlation between macroinvertebrate populations and nutrients levels could be measured in this ecological subregion, the Inner Nashville Basin.

4.4.0 Nutrient Data

Background phosphorus levels of streams in the Inner Nashville Basin are higher than any other Tennessee subregion except the Northern Mississippi Alluvial Plain (Denton et al, 2001). It should be noted that additional data collected since the 2001 report has shown phosphorus levels in 71i are significantly higher than in 71h, the Outer Nashville Basin, where it was originally grouped. The 90^{th} percentile of data for the Inner Nashville Basin is 0.22 mg/l.

Reference nitrate+nitrite levels are comparable to those seen in the Outer Nashville Basin and the Eastern Highland Rim (71g). The 90^{th} percentile of reference nitrate+nitrite data is 0.94 mg/l for these three regions (recalculated since 2001 with additional data). Another subregion in the Interior Plateau, the Western Pennyroyal Karst (71e), had significantly higher background nitrate+nitrite levels while the Western Highland Rim (71f) was much lower. Only one region the Loess Plains (74b), which is located in west Tennessee outside the Interior Plateau ecoregion, had higher nitrate+nitrite levels.

Nitrate+nitrite guidelines were exceeded more often than total phosphorus guidelines at the 50 probabilistic test sites (Figure 15). Nitrate+nitrite levels were exceeded for 33% of the 208 samples collected between January 2000 and June 2001. Only 13 of the 50 sites had values within regional guidelines for the entire study period. Three sites; Cedar Creek in Maury County, Richland Creek in Marshall County and Wilson Creek in Bedford County exceeded nitrate+nitrite guidelines during every sampling event. The range of values for sites exceeding nitrate+nitrite guidelines was 0.95 – 5.49 mg/l with a mean of 1.86 mg/l.

Total phosphorus guidelines were only exceeded for 8% of the samples. The range of values for sites exceeding guidelines was 0.230 – 1.210 mg/l with a mean of 0.451 mg/l. Thirty-nine sites had values within regional guidelines for the entire study period. Total phosphorus guidelines were not exceeded for all sampling events at any test site.

Seven sites exceeded both nitrate+nitrite and total phosphorus guidelines. Typically, both parameters were not elevated at the same time. Only two sites, Big Rock Creek in Marshall County (January 2000 and May 2001) and Spring Creek in Wilson County (January 2000), exceeded both parameters during the same sampling event.

Values for both nutrient parameters stayed below regional guidelines at 10 sites throughout the entire study period. Nitrate+nitrite and total phosphorus data for each sampling event are provided in Appendix B.

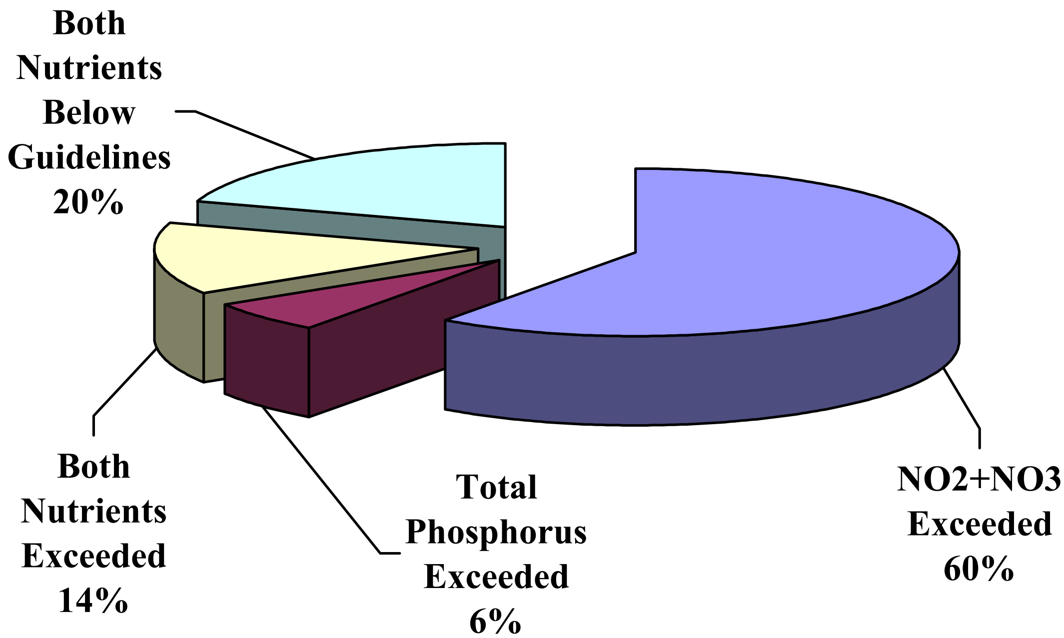


Figure 15: Comparison of 50 probabilistic monitoring sites to nutrient guidelines for the Inner Nashville Basin.

4.4.1 Macroinvertebrate Data

Macroinvertebrate data from the probabilistic sites were analyzed by calculating seven individual biometrics and combining them into a single index, the Tennessee Macroinvertebrate Index, TMI (Table 2). The index score from each site was then compared to biocriteria guidelines developed for the Inner Nashville Basin (Arnwine and Denton, 2001). The TMI score is expected to decrease as water quality decreases and the macroinvertebrate community becomes stressed. Values for all metrics can be found in Appendix B.

Ephemerella spp. is an intolerant mayfly often found in reference streams in the Inner Nashville Basin.

Table 2: Biometrics used for biocriteria guidelines in the Inner Nashville Basin

Biometric	Definition	Expected Response to Stress
Taxa Richness (TR)	The number of distinct taxa.	Decrease
Ephemeroptera Plecoptera and Trichoptera Richness (EPT)	The number of taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies).	Decrease
Percent Ephemeroptera, Plecoptera and Trichoptera (%EPT)	Percent contribution of the composite of mayflies, stoneflies and caddisflies compared to the total number of organisms.	Decrease
Percent Oligochaeta and Chironomidae (%OC)	Percent contribution of the composite of Oligochaeta (aquatic worms) and Chironomidae (midge larvae)	Increase
North Carolina Biotic Index (NCBI)	Assigns tolerance values to individual taxa to weight abundance in an estimate of overall pollution.	Increase
Percent Dominant Taxon (%DOM)	Percent of single most abundant taxon compared to the total number of organisms.	Increase
Percent Clingers (%CLING)	Percent of organisms having fixed retreats or adaptations for attachment to surfaces.	Decrease

A biometric developed by the Kentucky Division of Water Quality (Brumley et al, 2003) was also evaluated. The percent of nutrient tolerant organisms (%NUTOL) combines 14 taxa that are considered nutrient tolerant. This includes three EPT genera (*Cheumatopsyche*, *Baetis* and *Stenacron*), one crustacean genus (*Lirceus*), two snail genera (*Physella* and *Elimia*), two beetle genera (*Psephenus* and *Stenelmis*), one black fly genus (*Simulium*), four midge genera (*Polypedilum*, *Rheotanytarsus*, *Cricotopus* and *Chironomus*) and the aquatic worms (Oligochaeta).

Macroinvertebrate samples were collected once in the fall (2000) and twice in spring (2000 and 2001). In this subregion, a significant difference was seen in reference macroinvertebrate populations between fall and spring. Fall guidelines are lower than spring since the benthic population exhibits more stress even in reference streams. Often habitat that was available in spring is no longer present in fall due to reduced flow.

Only 12 sites had healthy macroinvertebrate communities for both seasons throughout the survey period while three sites failed both seasons (Figure 16). Twenty-seven sites were dry in the fall. Of these, the majority failed to meet guidelines in the spring (18 sites). Usually the spring populations were the ones to exhibit stress when sites failed only one season and flow was available year round. The benthic population at only one site, West Fork Stones River, passed guidelines in the spring but failed in the fall.

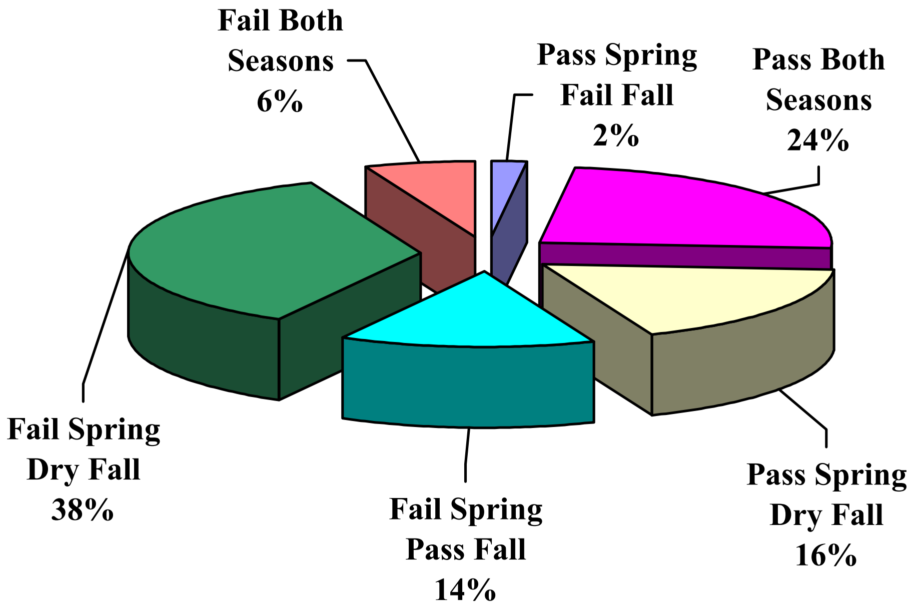


Figure 16: Comparison of Tennessee Macroinvertebrate Index (TMI) scores to regional biocriteria guidelines at 50 probabilistic monitoring sites in the Inner Nashville Basin.

Macroinvertebrate populations in this subregion have adapted to streams that routinely have little or no flow in the late summer and fall. Index scores for streams that passed guidelines in the spring but were dry in the fall were generally equivalent to those in streams that had flow year round (Figure 17).

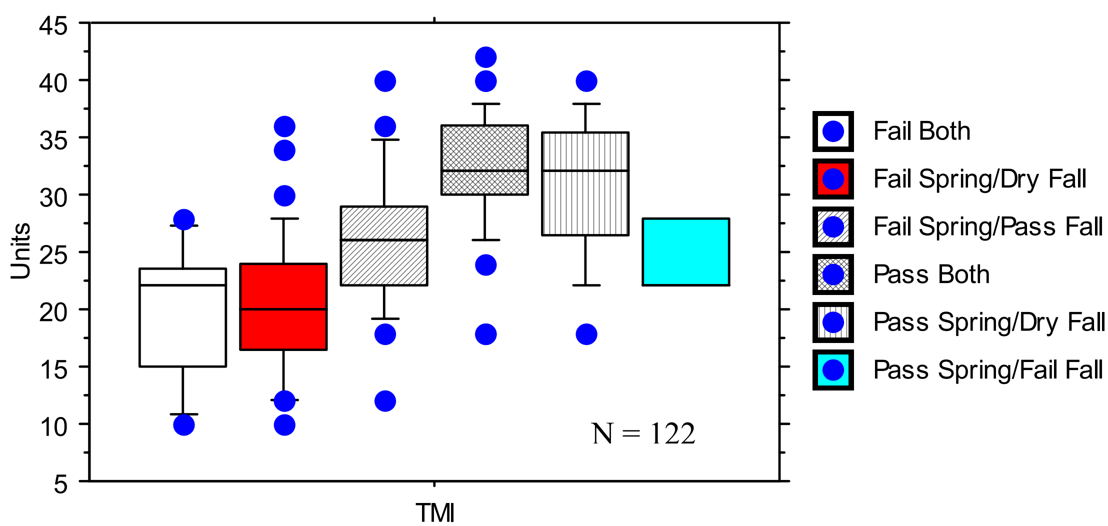


Figure 17: Distribution of Tennessee Macroinvertebrate Index (TMI) scores for 50 probabilistic monitoring sites in the Inner Nashville Basin.

Spring macroinvertebrate populations in streams that are dry in the fall are more diverse than populations in streams with year-round flow that failed fall guidelines but passed in the spring. When looking only at sites passing spring guidelines, EPT taxa were more numerous in the spring at streams that were dry in the fall than those that had flow but failed to meet guidelines in the fall (Figure 18). In fact, the seasonally dry streams were within the same range as those with continuous flow although the median was slightly lower. EPT measures the number of different taxa in one of three aquatic insect orders (Ephemeroptera, Plecoptera or Trichoptera). Many of these taxa are considered intolerant to pollution.

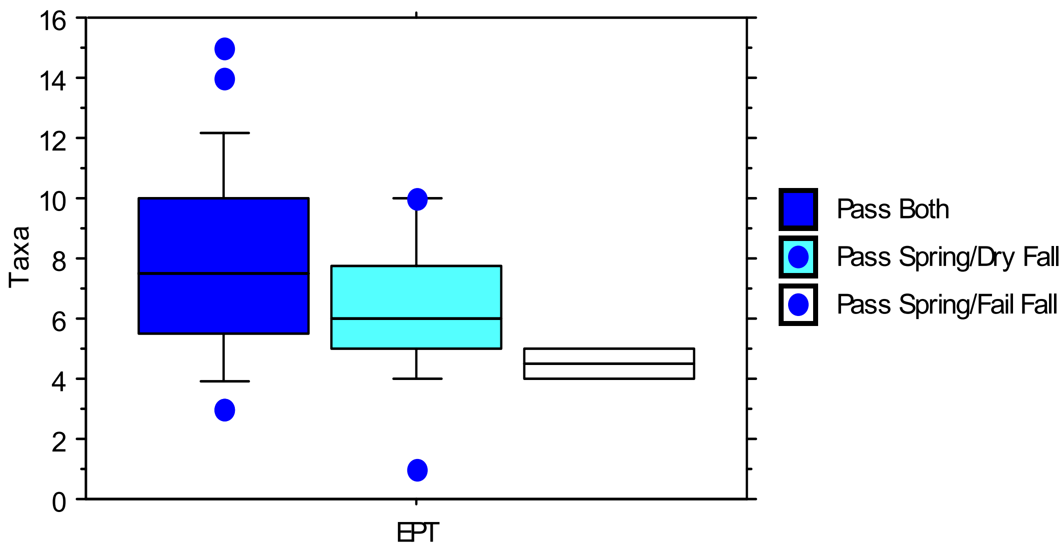


Figure 18: Distribution of EPT richness for 21 probabilistic sites passing spring regional guidelines. Data represent only spring samples. Macroinvertebrates were collected twice (2000 and 2001) at each site for a total of 42 samples.

Other biometrics, including EPT abundance, NCBI and percent clingers showed similar patterns. On the other hand, the abundance of oligochaetes and chironomids, and the percent contribution of dominant taxon were comparable between stations.

4.4.2 <u>Comparison of Nutrient Levels and Biometrics</u>

As mentioned earlier, the primary goal of this phase of the 71i probabilistic study was to determine if a correlation between macroinvertebrate populations and nutrient levels could be measured in the Inner Nashville Basin. The highest nitrate+nitrite levels were observed in the winter (Figure 19). Total phosphorus levels remained relatively consistent year round (Figure 20). Macroinvertebrates were collected in spring and fall so it is uncertain whether the higher nitrate+nitrite levels in winter had an effect.

If the elevated winter levels were the only factor, macroinvertebrate populations would be expected to exhibit more stress in the spring since it often takes several months for benthic populations to recover from stressors. However, the greatest biological response to nutrients was the fall when water levels were low and temperatures were high.

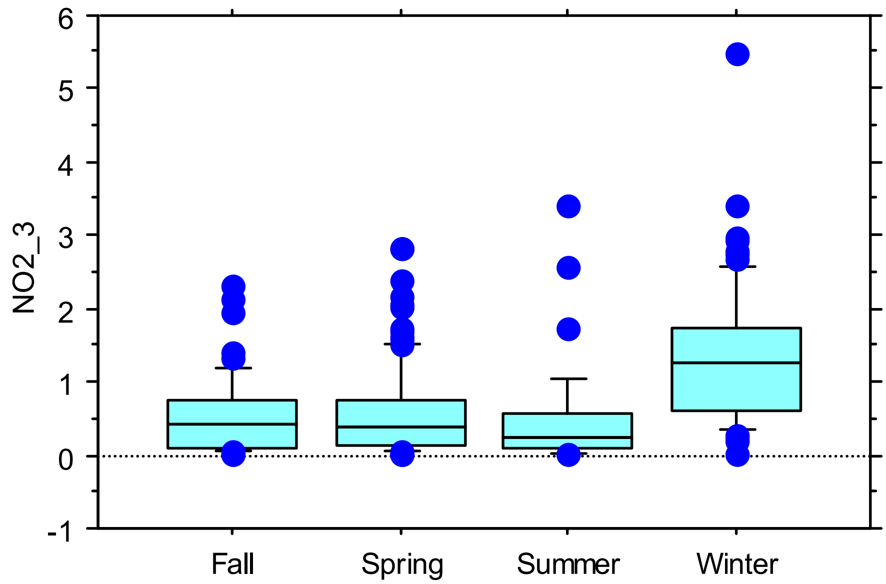


Figure 19: Seasonal distribution of nitrate+nitrite levels at 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin. Data collected between 1996 (ecoregion sites) and 2002. N for Fall = 51, Spring = 122, Summer = 34 and Winter = 71.

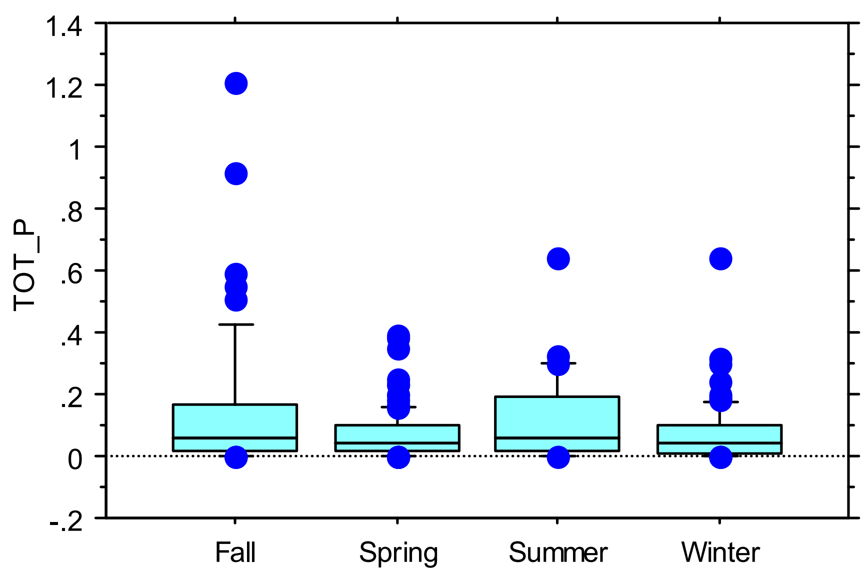


Figure 20: Seasonal distribution of total phosphorus levels at 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin. Data collected between 1996 (ecoregion sites) and 2002. N for Fall = 51, Spring = 122, Summer = 34 and Winter = 71.

Bivariate and multiple linear regression analyses (adjusted R^2) were calculated to determine if a direct correlation existed between various components of the macroinvertebrate population and nutrient levels (Table 3). The coefficient of determination (R^2) is the proportion of a dependent variable that is explained by the independent variables (maximum value of 1). For example, an R^2 of 0.70 means that 70% of the dependent variable's variation is explained by the independent variable.

When additional independent variables are assigned to an existing regression value the coefficient of determination is guaranteed to increase. Therefore, the R^2 was adjusted by applying a penalty to the value based on the number of variables assigned in multiple regression analysis (SAS, 1999). Correlations with a *p*-value less than 0.05 were considered statistically significant.

The macroinvertebrate community was measured using the Tennessee Macroinvertebrate Index (TMI), the seven individual biometrics that make up the index and the %NUTOL developed by the state of Kentucky. Nutrients were measured as nitrate+nitrite and total phosphorus. Data were tested for normal distribution using the Kolmogorov-Smirnov test ($p < 0.05$) and visual interpretation of histogram curves when less than 50 data points were available. The biometric and canopy measures had normal distributions (both seasonal and combined) so transformation was not needed. Logarithmic transformation was used on nitrate+nitrite data and cube root transformation was used on total phosphorus data to normalize data.

There were no significant direct correlations between nutrients and any of the biological metrics in spring. Weak correlations were observed in the fall. A negative correlation was measured between total phosphorus levels and the number of EPT taxa. (Figure 21) This was the only metric that showed a response to total phosphorus levels when other variables were not considered.

The EPT metric measures number of distinct genera in the three orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Many of the organisms in this group are considered intolerant of pollution and values generally decrease in response to an increase in pollution. Sites low in phosphorus had as many as 11 EPT taxa while the most EPT found at a site having phosphorus levels above TDEC's guidelines for the Inner Nashville Basin were four taxa (Figure 22).

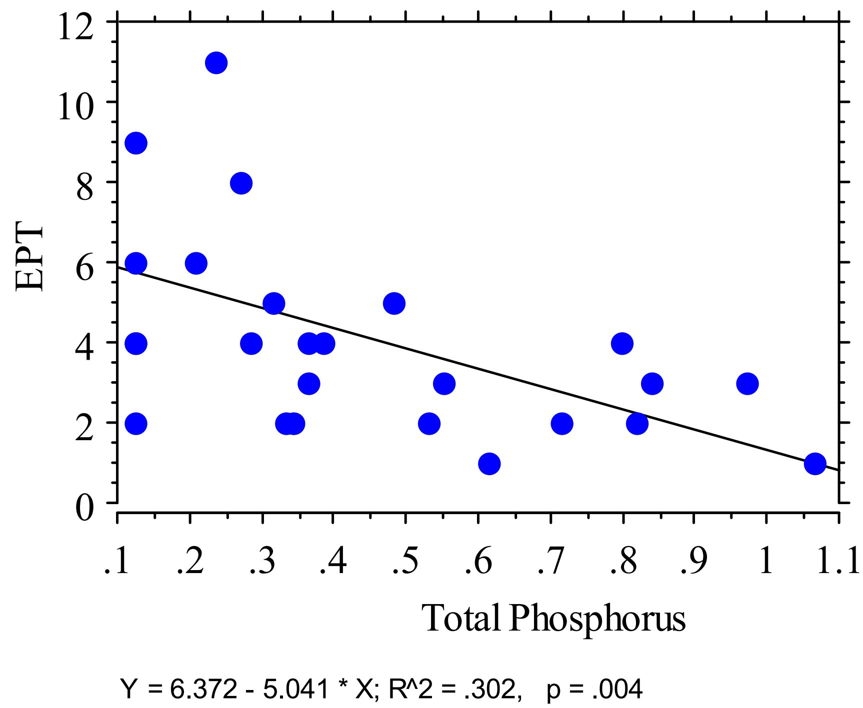


Figure 21: Relationship between total phosphorus levels and EPT taxa richness during low flow conditions. Data represents 21 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

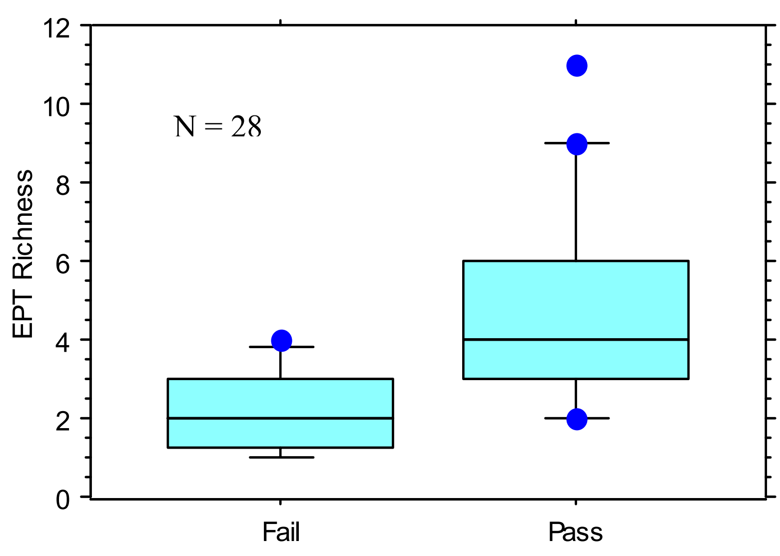
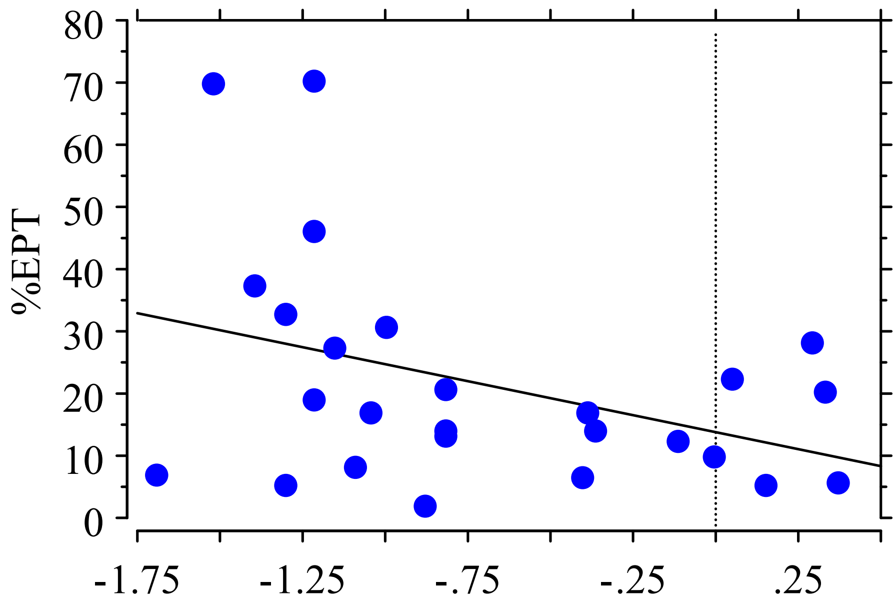


Figure 22: Distribution of EPT taxa found at sites with total phosphorus levels above (fail) and below (pass) regional guidelines. Data represent 21 probabilistic sites and two ecoregion reference sites collected in fall 2000 in ecological subregion 71i (Inner Nashville Basin).

Three components of the macroinvertebrate community had a measurable relationship with nitrate+nitrite levels in the fall. The percent nutrient tolerant taxa (%NUTOL) developed by the state of Kentucky had the strongest correlation with the percentage of these taxa generally rising as nitrate+nitrite levels increased.

Unlike the relationship observed with total phosphorus, the number of different types of EPT taxa did not decline as nitrate+nitrite levels increased. However, fewer numbers of each taxon were present as measured by the percent EPT metric which measures relative abundance (Figure 23).



Y = 13.866 - 11.004 * X; R^2 = .149, p = 0.05

Figure 23: Relationship between nitrate+nitrite levels and EPT abundance (%EPT) during low flow conditions. Data represents 21 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

The abundance of oligochaetes and chironomids (%OC) were also affected by increases in nitrate+nitrite levels in the fall (Figure 24). Oligochaetes (aquatic worms) and chironomids (midge larvae) are generally tolerant organisms that increase in abundance with adverse conditions. The preferred habitat of many of the animals in this group is sediment and algae mats. The relative abundance of these organisms tended to increase as nitrate+nitrite levels increased.

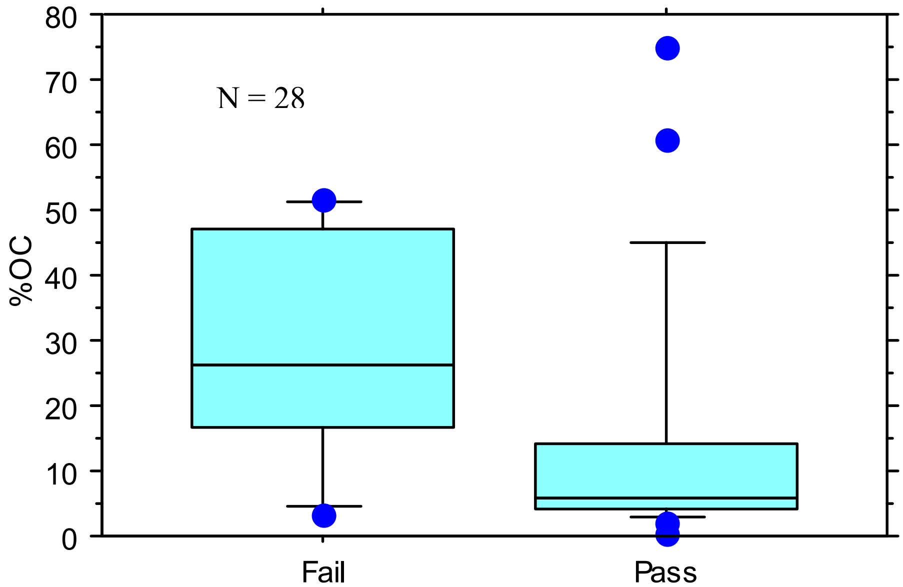


Figure 24: Distribution of Oligochaeta and Chironomidae abundance at sites with nitrate+nitrite levels above (fail) and below (pass) regional guidelines. Data represent 21 probabilistic sites and two ecoregion reference sites collected in fall 2000 in the Inner Nashville Basin.

The relationships between nutrient levels and the biological metrics were not strengthened when both nitrate+nitrite and total phosphorus were treated as independent variables in multiple regression analysis. Generally, both nutrients were not elevated at the same time. Only two sites exceeded guidelines for both parameters during the same sampling period.

4.4.3 Comparison of Nutrient Levels, Biometrics and Canopy Cover

Nutrients are generally considered a secondary stressor rather than a direct toxicant. Elevated nutrients, under certain conditions, promote the growth of algae. Excessive algae growth is harmful to macroinvertebrate populations because it can decrease nighttime oxygen levels through respiration and cause super-saturation of oxygen during daylight hours. Additionally algae can cover the substrate, making habitat unavailable for colonization. Increased algae levels are generally associated with an increase in tolerant macroinvertebrates.

Since nutrients are associated with algae growth, additional factors that are needed for algae to thrive were assessed. A key component necessary for the growth of any green plant, including algae, is sunlight. Sunlight availability was measured mid-stream at each site using a spherical densiometer, which measures the percent of canopy.

Spherical densiometers were used to measure canopy cover at each site. The percent canopy cover is an important factor in determining the potential effect of nutrients on algal growth. *Photos provided by Joellyn Brazile, Memphis Environmental Assistance Center.*

Algae abundance was estimated during spring and fall field visits. The amount of algae present was divided into four categories.

1 – No algae present
2 – Slight amount of algae present
3 – Moderate amount of algae present
4.- Algae chokes the stream reach

Algae levels at the moderate and choking levels are generally considered undesirable. The amount of canopy cover appeared to affect the amount of algae present (Figure 25). Densiometer readings of less than 50 percent canopy often resulted in a moderate abundance of algae. Streams were usually choked with algae when canopy was less than 30%. Only one site did not have algae present during the sample period. Although canopy covered only 30% of the reach, both total phosphorus and nitrate+nitrite levels were below criteria guidelines. Therefore, nutrient levels were probably not sufficient to encourage algae growth despite a lack of stream shading.

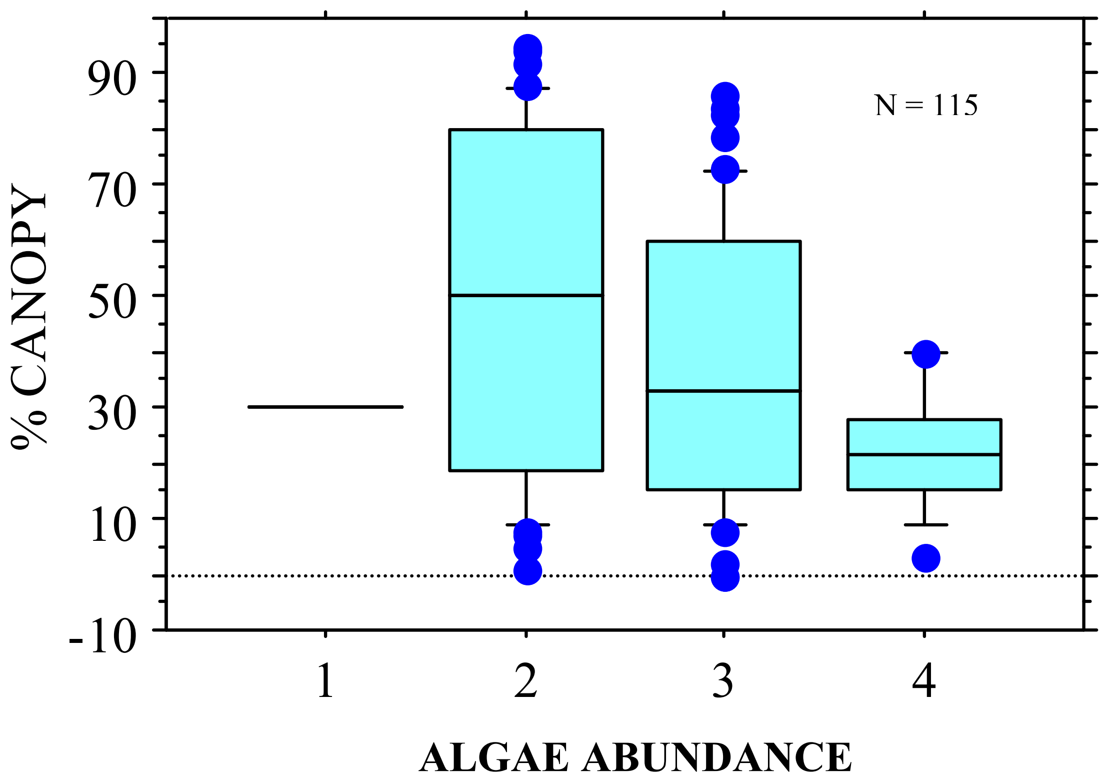


Figure 25: Distribution of percent canopy cover by algae abundance. Algae abundance based on field observations at 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

Further evidence of the affects of canopy on algal abundance can be seen by looking at nutrient levels in each of these four categories (Figures 26 and 27). High levels of either total phosphorus or nitrate+nitrite values did not necessarily result in moderate or choking algae in the stream. Other factors, such as sunlight, also needed to be available.

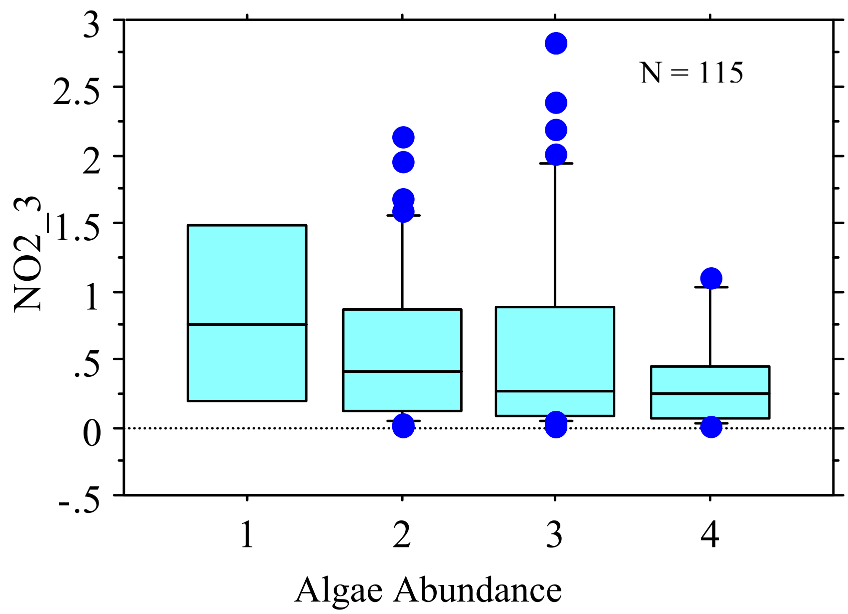


Figure 26: Distribution of nitrate+nitrite by algae abundance. Algae abundance based on field observations at 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

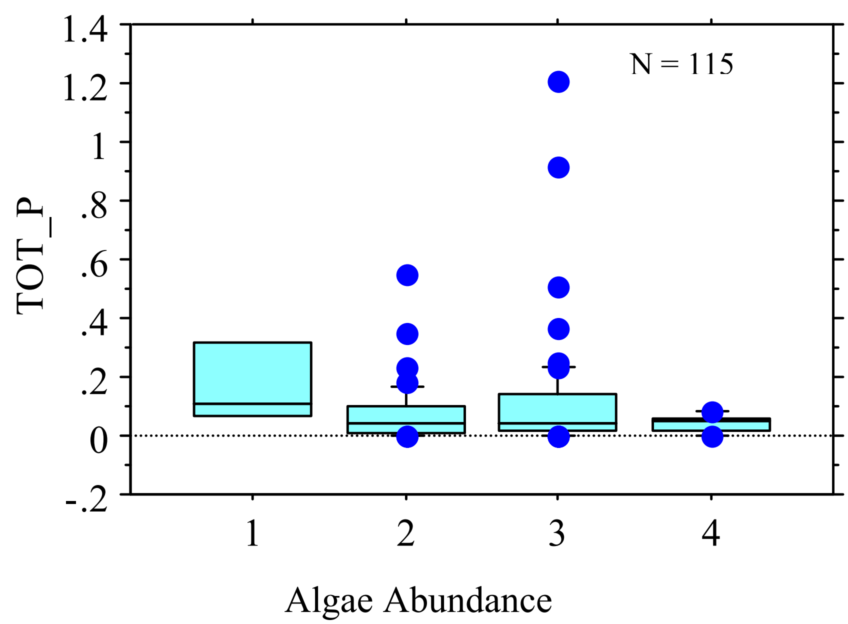


Figure 27: Distribution of total phosphorus by algae abundance. Algae abundance based on field observations at 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

Multiple regression analyses were used to help determine the relationship between nutrient levels, percent canopy and the macroinvertebrate community (Table 4). The amount of canopy cover tended to strengthen correlations between macroinvertebrates and nutrient levels. Relationships were stronger in both spring and fall when canopy was included as a variable in the comparisons between nutrients and macroinvertebrates.

While no significant relationship was observed in the spring when NO2-NO3 and TP were the only independent variables, weak correlations were observed for three biometrics when canopy was included. The percent chironomids and oligochaetes (%OC) and the percent clingers (%CLING) showed a slight correlation with total phosphorus. The North Carolina Biotic Index (NCBI) was responsive to NO2-3.

The strongest relationships were observed in the fall when warm temperatures and low flows created favorable conditions for abundant algae growth. The Tennessee Macroinvertebrate Index (TMI) was the only biometric which demonstrated a direct correlation with canopy cover when nutrients were not included. This relationship was strengthened from $R^2 = .243$ to adjusted $R^2 = .566$ ($p < 0.5$) when total phosphorus was added as an independent variable. There was no significant relationship with NO2-3.

Two other components of the fall macroinvertebrate community showed a response to total phosphorus levels after canopy was included as a variable. These were the North Carolina Biotic Index (NCBI) and the percent clingers (%CLING). No effect on the relationship already observed between total phosphorus and EPT richness was observed when percent canopy was added to the multiple regression analyses in the fall.

The correlation between NO2-3 and one biometric, the percent oligochaetes and chironomids (%OC), was increased with the addition of percent canopy. Many of the aquatic worms and midges measured by this metric are tolerant of low DO, which is associated with the nighttime respiration and decomposition of algae. One of the most abundant midges, *Chironomus* spp., has hemoglobin that gives it a red color and enables it to survive in low DO conditions. The dominant midge larvae found in these streams, *Tanytarsus* and *Polypedilum* are collector-gatherers, which can use algae as a food source. This relationship between algae eaters and nutrient levels is supported in studies conducted by USGS in the Tennessee River Basin, which indicated a correlation between nitrate levels and scraper/omnivore abundance (Hoos, Unpublished data, 2003).

Two metrics, %EPT and %NUTOL no longer had a significant relationship with NO2-3 when canopy was added as an independent variable. This indicates a factor other than algae growth, is causing a response in these taxa when nitrates and nitrites are elevated.

Taxa richness and the percent dominant taxon were the only metrics that never exhibited a significant correlation with either nitrate+nitrite or total phosphorus. A review of the taxa lists at each site showed taxa richness did not decrease because less tolerant organisms were replaced by a rich population of tolerant and facultative worms and midges. Likewise, no single animal was dominant since several different tolerant and facultative organisms are equally able to compete in these conditions.

Table 3: Relationship (adjusted R^2) between nutrient levels and nine biometrics at 50 test sites and two reference sites. Values in bold $p < 0.05$.

	All Seasons			Fall			Spring		
Biometric	**NO2-3**	**TP**	**NO2-3 TP**	**NO2-3**	**TP**	**NO2-3 TP**	**NO2-3**	**TP**	**NO2-3 TP**
Count	128	128	128	26	26	26	101	101	101
TMI	-.002	+.005	.010	-.001	-.086	.010	-.001	+.025	.005
TR	-.001	+.003	.003	+.049	-.014	..057	-.006	+.012	.016
EPT	+.001	-.017	.001	+.071	**-.302**	**.283**	-.002	+.004	.005
%EPT	-.003	-.0002	.004	**-.149**	-.016	.110	+.004	+.00003	.004
%OC	+.020	+.007	.014	**+.190**	+.004	.137	+.003	+.025	.011
NCBI	-.020	+.001	.004	-.042	+.117	.067	-.020	-.011	.015
%DOM	+.001	-.022	.006	-.005	+.002	.006	+.001	-.036	.016
%CLING	-.001	+.0002	.008	+.009	-.133	.060	-.002	-.091	.073
%NUTOL	+.009	+.001	.010	**+.221**	+.009	**.186**	-.003	+.013	.015

Table 4: Relationships (adjusted R^2) between nutrient levels, canopy cover and nine biometrics. Samples collected at 50 probabilistic monitoring sites and two reference sites. Values in bold are statistically significant ($p < 0.05$)

	All Seasons				Fall				Spring			
Biometric	**Canopy**	**Canopy NO2-3**	**Canopy TP**	**Canopy NO2-3 TP**	**Canopy**	**Canopy NO2-3**	**Canopy TP**	**Canopy NO2-3 TP**	**Canopy**	**Canopy NO2-3**	**Canopy TP**	**Canopy NO2-3 TP**
Count	108	106	106	106	16	16	16	16	92	90	90	90
TMI	+.0001	.002	.006	.007	**+.243**	.161	**.566**	**.549**	+.007	.007	.013	.002
TR	+.015	.003	.041	.013	+.080	.082	.084	.017	+.012	.001	.031	.023
EPT	-.0003	.007	.006	.007	+.053	.058	**.280**	.237	-.022	.017	.002	.025
%EPT	-.002	.003	.001	.003	+.039	.143	.078	.103	-.021	.002	.018	.026
%OC	**-.038**	**.051**	.061	**.089**	+.027	**.567**	.131	**.615**	**-.046**	.036	**.057**	**.064**
NCBI	+.028	.029	.015	.019	-.180	.054	**.417**	**.373**	**+.087**	**.108**	.089	**.108**
%DOM	+.0005	.00009	.002	.021	-.030	.033	.125	.126	+.001	.002	.028	.019
%CLING	-.0002	.011	.004	.013	+.221	.133	**.641**	**.626**	-.018	.006	**.055**	.078
%NUTOL	-.019	.001	.019	.021	+.001	.018	.082	.062	-.016	.015	.016	.017

West Fork Stones River in April 2000. High flows, cooler water temperatures and lower nutrient levels limit the amount of algal growth in the spring despite a lack of canopy.

Photo provided by David Stucki, Aquatic Biology, TDH

West Fork Stones River in October 2000. Lower flows and warmer temperatures, combined with elevated nutrient levels and sunlight contribute to the accelerated growth of algae.

Photo by Kim Sparks, WPC, TDEC

In addition to the amount of sunlight penetration, which helps regulate algae growth, canopy can also affect water temperature, leaf litter (a food source) and habitat availability. Therefore, additional regression analyses were conducted to determine if nutrient levels were the most significant factor in the relationship between canopy cover and macroinvertebrate populations.

The only biometric with a significant correlation with canopy when nutrients were not included was the fall TMI ($R^2 = 0.243$, $p = 0.04$). The correlation was much more pronounced ($R^2 = .566$, $p = .002$) when total phosphorus was added as a variable. The other metrics only showed a correlation with canopy when either NO2-3 or TP was included as an independent variable.

In order to further test the premise that the relationship canopy was measuring was directly related to nutrient levels and not an indication of increased habitat or food availability, regression analyses were conducted using the vegetative protection and riparian width scores of the habitat assessments (Table 5). These two components of habitat would most likely be associated with canopy measurements.

The vegetative protection score estimates the percent of each stream bank covered by native vegetation. Each bank is scored on a scale of 0 to 10. Banks with a mix of native vegetation including trees, understory shrubs, and macrophytes score higher than those dominated by fewer vegetation types. Trees are usually the absent vegetation type when scores are low. Even so, the vegetative protection score had very little correlation with percent canopy ($R^2 = 0.030$). A high level of bank vegetation does not necessarily mean a high percentage of canopy cover. The size and maturity of the vegetation as well as stream width play an important role.

Likewise, the width of the riparian zone did not correlate well with percent canopy ($R^2 = 0.048$). Once again, the size and maturity of the near-bank vegetation as well as the stream-width would affect the percent canopy.

Bank vegetation also appeared to have little relationship with macroinvertebrate populations when other variables were not included. The strongest correlation was only $R^2 = 0.072$ with the percent dominant taxon in the fall. Riparian zone width had a weak relationship similar to canopy cover for the NCBI, the percent dominant taxon and the percent clingers metrics in the fall but showed less correlation with the other four biometrics and the TMI.

Some biometrics, specifically those associated with EPT, percent dominant taxon and percent clingers, showed a slightly stronger response to the habitat parameters than to canopy in the spring However, canopy appeared to be a much more important component in the fall and exhibited strong relationships.

The habitat measures of bank vegetation and riparian width appear to be more important in spring while canopy is a bigger factor in the fall. In the spring, leaves are budding out and canopy is not fully developed. The median percent of canopy in spring was only 34%, while the median was 61% in the fall (Figure 28). Also, diurnal water temperatures are generally lower in spring and are not as conducive to accelerated algae growth. Finally, water levels are typically elevated in the spring which means a high potential for scouring in this bedrock dominated subregion, making it difficult for algae to become established.

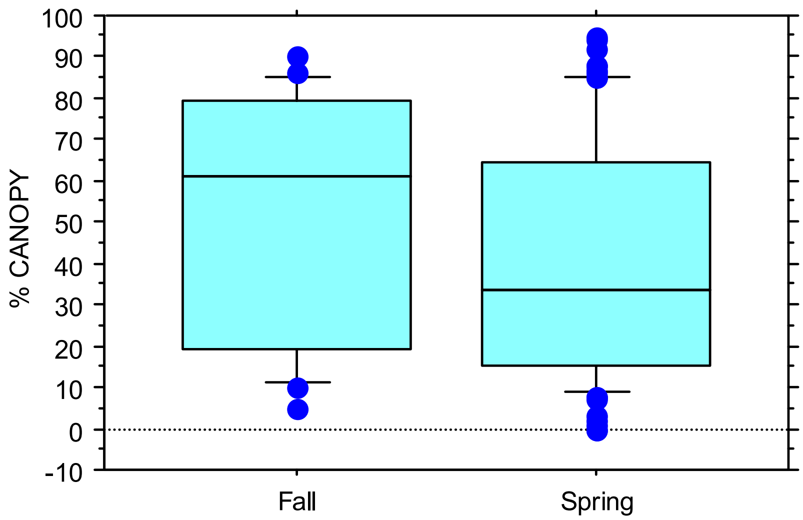


Figure 28: Seasonal comparison of percent canopy at 50 probabilistic sites and two ecoregion reference sites in the Inner Nashville Basin.

Table 5: Relationships (adjusted R^2) between macroinvertebrate populations, bank vegetation, riparian width, canopy and nutrient levels. Values in bold are statistically significant (p< 0.5). Data represent 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

Biometric	Fall				Spring			
	Bank Vegeta-tion	Riparian Width	Riparian Bank Veg. NO2-3	Riparian Bank Veg. TP	Bank Vegeta-tion	Riparian Width	Riparian Bank Veg. NO2-3	Riparian Bank Veg. TP
COUNT	28	28	26	26	105	105	100	100
TMI	+.002	+.033	.028	.034	**+.056**	+.027	.041	**.038**
TR	+.020	-.0004	.079	.027	+.015	+.031	.001	.012
EPT	+.052	+.021	.054	.056	+.008	+.016	.022	.016
%EPT	+.019	+.002	.036	.019	+.033	+.020	.011	.015
%OC	-.003	-.007	.086	.008	-.00005	+.002	.004	.002
NCBI.	+.001	-.126	.179	**.196**	-.022	-.004	.007	.004
%DOM	+.065	+.041	.068	.004	-.044	**-.038**	.019	.031
%CLING	+.003	**+.165**	.096	.112	**+.003**	+.012	**.071**	.049
%NUTOL	-.059	-.000001	.152	.069	-.018	**-.036**	.026	.017

The macroinvertebrate population showed little response to either bank vegetation or riparian width when combined with nutrients. There appeared to be a weak relationship between percent clingers and riparian width in the fall. However, the correlation with percent canopy and total phosphorus was much stronger (R^2 = 0.641, p = .0005).

The NCBI showed a relationship to total phosphorus when both riparian width and bank vegetation type were included as independent variables. The relationship was not as significant as the one between percent canopy and total phosphorus (R^2 = 0.417, p = .01).

Several weak correlations were observed in the spring. The biometrics which showed a significant (p <.05) relationship to either bank vegetation type or riparian width were the TMI, the percent dominant, the percent clingers and the percent nutrient tolerant organisms. Only the percent clingers demonstrated a slightly stronger correlation when a nutrient (NO2-3) was added as an independent variable.

Two different components of the macroinvertebrate community, the percent oligochaetes and chironomids and the North Carolina Biotic Index had shown correlations with percent canopy in the spring. Percent clingers also had a weak correlation with canopy and total phosphorus. Since similar relationships were demonstrated between bank vegetation type and percent canopy for this metric, it may be a response to habitat or food availability rather than sunlight when canopy is not as full as in the fall.

Since the strongest correlations were observed in the fall when dissolved oxygen and flow are lowest, data were tested to make sure these factors were not the primary influence on response of the macroinvertebrate community (Table 6). This had already been accounted for to some extent since fall data from nine sites where DO levels were less than 4 ppm and/or flow was not measurable were dropped prior to any analyses.

Only biometrics that did not demonstrate a relationship with canopy showed a correlation with DO. The %NUTOL showed a relationship when both dissolved oxygen and nitrate+nitrite were included as independent variables. However, this was not as strong as the relationship when nitrate+nitrite was the only variable. This metric had previously demonstrated no relationship to percent canopy. It appears that a factor other than algae growth or dissolved oxygen levels is affecting this group of organisms when nitrate+nitrite levels are elevated.

EPT taxa richness while demonstrating a negative correlation with total phosphorus had shown no relationship when percent canopy was included as a variable. Although a statistically significant correlation was observed with DO, flow and canopy as independent variables, none were as strong as total phosphorus alone (R^2= .302, p = .004). Neither DO nor flow had a significant correlation with EPT richness when total phosphorus was not included as a variable.

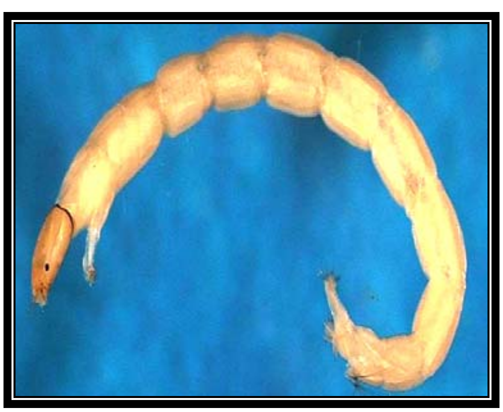
EPT abundance was not responsive to percent canopy but did show a relationship with flow and NO2-3. This was stronger than the relationship with NO2-3 as the only independent variable. It appears flow is a factor in the reduction of EPT abundance as nutrient levels increase. However, flow alone, had no significant relationship to EPT abundance without the additional stressor.

By correlating with flow levels, the North Carolina Biotic Index was the only biometric that demonstrated a direct relationship with either flow or dissolved oxygen. The NCBI score generally increased as flow levels decreased (R^2 = .173, p = .04). Higher NCBI scores indicate a more pollution tolerant macroinvertebrate community. This relationship was not observed when either nitrate+nitrite or total phosphorus was included with flow as independent variables. However, canopy appears to be a more significant factor than flow in the effect of total phosphorus on this biometric (R^2 = .417, p = .01).

Although flow alone did not affect the abundance of chironomids and oligochaetes, a correlation was observed when NO2-3 was added as a variable. However, the relationship with canopy and NO2-3 (R^2 = .567, p = 002) without regard to flow was much stronger.

Two metrics showed no response to DO or flow levels regardless of whether nutrients were included as variables. One of these was the percent clingers. This metric had shown a strong correlation (R^2 = .641, p = 0005) to canopy and total phosphorus. The other was the TMI, which combines all the metrics except %NUTOL. This metric had also shown a strong correlation to canopy and total phosphorus.

Neither dissolved oxygen nor flow levels greatly affected the relationship of metrics that had previously demonstrated a correlation with canopy and nutrient levels. However, flow and/or DO did increase the effects of nutrient levels on some components of the benthic community. This may be due to several reasons. Low flow reduces habitat availability for benthic organisms while at the same time making it easier for algae to attach to surfaces. Low dissolved oxygen places stress on the macroinvertebrate community making them more vulnerable to the presence of other pollutants. Sites with dissolved oxygen readings less than 4 ppm were discarded from the fall regression analyses. However these were daytime readings, the DO may have dropped lower at night especially if algae were abundant.



An increase in the abundance of chironomid (midge) larvae is usually associated with stressed conditions.

Table 6: Relationships (adjusted R^2) between macroinvertebrate populations and dissolved oxygen (DO), flow, canopy and nutrients (NO2-3 and TP) in the fall. Data in bold are statistically significant (*p* < 0.5). Data represent 50 probabilistic monitoring sites and two ecoregion reference sites in the Inner Nashville Basin.

Biometric	DO	Flow	DO NO2-3	DO TP	Flow NO2-3	Flow TP	DO Flow NO2-3	DO Flow TP	DO Flow TP NO2-3
COUNT	24	20	24	24	20	20	19	19	19
TMI	+.006	+.061	.026	.086	.008	.106	.136	.014	.178
TR	-.002	-.018	.028	.015	.087	.084	.102	.119	.128
EPT	+.005	+.035	.035	**.249**	.021	**.272**	.162	.220	.186
%EPT	-.002	+.168	.011	.016	**.286**	.122	.205	.075	.154
%OC	+.003	-.021	.086	.003	**.341**	.098	.206	.069	.202
NCBI.	-.022	**+.173**	.067	**.035**	.129	.179	.077	.116	.266
%DOM	+.035	-.007	.046	.039	.063	.064	.068	.075	.076
%CLING	+.001	+.102	.026	.085	.057	.139	.165	.092	.029
%NUTOL	+.0003	+.012	**.189**	.020	.032	.059	.060	.072	.133

4.5 Ecoregion Reference Stream Selection

Another objective of the study was to determine if the ecoregion reference streams that had been established in the Inner Nashville Basin were the best attainable. Additional sites from the probabilistic monitoring project were to be added or substituted for sites in the reference database if any were found to be equivalent or superior to existing reference sites.

It was especially difficult to locate acceptable reference streams in the Inner Nashville Basin during the initial ecoregion project. Only three streams were selected for monitoring. Of these, one was subsequently degraded by highway construction and dropped for reference consideration. This left two streams, one of which had observable agricultural impacts, to define reference condition for this difficult subregion. It was hoped that the probabilistic study could help determine if these two streams truly were the best attainable and most representative of the subregion.

After data analysis, it was found that four of the randomly selected sites had macroinvertebrate communities of equal or better quality than the established reference sites (Figure 29). These four sites (CEDAR0004.6WS, FALL003.6RU, HARPE105.7WI, LFLAT003.6MY) were added to the reference database and were used in refining biological, nutrient and pH criteria as well as dissolved oxygen and habitat guidelines in this subregion. With the addition of these new reference sites, four of the six watersheds found in the ecoregion were represented in the reference database (Old Hickory Reservoir, Stones River, Harpeth River, Upper Duck River). Unfortunately one of these sites, Fall Creek in Rutherford County, has since degraded due to land development and is no longer used as a reference stream.

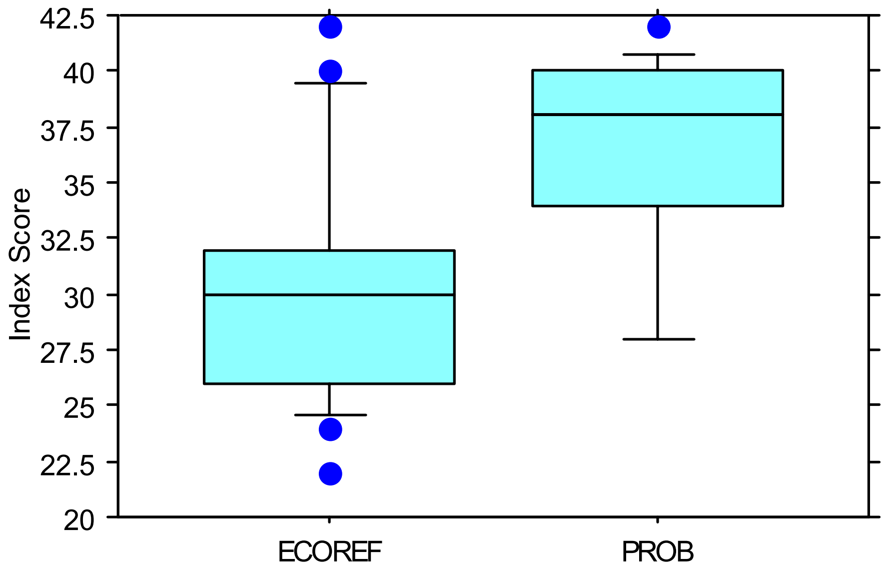


Figure 29: Comparison of Tennessee Macroinvertebrate Index scores between two ecoregion reference sites and four high quality probabilistic monitoring sites. Number of samples at ecoregion reference sites (ECOREF) is 18 collected 1996-2002. Number of samples from high quality probabilistic sites (PROB) is 11, collected between 2000-2002.

The seven biometrics used to evaluate the macroinvertebrate population were compared between the existing two ecoregion reference sites and the four sites identified through probabilistic monitoring using multivariate analysis and ordinal plots (Figure 30). The ordination method was non-metric multidimensional scaling (MDS). Distances between site pairs were determined using Gower's Similarity Coefficient. Based on biocriteria guidelines for this subregion, sites were grouped by sample type and season.

The analysis showed dissimilarity between the existing reference sites and the four new sites. As previously illustrated, the new sites generally had a more diverse and less pollution tolerant macroinvertebrate community as measured by the Tennessee Macroinvertebrate Index (TMI). This may be misleading since the established reference sites have been collected over a longer period of time and represent a larger data set with more varied climatic conditions. However, the probabilistic data has prompted moving one of the existing reference sites on the West Fork Stones River to a site with a more diverse benthic community. As more data are collected, results may warrant re-evaluating reference condition in this region.

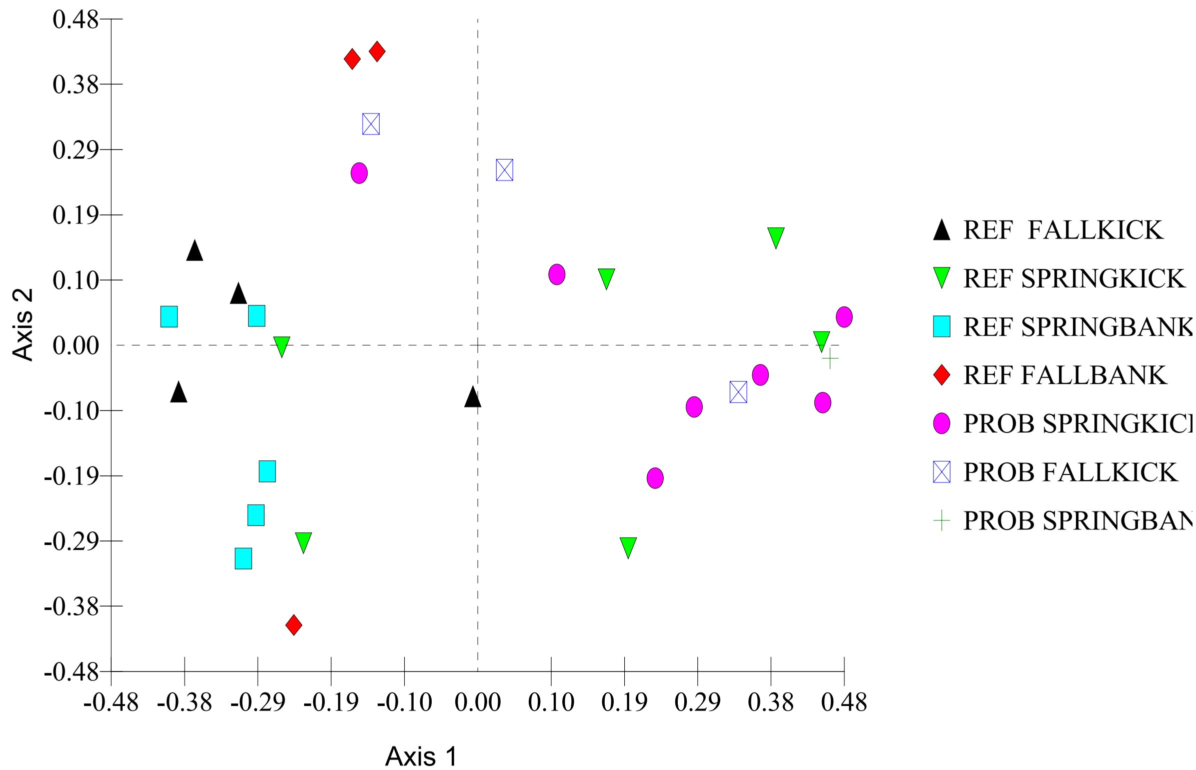


Figure 30: MDS ordination of seven biometrics between two ecoregion reference sites and four high quality probabilistic monitoring sites in the Inner Nashville Basin.

Since much of the land in the Inner Nashville Basin is used for agriculture, urban or other practices, all of the reference sites (new and established) had a significant portion of their upstream watersheds cleared of natural vegetation. Based on 1992 satellite imagery, in both the existing reference sites and the four new sites, often less than half of the upstream watershed was undeveloped (Figure 31).

Agriculture was the most prevalent land use with 35% to 77% of the land cleared for pasture or crops. Therefore, reference condition in this subregion is based on streams that may have been affected by these practices. However, these are the least impaired streams found through a combination of targeted and random monitoring. The Inner Nashville Basin does not extend beyond Tennessee so a broader base of stream data outside of state does not exist.

It is encouraging that three of these sites which have over half of their upstream drainage cleared for agriculture have macroinvertebrate populations comparable or even better than those with less development. The ability of these streams to support this quality of benthic community demonstrates that, with proper management practices, widespread use of land for agriculture does not necessarily result in stream impairment.

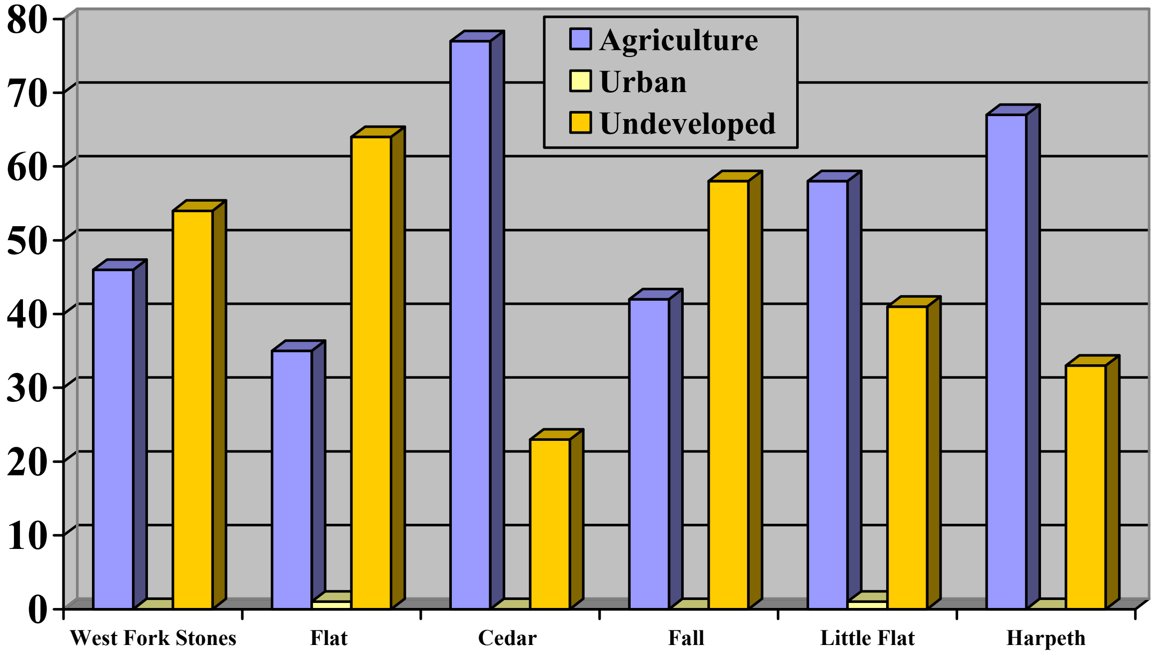


Figure 31: Percent land use upstream of two existing and four new ecoregion reference sites in the Inner Nashville Basin. Data based on 1992 satellite imagery.

4.6 Assessment Methodology

The final objective of the study was to develop assessment methodologies to distinguish naturally occurring environmental stresses in the Inner Nashville Basin from those caused by pollutants, land use and/or outside factors. To accomplish this goal, macroinvertebrate samples were collected in accordance with protocols established for the ecoregion reference project and used in biocriteria development. This involved a single habitat semi-quantitative sample technique. Because of the unique nature of the streams, this was the only subregion where two different sample types (riffle kick and rooted bank) were used depending on stream type and season.

The resulting data were then compared to the proposed biocriteria developed from the reference database to determine if the technique was responsive to various pollutants without imposing penalties for natural stressors. The majority of streams assessed in the probabilistic monitoring project had observable impacts from urban runoff, land development, habitat destruction, riparian loss, erosion and/or unrestricted livestock access. Comparison to the reference database using the seven metrics proposed for biocriteria, demonstrated that the assessment method was able to isolate impairment (Table 7). On the other hand, streams where limited impacts were observed in the field passed proposed biological criteria for the subregion.

Table 7: Biometrics and proposed biocriteria guidelines for the Inner Nashville Basin.

Bioregion 71i **Target Index Score (January – June) = 30** **Target Index Score (July – December) = 26**			**Method = SQKICK** **Order = 3, 4**	
Metric	**6**	**4**	**2**	**0**
Taxa Richness (TR)	> 23	16 – 23	8 – 15	< 8
EPT Richness (EPT)	> 7	5 – 7	2 – 4	< 2
% EPT	> 41.5	27.7 – 41.5	13.8 – 27.6	< 13.8
% OC	< 30.5	30.5 – 53.6	53.7 – 76.8	> 76.8
NCBI	< 5.54	5.54 – 7.02	7.03 – 8.51	> 8.51
% Dominant	< 39.6	39.6 – 59.7	59.8 – 79.8	> 79.8
% Clingers	> 41.5	27.7 – 41.5	13.8 – 27.6	< 13.8

Bioregion 71i **Target Index Score (January – June) = 32** **Target Index Score (July – December) = 24**			**Method = SQBANK** **Order = 3**	
Metric	**6**	**4**	**2**	**0**
Taxa Richness (TR)	> 32	22 – 32	11 – 21	< 11
EPT Richness (EPT)	> 7	5 – 7	3 – 4	< 3
% EPT	> 33.2	22.2 – 33.2	11.1 – 22.1	< 11.1
% OC	< 30.9	30.9 – 53.9	54.0 – 77.0	> 77.0
NCBI	< 6.87	6.87 – 7.91	7.92 – 8.96	> 8.96
% Dominant	< 34.9	34.9 – 56.5	56.6 – 78.2	> 78.2
% Clingers	> 21.3	14.2 – 21.3	7.0 – 14.1	< 7.0

As mentioned earlier, seasonality played a big part in this subregion. Over half the sites were dry, subterranean or reduced to isolated pools in the fall. Of those with year round flow, spring and fall assessments often did not agree. Seventy eight percent of the sites passed fall guidelines when the target index score is lower due to the presence of natural stressors such as high temperatures and low water levels that reduced habitat availability. However, one third of the sites passing fall guidelines failed spring guidelines when expectations, based on reference data, were higher.

It appears that assessments conducted in the late winter through early summer period (February through June) would provide the most accurate picture of the benthic population health. Surveys conducted during this time period would insure streams had adequate flow and supported the most diverse benthic community. Assessments would also be more comparable to reference streams that generally had extremely reduced flow in the dry season. Streams failing to meet guidelines in late summer or fall may be measuring natural stress or the amount of water available instead of pollution. On the other hand, streams passing fall guidelines may only be reflecting more year-round flow and therefore fewer natural stressors than was factored into the criteria based on the reference streams, which had extremely reduced or no fall flow.

5. CONCLUSIONS

Results from this study provided insight to each of the six project objectives. A primary objective of the study was to determine the relationship between the biological community and nutrient levels. Weak correlations were observed between three metrics (%EPT, %OC and %NUTOL) and nitrate+nitrite in the fall. EPT Richness was the only metric to exhibit a direct correlation with total phosphorus. Stronger correlations were observed when percent canopy was included as a variable. The %OC showed the strongest relationship to NO2+NO3 while the TMI, NCBI and percent clingers were responsive to total phosphorus. Relationships were weak in the spring.

These relationships were based on a single fall and two spring sampling event at each site. Additional data are needed to help confirm these preliminary findings. Results are only applicable to the Inner Nashville Basin. Macroinvertebrate, nutrient and canopy data from other ecoregions are needed to determine if similar relationships exist in other parts of the state.

Another objective of the study was to characterize water quality at each station. Fifty-four percent of the sites were assessed as impaired. This information was included in the 2002 305(b) report and the proposed final 2002 303(d) list. Despite the increased urbanization of the subregion, the majority of impaired sites were impacted by agricultural activities.

The third objective of the study was to extrapolate data to the entire subregion. The 31 impaired stream segments represented 57% of the assessed miles in the subregion.

The fourth objective of the study was to compare water quality assessment information extrapolated from the probabilistic sampling to historic assessments within 71i. Based on probabilistic data, 43% of the stream segments were fully supporting. Historic targeted monitoring assessed 65% of the streams as fully supporting. A combination of both probabilistic and targeted monitoring data was used to determine use support for streams in the Inner Nashville Basin. After data were combined, 57% of the stream miles in this subregion were assessed as fully supporting.

Another objective of the study was to determine if the ecoregion reference streams in the Inner Nashville Basin were appropriately selected. Results prompted relocating one of the two original reference sites and the addition of four new reference sites. As more data are collected, the reference condition in this subregion will continue to be evaluated.

The final objective of this study was to develop assessment methodologies to account for naturally occurring environmental stresses in the Inner Nashville Basin. The methodologies developed for the ecoregion reference project and used in biocriteria development proved suitable for this purpose. These methods have been included in the Division’s QS-SOP for macroinvertebrate surveys published in March 2002. Based on data analyses, it appears that assessments conducted in the late winter through early summer period would provide the most accurate assessment of the benthic population.

LITERATURE CITED

Arnwine, D.H., J.I. Broach, L.K. Cartwright and G.M. Denton. 2000. *Tennessee Ecoregion Project.* Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, Tennessee.

Arnwine, D.H. and G.M. Denton. 2001. *Development of Regionally-based Interpretations of Tennessee's Existing Biological Integrity Criteria.* Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, Tennessee.

Arnwine, D.H. and G.M. Denton. 2001. *Habitat Quality of Least-Impacted Streams in Tennessee.* Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, Tennessee.

Arnwine, D.H. and G.M. Denton 2002. *Inner Nashville Basin Probabilistic Monitoring Project.* Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, Tennessee.

Barbour, M.T., Gerritsen, J., Snyder, B.D. and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.* EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

Brightbill R.A. and E.H. Koerkle. 2003. *Relations of Biological Indicators to Nutrient Data for Lakes and Streams in Pennsylvania and West Virginia, 1990-998*. Water Resources Investigations Report 03-4033. U.S. Geological Survey, New Cumberland, Pennsylvania.

Brumley J.F., G.J. Pond and M.C. Compton. 2003. *Determining Nutrient Impairment Using Biological and Other Non-Chemical Indicators in Kentucky Streams.* Kentucky Department for Environmental Protection, Division of Water, Frankfurt, Kentucky.

Denton, G.M., D.H. Arnwine and S.H. Wang. 2001. *Development of Regionally-Based Interpretations of Tennessee's Narrative Nutrient Criterion.* Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville. Tennessee.

Denton, G.M., K.J. Sparks, D.H. Arnwine and L.K. Cartwright. 2002. *The Status of Water Quality in Tennessee: Year 2002 305(b) Report.* Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, Tennessee.

Griffith, G.E., J.M. Omernik and S. Azevedo. 1997. *Ecoregions of Tennessee.* EPA/600/R-97/022. NHREEL, Western Ecological Division, U.S. Environmental Protection Agency, Corvallis, Oregon.

Hoos, A.B., Hydrologist. February 23, 2003, personnel communication concerning unpublished data on the relation of water-column nutrient concentration and macroinvertebrate communities in the Tennessee River Basin, U.S. Geological Service, Water Resources Division, Nashville, Tennessee.

Lenat, D.R. 1993. *A biotic Index for the Southeastern United States: Derivation and List of Tolerance Values, With Criteria for Assigning Water Quality Ranges.* Journal of the North American Benthological Society 12:279-290.

North Carolina Department of Environment and Natural Resources. 2001. *Standard Operating Procedure for Benthic Macroinvertebrates*, Environmental Science Branch, Division of Water Quality, Raleigh, North Carolina.

Rosgen, Dave, 1996. *Applied River Morphology,* Wildland Hydrology, Pagosa Springs, Colorado.

SAS Institute, 1999. S*TATVIEW Reference*. SAS Institute Inc., Cary, North Carolina.

Tennessee Department of Environment and Conservation. 1998. *Final 1998 303(d) List.* Planning and Standards Section, Division of Water Pollution Control, Nashville, Tennessee. 35 pp.

Tennessee Department of Environment and Conservation. 2002. *Proposed Final 2002 303(d) List*. Planning and Standards Section, Water Pollution Control. Nashville, Tennessee. 117 pp.

Tennessee Department of Environment and Conservation. 1999. *Rules of the Tennessee Department of Environment and Conservation Division of Water Pollution Control*, Chapter 1200-4-3, General Water Quality Crigeria. Division of Water Pollution Control. Nashville, Tennessee.

APPENDIX A

PROBABILISTIC MONITORING SITE LIST

Station ID	Stream	Location	LAT _ DD	LONG_DD	Watershed	County	Topo
ALEXA004.0BE	Alexander Creek	1/4 mi u/s Pepper Hill Rd	35.6430556	-86.5215	TN06040002	Bedford	71NE
BARTO017.6WS	Bartons Creek	50 yards d/s Medlin Rd	36.15494	-86.34858	TN05130201	Wilson	314NE
BRADL003.8RU	Bradley Creek	80 yards d/s Rhodes Ln	35.93372	-86.26525	TN05130203	Rutherford	315NE
BROCK006.0ML	Big Rock Creek	100 yds d/s Verona	35.5313	-86.76867	TN06040002	Marshall	64SE
BUSHM002.2RU	Bushman Creek	100 yds u/s Osborne Rd	35.89635	-86.3725	TN05130203	Rutherford	315NE
CEDAR002.2MY	Cedar Creek	off Cedar Creek Rd	35.55297	-86.846	TN06040002	Maury	64SE
CEDAR004.6WS	Cedar Creek	Centerville Rd (0.5 mi S Hwy 141)	36.28425	-86.20339	TN05130201	Wilson	317SW
CEDAR011.8WS	Cedar Creek	50 yds u/s Old Railroad Rd	36.19489	-86.45936	TN05130201	Wilson	314NW
CHRIS000.7RU	Christmas Creek	500 yds d/s Crescent Rd	35.7447222	-86.4193333	TN05130203	Rutherford	78NW
CLEM000.4BE	Clem Creek	200 yds d/s Old Pencil Mill Rd	35.5946111	-86.55025	TN06040002	Bedford	71SE
CRIPP003.0RU	Cripple Creek	150 yds d/s Cranor Rd	35.85028	-86.26189	TN05130203	Rutherford	315SE
CROOK000.2MY	Crooked Creek	200 yds u/s Tom Lunn Rd	35.71153	-86.89589	TN06040003	Maury	64NW
DAVIS000.2BE	Davis Branch	300 yds u/s Richmond Pike	35.4526389	-86.50482	TN06040002	Bedford	72NE
EFSTO026.6RU	East Fork Stones River	400 yds u/s Guy James Rd	35.88561	-86.2972	TN05130203	Rutherford	315NE
EROCK020.8BE	East Rock Creek	100 yds d/s Pickle Rd	35.4218333	-86.6384167	TN06040002	Bedford	72NW
FALL003.0BE	Fall Creek	100 yds d/s Gregory Mill Rd	35.5650556	-86.5181111	TN06040002	Bedford	71SE
FALL003.6RU	Fall Creek	100 yds u/s Mona Rd	36.02894	-86.41381	TN05130203	Rutherford	314SW
FALL018.8WS	Fall Creek	Simmons Bluff Rd (0.7 mi E Salem)	36.02786	-86.26389	TN05130203	Wilson	314SE
FLORI002.4WS	Florida Creek	100 yds u/s Cainsville Rd	36.00297	-86.24194	TN05130203	Wilson	318SW
HARPE105.7WI	Harpeth River	125 yds d/s McDaniel Rd	35.83272	-86.70019	TN05130204	Williamson	70SW
HENRY001.5RU	Henry Creek	0.25 mile u/s Christiana Rd	35.70175	-86.3784167	TN05130203	Rutherford	78NW
HURRI002.0RU	Hurricane Creek	off Cobbs Rd, 0.3 mile East Hwy 41	35.72536	-86.30531	TN05130203	Rutherford	78NE
HURRI004.2BE	Hurricane Creek	200 yds u/s Midland Rd	35.5436389	-86.4619444	TN06040002	Bedford	78SW
JOHNS000.4WS	Johnson Creek	450 yds u/s Big Springs Rd	36.26794	-86.18542	TN05130201	Wilson	317SW
LFLAT003.6MY	Little Flat Creek	200 yds u/s Will Brown Rd	35.69903	-86.838872	TN06040002	Maury	64NE
LITTL001.8WS	Little Creek	150 yds d/s Mays Chapel Rd	36.25292	-86.48231	TN05130201	Wilson	313SW
LSINK001.0BE	Little Sinking Creek	100 yds d/s Simms Rd	35.4853056	-86.5819167	TN06040002	Bedford	72NE

Station ID	Stream	Location	LAT _ DD	LONG_DD	Watershed	County	Topo
LYTLE000.6RU	Lytle Creek	@ Old Stone Fort	35.85033	-86.40633	TN05130203	Rutherford	315SW
MCKNI001.2RU	McKnight Branch	Halls Hill Pk, 600 yds E Trimble Rd	35.867	-86.18869	TN05130203	Rutherford	319SW
MILL012.4DA	Mill Creek	300 yds u/s Antioch Pike	36.06847	-86.68528	TN05130202	Davidson	311SW
MILL021.2DA	Mill Creek	300 yds u/s Concord Rd	35.99511	-86.6905	TN05130202	Davidson	70NW
NFORK007.7BE	North Fork Creek	100 yds u/s Hwy 41A	35.584472	-86.616	TN06040002	Bedford	71SE
NFORK016.4BE	North Fork Creek	¼ mi d/s Squire Hall Rd	35.64025	-86.4379722	TN06040002	Bedford	78NW
OVERA009.4RU	Overall Creek	¼ mi d/s Mooreland Ln	35.83711	-86.48603	TN05130203	Rutherford	315SW
RICH000.5ML	Richland Creek	50 yds u/s Coble Rd	35.57739	-86.71058	TN06040002	Marshall	71SW
SINKI001.2BE	Sinking Creek	150 yds u/s Wheel Rd	35.5351111	-86.5896389	TN06040002	Bedford	71SE
SINKI004.0WS	Sinking Creek	Piedmont Rd (0.2 mi SW HWY 231)	36.185502	-86.29926	TN05130201	Wilson	314NE
SINKI008.9BE	Sinking Creek	200 yds u/s Grant Rd	35.4585	-86.6111	TN06040002	Bedford	72NE
SPENC005.0WS	Spencer Creek	75 yds d/s Northern Rd	36.266	-86.44361	TN05130201	Wilson	313SW
SPRIN004.4WS	Spring Creek	75 yds u/s Belotes Ferry Rd	36.27861	-86.29697	TN05130201	Wilson	313SE
SPRIN016.0WS	Spring Creek	200 yds u/s Hwy 141	36.20867	-86.23094	TN05130201	Wilson	318NW
SPRIN027.0WS	Spring Creek	100 yds u/s Chicken Rd	36.10686	-86.23656	TN05130201	Wilson	318SW
STEWA018.2RU	Stewart Creek	300 yds u/s Burnt Knob Rd	35.88228	-86.56733	TN05130203	Rutherford	70NE
SUGGS007.7WS	Suggs Creek	50 yds u/s Mt Juliet Rd	36.13017	-86.51817	TN05130203	Wilson	311NE
THICK02.0ML	Thick Creek	100 yds u/s Pyles Rd	35.65997	-86.73769	TN06040002	Marshall	71NW
WALLA000.8WI	Wallace Creek	200 yds u/s Flat Creek Rd	35.71686	-86.77778	TN06040002	Williamson	64NE
WEAKL005.2BE	Weakley Creek	150 yds u/s Coopertown Rd	35.6360278	-86.55025	TN06040002	Bedford	71NE
WFSTO013.6RU	West Fork Stones R.	600 yds d/s Compton Rd	35.89153	-86.42503	TN05130203	Rutherford	315NW
WFSTO023.2RU	West Fork Stones R.	100 yds u/s closed ford Barfield Rd	35.80539	-86.42519	TN05130203	Rutherford	315SW
WILSO005.2BE	Wilson Creek	100 yds u/s Chapel Hill/Unionville	35.6361667	-86.6226667	TN06040002	Bedford	71NE
Reference Sites							
ECO71I09	West Fork Stones R.	25 yds u/s Rock Springs Rd	35.0197222	-86.4666389	TN05130203	Rutherford	78NW
ECO71I10	Flat Creek	150 yds u/s Hazelwood Rd	35.68647	-86.80186	TN06040002	Marshall	64NE

APPENDIX B

PROBABILISTIC MONITORING FIELD DATA WITH LABORATORY ANALYSES OF CHEMICAL, BACTERIOLOGICAL AND BIOLOGICAL SAMPLES

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
ALEXA004.0BE	1/10/00	0905	14.50	75	20.0	20.0	124	1.35	0.020	1600	1600	8.79		9.9											
ALEXA004.0BE	4/13/00	1248	37.20	80	14.0	16.0	120	0.41	0.012	410	340	9.77	92	11.8	SQK	10	7	2	6.5	0.0	7.42	84.5	0.6	85.7	2
ALEXA004.0BE	5/10/01	1030	0.07	79	16.0	14.0	152	0.66	0.020	65	52	6.97	68	16.8	SQB	14	16	1	3.2	1.1	7.49	62.7	0.5	68.1	2
BARTO017.6WS	1/4/00	1145	9.43	5	3.0	1.0	68	1.26	0.150	2400	3500	10.61	99	11.2											
BARTO017.6WS	5/1/00	911	2.56	0	3.0	2.0	73	0.05	0.009	220	210	11.32	108	13.2	SQK	22	22	4	13.0	23.2	6.35	42.5	16.9	73.4	3
BARTO017.6WS	6/12/01	0830	0.06	10	7.0	3.0	105	0.04	0.080	130	110	5.20	57	18.9	SQK	18	30	2	2.4	77.1	5.73	30.7	9.0	34.3	3
BRADL003.8RU	1/31/00	0840	33.44	85	17.0	12.0	109	1.63	0.060	440	140	11.99	98	5.8											
BRADL003.8RU	4/13/00	1130	89.90	20	10.0	5.0	122	0.84	0.101	460	440	11.90		12.7	SQB	32	33	6	30.2	38.5	4.87	11.7	11.7	32.7	3
BRADL003.8RU	7/25/00	1150	0.08	20	13.0	15.0	109	0.57	0.017	70	110	11.20	134	23.9											
BRADL003.8RU	10/17/00	1100	0.02	40	14.0	8.0	108	0.43	0.048	15	13	10.90	118	18.1	SQB	28	32	4	14.2	14.2	6.65	14.7	13.2	17.6	4
BRADL003.8RU	6/1/01	0840	5.97	39	14.0	8.0	122	0.94	0.020	180	150	7.91	103	18.7	SQB	24	37	2	2.0	26.4	6.34	15.2	2.5	28.9	2
BROCK006.0ML	1/26/00	0915	47.63		11.0	9.0	145	2.58	0.240	140	83	10.98	94	6.8											
BROCK006.0ML	5/3/00	1000	70.00	10	18.0	13.0	155	0.68	0.100	99	110	8.84	90	16.3	SQK	28	21	4	4.3	16.7	4.58	54.1	61.6	84.9	1
BROCK006.0ML	7/13/00	0920	1.74	5	14.0	9.0	140	1.74	0.190	72	63	5.95	76	26.3											
BROCK006.0ML	10/30/00	0930	2.50		13.0	11.0	137	2.14	0.009	63	60	6.46	70	17.3	SQK	32	14	6	20.4	3.3	4.07	35.0	70.4	78.3	2
BROCK006.0ML	5/31/01	1130	22.46		15.0	18.0	143	1.72	0.380	300	190	8.85		18.2	SQK	30	19	5	13.0	15.7	5.04	50.0	67.4	83.9	
BUSHM002.2RU	1/31/00	1211	39.35	40	13.0	10.0	144	2.23	0.002	200	110	12.34	115	11.4											
BUSHM002.2RU	4/13/00	1400	82.80	40	11.0	12.0	120	0.67	0.043	550	470	11.00		13.3	SQK	34	40	14	29.1	31.8	4.12	18.7	25.3	37.4	3
BUSHM002.2RU	7/24/00	1240	1.26	35	15.0	13.0	128	0.61	0.002	300	120	9.80	116	24.1											
BUSHM002.2RU	10/18/00	1230	1.16	73	16.0	10.0	124	0.15	0.002	410	510	8.21	88	17.5	SQB	36	31	9	20.8	4.6	4.82	21.4	40.5	24.8	3
BUSHM002.2RU	6/4/01	1115	3.68	60	12.0	4.0	111	0.78	0.002	980	300	14.52	97	21.7	SQB	36	32	8	23.8	17.0	3.74	35.0	31.4	38.6	
CEDAR002.2MY	1/26/00	1100	2.12		11.0	5.0	111	1.65	0.007	44	24	13.78	101	2.4											
CEDAR002.2MY	4/11/00	0920	6.60	20	15.0	7.0	137	1.24	0.002	150		10.77	104	13.2	SQK	24	22	5	6.1	44.5	5.96	36.1	15.0	60.0	4
CEDAR002.2MY	5/31/01	1410	27.40	26	14.0	18.0	117	0.95	0.050	2400	5800	10.78	123	20.8	SQK	22	32	5	4.1	70.2	6.28	41.7	19.3	34.4	3
CEDAR004.6WS	1/13/00	1235	0.27	30	18.0	20.0	162	0.65	0.060	40	25	10.81	110	14.8											
CEDAR004.6WS	4/19/00	1244	35.50	10	8.0	9.0	142	0.51	0.060	110	77	12.30	127	16.8	SQK	38	29	9	38.3	22.1	4.64	19.4	40.5	45.0	2
CEDAR004.6WS	7/19/00	1125	0.06	30	18.0	13.0	135	0.21	0.100	580	510	7.01	87	21.3											
CEDAR004.6WS	11/1/00	1100	0.75	80	16.0	15.0	135	0.06	0.002	1200	540	2.31	24	16.4	SQK	38	31	9	19.3	13.5	4.05	24.2	78.9	68.2	2
CEDAR004.6WS	5/7/01	1330			18.0	12.0	157	0.31	0.090			9.52		22.6	SQK	36	34	12	23.1	30.7	4.72	21.8	44.5	66.8	

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
CEDAR011.8WS	1/5/00	1300	31.50		11.0	10.0	98	1.38	0.090	2400	2700	12.07	104	7.8											
CEDAR011.8WS	4/17/00	1240	24.40	11	12.0	12.0	108	2.83	0.050	160	120	12.66	127	15.2	SQK	40	28	9	35.8	25.6	5.11	19.5	49.3	48.4	3
CEDAR011.8WS	7/17/00	1030	0.20	15	14.0	13.0	106	0.15	0.009	35	46	11.82	151	28.1											
CEDAR011.8WS	10/30/00	1045	0.20	10	9.0	7.0	113	0.15	0.002	34	32	9.30	98	17.0	SQB	32	25	4	14.1	11.8	6.60	18.0	23.4	9.8	2
CEDAR011.8WS	5/29/01	1255	7.74	20	15.0	14.0	119	2.19	0.030	150	83	11.91	135	21.4	SQK	24	26	5	7.3	69.0	5.42	44.8	16.8	78.4	3
CHRIS000.7RU	1/11/00	1215	6.16	50	10.0	4.0	128	1.95	0.007	650	420	9.98	94	11.2											
CHRIS000.7RU	4/12/00	1215	36.40	85	11.0	16.0	120	0.53	0.020	2400	2100	10.90		14.1	SQB	22	29	6	5.5	30.7	7.59	38.7	1.5	51.5	2
CHRIS000.7RU	5/6/01	1250	0.30	92	12.0	4.0	99	1.28	0.002	370	260	5.80	65	17.4	SQB	20	29	2	2.3	13.6	7.57	42.3	9.1	17.3	2
CLEM000.4BE	2/7/00	1030	1.70		16.0	12.0	143	1.42	0.004	1	1	14.34	110	3.8											
CLEM000.4BE	4/17/00	0929	14.70	9	11.0	11.0	119	1.63	0.005	410	170	10.44	70	16.6	SQK	21	21	3	14.4	42.5	5.65	17.5	6.3	45.0	3
CRIPP003.0RU	5/1/96	1030					150	0.23	0.030		240	8.35		24.1											
CRIPP003.0RU	2/1/00	1020	0.78	60	18.0	20.0	143	1.40	0.002	67	38	12.90	103	4.4											
CRIPP003.0RU	4/11/00	1050	6.01	60	18.0	20.0	142	0.45	0.002	88		10.20		13.3	SQB	22	35	4	10.8	37.1	7.20	18.0	2.4	50.0	2
CRIPP003.0RU	7/25/00	0935	0.01	95		18.0	148	0.06	0.019	150	90	3.79	42	20.8											
CRIPP003.0RU	10/17/00	1010	0.01	81	15.0	16.0	135	0.03	0.057	10	13	4.20	42	14.6	SQB	34	22	4	70.0	4.0	4.24	41.7	46.2	4.4	
CRIPP003.0RU	6/4/01	1000	0.59	88	15.0	19.0	125	0.13	0.020	340	220	6.42		17.8	SQB	20	20	2	6.3	3.1	6.73	26.7	5.2	27.7	3
CROOK000.2MY	1/25/00	1015	2.48	55	10.0	5.0	111	0.52	0.120	53	25	13.50	96	1.5											
CROOK000.2MY	4/11/00	1205	2.30	70	10.0	6.0	104	0.14	0.002	30		10.07	95	12.1	SQB	14	11	3	8.2	1.8	7.26	84.1	1.2	84.7	
CROOK000.2MY	7/11/00	1030	0.03		8.0	6.0	116	0.51	0.070	370	400	2.28	26	21.7											
CROOK000.2MY	5/30/01	1230	0.18	88	11.0	9.0	112			1600	1100	8.65	91	16.9	SQK	22	32	2	5.1	49.4	6.19	25.3	7.3	41.6	2
DAVIS000.2BE	1/13/00	1130	0.15		2.0	0.0	89	1.39	0.040	130	85	13.14	131	13.7											
DAVIS000.2BE	4/18/00	1215	1.41	0	10.0	0.0	128	0.01	0.043	310	130	13.29	134	14.9	SQK	26	26	9	12.7	37.1	5.65	31.7	25.3	70.1	.3
DAVIS000.2BE	5/9/01	1230	0.04	18	10.0	0.0	88	0.04	0.040	120	120	13.01	150	22.6	SQK	22	32	5	6.0	62.5	6.81	18.0	10.0	53.0	2
ECO71I03	5/2/96	1205						0.38	0.020		210	9.12		14.9											
ECO71I03	7/26/96				15.0	12.0	142																		
ECO71I03	9/3/96	1140					134	0.68	0.090		13000	6.02		18.3											
ECO71I03	9/4/96	1130		63	16.0	8.0	129	0.70	0.113		1400	6.46		16.4											
ECO71I03	9/5/96	1111			16.0	8.0	119	0.76	0.112		2100	6.34		16.8	SQK	26	26	5	12.6	74.8	5.49	29.8	19.8	46.2	1
ECO71I03	11/25/96	0910						0.64	0.030		450	8.61		14.2											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
ECO71I03	11/26/96	0905	43.21					0.55	0.020		1400	8.62		13.3											
ECO71I03	11/27/96	1500						0.57	0.103			8.98		13.2											
ECO71I03	2/6/97	1400	63.82					0.38	0.105		120	9.88		12.2											
ECO71I03	4/23/97	1015	4.40	63	16.0	15.0	139	0.36	0.007		230	10.50		13.6	SQK	40	28	9	56.0	21.0	4.19	28.0	37.5	32.0	
ECO71I03	10/1/97	1530	0.80	90	16.0	12.0	127	2.32	0.590		200			16.7	SQK	24	27	3	5.8	51.7	6.05	31.6	24.7	30.4	
ECO71I03	11/24/97	1300	7.67					1.33	0.101		106	9.09		12.6											
ECO71I03	2/25/98	1445						0.61	0.060	55	31	10.70		13.8											
ECO71I03	10/31/01	0855	1.89					0.73	0.002	72	52	7.91		11.5											
ECO71I03	11/28/01	0930	27.45					0.95	0.183	2400	4000	7.39		14.6											
ECO71I03	12/19/01	0925	32.11					0.71	0.103	110	67	7.31		13.2											
ECO71I03	1/15/02	0920	5.52					0.62	0.032	34	51	10.18		9.3											
ECO71I03	2/25/02	0910	12.76					0.47	0.060	53	59	10.22		12.0											
ECO71I03	3/7/02	0940	9.79					0.56	0.060	32	32	9.70		12.2											
ECO71I03	4/16/02	0925	12.50					0.60	0.040	520	410	8.68		14.8											
ECO71I03	5/8/02	0925	28.16					0.62	0.040	210	300	8.93		15.0											
ECO71I03	6/24/02	0915	0.76					0.55	0.326	440	320	5.90		20.2											
ECO71I09	5/1/96	0900						0.26	0.020		340	10.60		13.0											
ECO71I09	7/18/96				16.0	14.0	121																		
ECO71I09	9/3/96	0940						0.30	0.053		1000	4.75		20.4											
ECO71I09	9/4/96	0900			16.0	17.0	131	0.35	0.032		156	5.04		20.4											
ECO71I09	9/5/96							0.32	0.032		160	3.80		20.5											
ECO71I09	10/8/96				17.0	13.0	134								SQK	34	40	9	55.5	12.1	6.74	48.7	21.3	7.7	
ECO71I09	11/25/96	1015						0.88	0.015		240	9.26		13.4											
ECO71I09	11/26/96	1010	30.13					0.50	0.055		1700	9.50		11.0											
ECO71I09	11/27/96	1400						0.78	0.029			10.96		10.1											
ECO71I09	2/6/97	1245	26.06					0.58	0.024		170	11.81		10.1											
ECO71I09	4/23/97	1300	60.89		14.0	14.0	130	0.25	0.002		500	10.30		15.0	SQB	42	45	12	44.4	24.0	5.81	27.1	24.4	14.2	
ECO71I09	10/1/97	1130			9.0	8.0	114	1.41	0.023		280			18.0	SQ	22	36	4	5.6	46.9	5.57	22.8	13.6	58.0	3
ECO71I09	11/13/97	1000	2.88					0.98	0.002		43	10.13		8.5											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	ºC											
ECO71I09	2/25/98	1330						0.64	0.002	20	19	12.16		13.1											
ECO71I09	4/27/98	1300	10.36					0.37	0.002	190	160	11.65		15.4											
ECO71I09	5/19/98				14.0	13.0	125					11.65			SQB	30	43	8	9.2	26.6	6.64	30.7	6.9	41.7	4
ECO71I09	9/1/98	1000			17.0	16.0	143	0.39	0.020	170	300	9.09		21.8	SQB	32	44	8	6.7	60.7	5.87	15.2	31.5	37.1	
ECO71I09	12/2/98	1145						0.02	0.060	29	20	9.16		11.3											
ECO71I09	2/16/99	1200	14.60					0.75	0.010	77	45			12.0											
ECO71I09	6/3/99	1000	0.29		13.0	13.0	117	0.34	0.020	20	340	4.78		21.6	SQB	28	42	6	13.9	32.6	5.80	20.3	22.5	9.6	
ECO71I09	1/11/00	0845	12.86	5	16.0	11.0	169	2.76	0.002	310	450	8.78		9.8											
ECO71I09	4/19/00	1100	15.55	8			148	0.82	0.002	68	83	12.22	121	14.3	SQK	38	23	6	53.3	28.8	3.97	26.6	51.1	17.9	2
ECO71I09	10/17/00	1145						0.14	0.174	13	12	2.53		14.8											
ECO71I09	6/11/01	1040	2.20		8.0	2.0	103	0.88	0.040	1300	470	7.86		18.7	SQK	26	37	9	8.4	78.1	5.55	31.6	38.6	74.4	3
ECO71I09	10/11/01	1000	0.98					0.47	0.036	280	870	6.27		16.2											
ECO71I09	11/28/01	1055	5.34					0.56	0.014	380	300	7.28		15.1											
ECO71I09	12/4/01	0950	9.55					1.25	0.026	330	370	10.09		12.4											
ECO71I09	1/3/02	1030	2.88					0.99	0.033	140	140	12.51		5.0											
ECO71I09	2/12/02	0925	15.75					0.67	0.030	140	90	10.38		8.0											
ECO71I09	3/19/02	0925	83.99					0.61	0.040	730	770	9.91		13.5											
ECO71I09	4/18/02	1010	5.46					0.41	0.002	310	400	9.75		18.7											
ECO71I09	6/25/02	0945	2.12		18.0	16.0	147	0.15	0.023	460	430	6.23		23.1											
ECO71I10	5/20/96	1125						0.35	0.090		80	9.40		22.7											
ECO71I10	9/3/96	1324						0.09	0.220		4100	7.01		21.8											
ECO71I10	9/4/96	1245	1.00		18.0	16.0	131	0.03	0.189		700	8.65		23.0											
ECO71I10	9/5/96	1115						0.03	0.130		210	7.65		22.2											
ECO71I10	10/18/96				20.0	4.0	98								SQB	28	27	2	44.2	10.8	7.22	43.9	16.6	4.7	
ECO71I10	11/19/96	1115						0.67	0.184		1500	10.74		12.5											
ECO71I10	11/20/96	1143						0.57	0.020		640	11.53		10.8											
ECO71I10	11/21/96	1105						0.54	0.001		380	9.75		12.8											
ECO71I10	2/10/97	1040	28.30					0.49	0.030		180	14.60		6.2											
ECO71I10	4/28/97	1115	6.21					0.04	0.002		110	10.84		14.8											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
ECO71I10	5/1/97				18.0	16.0	165					10.84			SQB	30	43	8	21.4	57.8	6.80	20.8	9.9	48.4	3
ECO71I10	10/9/97	1100			20.0	20.0	128	0.04	0.150		52	8.02		20.8	SQB	30	23	2	37.3	5.6	6.99	36.6	23.6	4.3	
ECO71I10	11/13/97	1300	0.64					0.03	0.090		25	11.36		8.4											
ECO71I10	2/25/98	1155						0.37	0.080	36	26	14.46		10.5											
ECO71I10	4/27/98	1100	12.18					0.03	0.040	180	180	10.00		15.4											
ECO71I10	5/19/98				20.0	19.0	154					10.00			SQB	26	32	3	2.9	39.3	6.56	11.7	16.3	23.8	2
ECO71I10	12/2/98	1330						0.02	0.320	46	59	10.19		12.9											
ECO71I10	2/16/99	1330	25.89					0.60	0.090	130	130			10.7											
ECO71I10	6/8/99	1430	0.09		20.0	10.0	113	0.29	0.110	7	300	8.60		30.5	SQB	30	37	5	17.0	12.0	7.20	27.8	8.5	10.8	
ECO71I10	11/9/99	1250	0.06					0.25	0.240	76	320	13.30		18.6											
ECO71I10	1/6/00	1400	12.66					0.73	0.100	1700	1700	14.79		7.3											
ECO71I10	1/25/00	0910	16.68				161	0.39	0.020	150	130	13.69	96	1.1											
ECO71I10	4/6/00	1320						0.50	0.110	200	250	12.60		16.4											
ECO71I10	4/12/00	0930	77.18	30	18.0	16.0	159	0.29	0.165	2000	3800	11.30	106	12.0	SQK	36	24	6	20.1	26.1	5.01	18.1	55.3	55.8	
ECO71I10	5/30/01	1000	0.94		11.0	20.0	131	0.06	0.120	120	93	7.39		18.3	SQK	26	27	6	11.4	69.9	5.73	24.9	33.2	65.3	2
ECO71I10	9/11/01	1230						0.03	0.160	55	55														
EFSTO026.6RU	1/31/00	1030	211.9	10	10.0	14.0	105	1.75	0.050	390	190	12.46	104	6.4											
EFSTO026.6RU	4/11/00	0900	250.8	10	9.0	13.0	107	0.80	0.030	140		9.90		13.1	SQB	32	44	12	19.0	35.8	5.06	28.5	8.9	53.6	2
EFSTO026.6RU	7/25/00	1050	8.74	35	9.0	10.0	109	0.09	0.033	90	83	7.20	85	23.4											
EFSTO026.6RU	10/18/00	1010	5.61	64	12.0	6.0	117	0.06	0.002	66	66	5.70	62	17.2	SQ	36	23	6	70.6	5.8	3.98	15.5	38.0	26.7	3
EFSTO026.6RU	6/4/01	1200	52.30	7	14.0	8.0	127	0.92	0.150	200	90	11.71		20.4	SQ	18	13	7	20.7	60.9	4.99	60.4	13.6	83.4	2
EROCK020.8BE	1/13/00	0850	3.30	10	14.0	0.0	144	3.42	0.180	930	170	10.19	95	10.7											
EROCK020.8BE	4/18/00	0855	14.65		12.0	2.0	109	0.46	0.106	290	320	10.28	98	12.4	SQK	36	20	7	40.9	15.2	4.65	29.8	64.3	50.3	3
EROCK020.8BE	5/9/01	0945	0.60	28	16.0	6.0	142	2.02	0.200	290	300	7.90	80	17.8	SQK	18	24	1	7.3	71.3	6.73	18.8	9.9	58.8	3
FALL003.0BE	1/12/00	0945	12.10		12.0	6.0	150	2.19	0.002	120	100	10.41	89	7.4											
FALL003.0BE	4/13/00	1137	156.2	40	9.0	3.0	106	0.92	0.066	1100	1000	10.36	98	12.3	SQK	24	15	5	26.4	3.9	6.21	54.5	16.3	64.6	2
FALL003.0BE	5/8/01	1100	3.86	59	16.0	12.0	159	0.24	0.030	490	510	7.80	88	19.9	SQK	38	34	9	42.4	21.5	5.07	25.0	22.0	42.0	3
FALL003.6RU	10/21/99	1045					104			980	1010	8.27		10.6											
FALL003.6RU	1/6/00	1031	133.5	15	16.0	14.0	104	2.36	0.080	2400	4300	11.12	101	10.2											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	ºC											
FALL003.6RU	1/11/00	1100								411	250	9.84		6.0											
FALL003.6RU	5/1/00	1023	54.54	20	17.0	14.0	110	0.24	0.140	30	18	12.70		16.0	SQK	40	28	10	38.2	7.8	4.10	28.4	57.4	57.8	4
FALL003.6RU	10/31/00	1016	0.10	15	17.0	15.0	139	0.07	0.002	34	56	5.59		17.8	SQK	28	24	4	27.3	2.1	5.75	26.5	21.0	19.7	4
FALL003.6RU	5/7/01	1530		15	17.0	14.0	119	0.05	0.020			14.20	161	21.9	SQB	28	26	4	17.5	9.5	5.11	24.5	13.0	36.0	3
FALL003.6RU	10/30/01	1410	5.81					0.12	0.073	46	47	5.54		13.7											
FALL003.6RU	11/6/01	1400	5.81					0.15	0.069	40	18	12.87		12.1											
FALL003.6RU	12/3/01	1450	55.20					0.55	0.056	460	320	11.36		13.5											
FALL003.6RU	1/10/02	1350						0.26	0.033	91	80	14.77		9.6											
FALL003.6RU	2/14/02	1405						0.23	0.020	17	7	14.58		11.8											
FALL003.6RU	3/12/02	1345						0.15	0.020	35	22	12.56		11.6											
FALL003.6RU	5/29/02	1320	9.83					0.02	0.002	150	100	17.10		22.2											
FALL003.6RU	6/12/02	1320	1.76					0.01	0.002	19	12	13.52		29.7											
FALL018.8WS	1/6/00	0830	29.96	60	18.0	14.0	136	2.69	0.110	2400	2700	11.10	95	3.3											
FALL018.8WS	4/18/00	1100	24.90	45	14.0	14.0	125	0.01	0.088	220	200	13.23	125	12.9	SQK	34	28	7	17.4	23.7	4.99	45.5	59.8	66.5	2
FALL018.8WS	5/30/01	1015	5.97	84	13.0	6.0	112	0.08	0.160	73	110	6.10	67	19.2	SQK	30	31	7	13.4	45.5	5.49	30.6	32.4	72.2	3
FLORI002.4WS	1/4/00	0945	6.00	5	4.0	2.0	64	0.76	0.200	2400	3000	10.49	98	11.1											
FLORI002.4WS	4/18/00	0912	9.50	28	4.0	2.0	76	0.01	0.086	330	220	11.71	109	12.5	SQK	32	24	8	17.2	18.3	5.78	37.4	17.7	64.0	3
FLORI002.4WS	10/31/00	1330	0.10	15	13.0	5.0	95	0.06	0.169	44	35	12.97	156	23.6	SQK	26	20	3	46.1	3.7	6.55	44.2	4.1	17.5	3
FLORI002.4WS	5/30/01	0832	0.29	47	12.0	5.0	104	0.09	0.230	160	200	6.08	66	18.6	SQK	32	34	7	11.0	36.4	5.35	23.2	52.6	71.3	4
HARPE0105.7WI	1/24/00	1015	49.89	15	12.0	6.0	130	1.05	0.170	130	80	11.94	82	3.1											
HARPE0105.7WI	5/3/00	1230	43.66	20	18.0	10.0	148	0.55	0.110	200	190	10.83	118	19.4	SQK	40	32	9	44.6	23.2	5.47	28.0	32.2	21.8	3
HARPE0105.7WI	7/13/00	1220	0.70	25	9	5	108	0.50	0.160	410	370	6.24	80	26.9											
HARPE0105.7WI	10/31/00	1003	0.09		7.0	11.0	100	0.09	0.920	83	48	10.10	10	17.7	SQK	34	25	3	16.9	14.8	5.15	26.5	42.9	58.2	3
HARPE0105.7WI	5/9/01	1430		50	18.0	11.0	125	0.42	0.250	75	80	9.78		20.0	SQK	42	30	10	42.4	21.7	4.55	21.2	45.3	51.2	
HARPE0105.7WI	10/9/01	1340	11.34					0.93	0.211	550	400	10.39		14.7											
HARPE0105.7WI	11/8/01	1330	5.03					0.21	0.153	25	53	11.48		11.3											
HARPE0105.7WI	12/12/01	1215	187.5					1.11	0.142	370	330	10.12		12.7											
HARPE0105.7WI	1/29/02	1230						0.96	0.190	110	100	10.39		13.0											
HARPE0105.7WI	2/21/02	1235	77.29					0.26	0.120	160	130	12.92		11.0											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	ºC											
HARPE0105.7WI	3/18/02	1010						0.37	0.390	2400	7800	9.47		13.1											
HARPE0105.7WI	4/10/02	1305	104.1					0.35	0.070	420	230	11.16		15.7											
HARPE0105.7WI	5/23/02	1300						0.83	0.131	2400	93	12.86		16.0											
HARPE0105.7WI	6/11/02	1130	3.03					0.72	0.220	460	410	6.62		19.4											
HARPE0105.7WI	6/21/02	1400		72			128					7.14		25.3											
HENRY001.5RU	1/11/00	1115	0.85	65	4.0	4.0	108	2.13	0.002	520	270	10.24	91	8.8											
HENRY001.5RU	4/12/00	1033	9.60	85	6.0	4.0	97	0.25	0.002	1400	2900	10.80		13.0	SQK	18	17	5	8.8	9.8	7.24	73.5	10.3	85.8	2
HURRI002.0RU	2/3/00	1200	2.89		6.0	6.0	83	1.34	0.010	44	9	13.80	115	6.3											
HURRI002.0RU	4/12/00	0900	59.00		10.0	5.0	106	0.34	0.020	1400	2100	10.60		12.5	SQK	14	13	6	6.4	2.0	7.43	90.1	2.0	91.3	3
HURRI002.0RU	6/5/01	0850	0.64	9	9.0	2.0	99	0.19	0.002	31	24	10.82	124	21.0	SQK	22	25	4	3.0	51.5	6.56	30.3	9.1	66.2	3
HURRI004.2BE	1/12/00	1115	3.17	10	10.0	0.0	115	2.53	0.002	2400	2300	12.26	109	8.8											
HURRI004.2BE	4/19/00	0830	8.34	3	13.0	4.0	107	0.45	0.005	350	280	11.64	110	12.1	SQK	16	13	4	5.7	11.4	7.61	44.0	6.3	90.3	.3
HURRI004.2BE	5/10/01	1230	0.72	8	4.0	4.0	102	0.04	0.009	550	270	14.77	169	22.6	SQK	24	28	4	5.3	16.2	5.26	46.1	6.1	83.8	4
JOHNS000.4WS	1/3/00	1050	0.06	10	13.0	11.0	80	0.45	0.070	820	900	9.47	100	17.4											
JOHNS000.4WS	4/19/00	1125	3.14	20	13.0	11.0	90	0.25	0.060	140	65	14.14	147	17.6	SQK	38	36	10	25.5	18.1	5.24	27.9	44.1	39.2	3
JOHNS000.4WS	7/19/00	1030	0.04	30	15.0	12.0	109	0.06	0.100	2000	1600	3.62	50	26.0											
JOHNS000.4WS	5/31/01	0950	0.74	70	14.0	8.0	117	0.12	0.090	290	580	8.79	95	18.0	SQK	32	31	5	8.5	24.2	5.43	30.0	40.2	73.5	4
LFLAT003.6MY	1/25/00	0930			13.0	7.0	131	0.35	0.008			14.37	103	1.4											
LFLAT003.6MY	1/26/00	0945	4.43					0.35	0.008	1600	350	14.37		1.4											
LFLAT003.6MY	4/11/00	1045	5.01	25	18.0	8.0	141	0.10	0.002	410		10.70	101	12.4	SQK	40	26	10	48.1	30.0	4.55	23.0	50.8	31.1	3
LFLAT003.6MY	5/9/01	1200		65	18.0	15.0	103	0.10	0.060		200	8.15		19.1	SQK	34	27	6	37.1	24.1	5.76	18.8	37.1	4026	
LFLAT003.6MY	9/12/01	1150						0.02	0.040		47	5.40		19.5											
LITTL001.8WS	2/3/00	0900	0.66	80	4.0	2.0	95	1.24	0.040	47	32	10.50	96	9.8											
LITTL001.8WS	4/17/00	1046	2.30	80	4.0	3.0	100	0.72	0.097	1300	1000	10.40	102	13.8	SQK	34	23	10	29.4	11.9	5.70	33.0	34.5	50.5	2
LITTL001.8WS	5/29/01	1003	0.93	94	12.0	7.0	118	0.75	0.160	980	450	7.50	76	14.6	SQB	28	38	3	2.7	40.4	5.94	13.4	16.7	62.9	2
LSINK001.0BE	2/7/00	0900	1.09	10	12.0	4.0	98	1.71	0.010	80	45	13.43	101	3.0											
LSINK001.0BE	4/18/00	1115	5.11	10	10.0	2.0	83	0.01	0.045	2400	3900	10.46	103	13.4	SQK	22	17	4	2.6	6.3	6.76	58.7	21.7	87.3	4
LSINK001.0BE	5/9/01	1130	0.07	40	8.0	4.0	89	0.26	0.060	86	73	9.29	97	17.5	SQK	30	28	4	34.2	11.8	5.32	31.6	7.2	83.5	3
LYTLE000.6RU	2/3/00	1340	12.29		13.0	17.0	114	1.63	0.010	16	12	15.57	130	6.4											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
LYTLE000.6RU	4/3/00	1015	266.3	30	15.0	13.0	122	0.49	0.150	2400	4900	8.35	88	15.9	SQK	18	24	3	2.9	79.6	6.83	38.8	5.0	88.3	3
LYTLE000.6RU	7/24/00	1110	1.83	38	13.0	12.0	109	0.89	0.029	490	900	9.40	111	23.7											
LYTLE000.6RU	10/16/00	1230		34	18.0	17.0	146	0.41	0.048	190	200	12.34	138	18.5	SQK	28	21	3	17.1	5.9	3.67	48.7	33.7	74.9	3
LYTLE000.6RU	6/1/01	1120	2.52	32	15.0	12.0	137	1.02	0.040	330	250	12.14	145	23.1	SQK	30	16	4	30.7	8.5	3.98	47.2	37.7	79.4	
MCKNI001.2RU	2/1/00	0800	0.07	85	17.0	15.0	113	2.44	0.002	2	2	8.30	63	3.7											
MCKNI001.2RU	4/11/00	1150	0.08	85	15.0	15.0	105	0.04	0.002	170		10.20		13.1	SQB	18	24	3	2.1	6.8	7.80	66.1	1.6	84.8	3
MILL012.4DA	1/24/00	1315	26.16		16.0	9.0	120	0.63	0.120	240	42	16.16	122	3.7											
MILL012.4DA	4/10/00	1200	77.97	15	16.0	15.0	140	0.28	0.160	110	80	13.40	129	13.0	SQK	28	29	6	20.0	66.0	4.46	11.9	15.7	65.9	2
MILL012.4DA	7/10/00	1150	0.89	25	14.0	11.0	124	0.04	0.230	33	57	6.34	87	29.1											
MILL012.4DA	10/31/00	1320	0.01		11.0	13.0	109	0.08	0.367	28	27	4.09		20.1	SQB	22	20	2	8.2	8.2	4.82	31.1	9.2	35.2	3
MILL012.4DA	6/12/01	1320	10.95	44	15.0	14.0	120	0.35	0.350	160	200	9.26	111	24.8	SQB	24	34	1	1.0	44.8	6.46	13.4	12..9	43.8	3
MILL021.2DA	1/24/00	1200	13.51	30	16.0	9.0	154	1.33	0.170	19	7	14.90	114	3.7											
MILL021.2DA	4/10/00	1020	28.24	50	16.0	12.0	145	0.54	0.140	36	200	13.49	124	11.2	SQK	28	27	5	14.0	61.3	5.23	15.6	19.9	69.9	2
MILL021.2DA	7/10/00	1000	0.01	45	16.0	10.0	131	0.17	0.060	41	30	2.61	31	23.7											
MILL021.2DA	10/31/00	1230	0.01		12.0	11.0	89	0.10	0.230	61	100	0.90	10	18.3	SQB	24	24	1	30.7	0.5	6.91	30.7	6.8	18.2	3
MILL021.2DA	5/31/01	0800	2.44	95	12.0	4.0	121					11.44	131	21.5	SQK	28	16	4	12.6	5.0	5.09	35.1	38.3	55.4	3
NFORK007.7BE	2/1/00	0900	28.50	10	14.0	6.0	137	2.80	0.002	160	190	12.12	90	2.7											
NFORK007.7BE	4/17/00	1030	58.50	15	16.0	6.0	149	2.83	0.018	120	93	10.72	112	16.4	SQK	26	17	6	18.1	18.1	6.27	52.2	18.1	71.4	2
NFORK007.7BE	5/8/01	1200	2.41	69	16.0	6.0	138	0.21	0.040	2400	3600	7.47	83	19.5	SQB	34	30	6	19.2	25.4	6.59	28.8	26.0	64.4	3
NFORK016.4BE	1/11/00	0945	0.71	75	16.0	20.0	146	5.49	0.030	730	530	9.05	80	8.2											
NFORK016.4BE	4/19/00	1000	0.89	30	16.0	14.0	87	1.53	0.040	490	340	8.96	86	12.6	SQK	16	16	3	1.8	11.0	7.36	79.7	2.6	82.8	2
NFORK016.4BE	5/10/01	1315	0.02	62	10.0	14.0	125	0.76	0.020	310	240	7.17	71	17.0	SQK	18	12	2	9.6	2.3	7.42	32.8	3.4	45.2	2
OVERA009.4RU	2/2/00	1020	10.01	60	17.0	14.0	122	1.12	0.002	120	50	12.68	105	6.2											
OVERA009.4RU	4/10/00	0850	37.80		16.0	18.0	124	0.69	0.040	82	31	10.80		11.8	SQK	34	43	15	35.8	33.3	4.45	15.8	20.8	22.9	3
OVERA009.4RU	7/24/00	0830	0.01	65			125	3.40	0.002	190	1500	5.10	56	19.7											
OVERA009.4RU	10/16/00	1055	0.01	86	8.0	10.0	91	1.96	0.032	340	320	6.04	60	14.5	SQB	36	29	5	28.3	16.8	4.49	30.4	29.8	42.4	2
OVERA009.4RU	6/11/01	1142	0.13	83	12.0	4.0	95	2.39	0.020	96	320	8.07	83	18.0	SQB	34	41	6	11.9	20.1	5.17	26.8	19.6	39.2	3
RICH000.5ML	1/27/00	0900	4.92		9.0	7.0	121	1.63	0.007	96	73	12.43	86	0.5											
RICH000.5ML	5/3/00	1055	15.36	35	14.0	11.0	144	1.05	0.002	610	440	9.94	104	17.2	SQK	26	21	5	12.1	39.7	5.28	19.5	24.7	55.2	2

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
RICH000.5ML	5/31/01	0630	6.05	87	8.0	11.0	111	1.69	0.180	2400	1100	7.99	84	17.0	SQK	20	32	4	2.9	71.2	6.63	21.5	7.3	59.0	2
SINKI001.2BE	1/12/00	0850	1.77	5	14.0	11.0	130	1.64	0.002	200	280	9.98	86	7.6											
SINKI001.2BE	4/13/00	0945	89.60	10	14.0	9.0	149	0.72	0.088	870	430	10.46	99	12.5	SQK	24	20	6	8.6	24.0	6.29	47.2	20.9	77.3	2
SINKI001.2BE	7/24/00	0810	0.01		16.0	10.0	98	0.23	0.640	140	210	6.27	72	21.0											
SINKI001.2BE	5/8/01	0950	0.10	28	16.0	12.0	139	0.07	0.060	1300	1000	6.89	76	19.3	SQK	18	26	1	5.7	73.1	6.57	24.0	9.7	22.8	3
SINKI004.0WS	1/4/00	1315	0.42	5	2.0	3.0	64	0.83	0.640	2400	20000	7.74	72	11.7											
SINKI004.0WS	4/18/00	1331	0.04	30	3.0	3.0	41	0.01	0.048	2400	1100	6.84	69	16.1	SQK	12	18	1	0.6	26.0	8.49	59.9	1.1	23.7	2
SINKI004.0WS	5/31/01	1335	0.01	58	12.0	3.0	79	0.50	0.110	2400	4500	6.53	69	20.6	SQB	10	10	0	0.0	4.5	8.11	75.0	0.6	5.1	0
SINKI008.9BE	1/13/00	1035	4.48	11	4.0	0.0	105	2.97	0.070	290	360	11.75	109	10.4											
SINKI008.9BE	4/18/00	1010	20.40	45	8.0	2.0	110	0.01	0.076	650	270	12.03	117	13.3	SQK	28	19	6	12.0	30.1	5.62	25.7	33.3	74.9	2
SINKI008.9BE	7/26/00	1010	0.01		14.0	4.0	66	0.03	0.030	120	110	7.70	91	22.6											
SINKI008.9BE	5/9/01	1015	0.46	44	10.0	6.0	122	0.12	0.140	690	590	8.72	92	18.5	SQK	32	24	6	14.7	13.2	5.96	21.8	34.5	71.1	3
SPENC005.0WS	1/5/00	1015	18.20	45	14.0	9.0	134	1.83	0.100	2400	1800	12.28	104	7.3											
SPENC005.0WS	4/17/00	0904	18.90		12.0	7.0	118	2.83	0.031	920	770	8.70	89	15.2	SQK	12	15	1	1.9	1.4	7.26	69.1	8.2	19.3	3
SPENC005.0WS	7/17/00	0811	0.12	70	10.0	9.0	78	0.04	0.060	1700	1200	3.87	44	21.7											
SPENC005.0WS	10/30/00	0830	0.01		15.0	3.0	126	0.15	1.210	41	120	0.86	8	15.0	SQB	26	25	1	13.5	21.3	7.10	17.4	17.4	86.5	3
SPENC005.0WS	5/29/01	0845	8.04	70	14.0	10.0	121	0.27	0.050	440	370	6.50	72	17.0	SQK	22	30	4	6.4	52.6	6.61	19.2	13.5	52.6	3
SPRIN004.4WS	1/5/00	0800	102.2	70	14.0	11.0	118	1.52	0.300	2400	19000	10.60	93	8.6											
SPRIN004.4WS	4/19/00	1351	67.21	40	14.0	8.0	112	0.13	0.070	180	87	13.46	143	18.2	SQK	34	35	10	24.2	23.0	5.78	22.9	22.1	53.3	3
SPRIN004.4WS	7/19/00	1240	0.50	20	17.0	11.0	125	0.16	0.300	90	550	7.77	102	27.0											
SPRIN004.4WS	11/1/00	0827	0.01	79	16.0	7.0	131	0.05	0.509	54	41	2.60	27	16.3	SQB	32	33	4	5.6	5.8	6.92	19.8	15.7	9.3	3
SPRIN004.4WS	5/31/01	1110	9.22	64	15.0	8.0	123	0.05	0.100	110	410	8.30	93	19.8	SQB	30	61	7	10.2	43.5	6.17	11.6	19.0	26.8	3
SPRIN016.0WS	1/3/00	1010	0.73	30	11.0	12.0	113	0.20	0.060	41	40	9.45	90	12.3											
SPRIN016.0WS	4/19/00	0915	46.05	20	10.0	10.0	106	0.19	0.080	240	200	10.20	97	13.3	SQK	36	30	10	39.1	18.7	5.57	24.0	35.6	57.8	3
SPRIN016.0WS	7/19/00	0830	0.27	30	12.0	5.0	108	0.32	0.300	190	190	4.76	64	26.0											
SPRIN016.0WS	11/1/00	1237	0.70	61	13.0	3.0	124	0.05	0.548	190	190	1.21		18.5	SQB	26	25	2	33.0	8.9	7.09	32.5	5.9	6.9	2
SPRIN016.0WS	5/31/01	0814	19.70	68	12.0	2.0	108	0.09	0.200	580	590	6.40	73	20.4	SQB	26	49	4	5.2	37.8	6.78	12.2	12.2	24.4	4
SPRIN027.0WS	1/4/00	0805	23.14	15	2.0	2.0	72	1.73	0.100	2400	20000	9.23	87	12.1											
SPRIN027.0WS	4/18/00	1228	6.60	10	2.0	2.0	77	0.01	0.237	530	330	12.84	124	13.8	SQB	36	30	9	25.2	3.8	6.29	45.7	27.4	67.5	2

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	ºC											
SPRIN027.0WS	7/18/00	1020	0.01		5.0	4.0	84	0.23	0.002	770	930	5.32	66	23.4											
SPRIN027.0WS	5/30/01	1054	0.94	65	2.0	2.0	82	0.02	0.150	1000	1200	13.79	162	22.2	SQB	18	40	2	5.2	31.2	7.76	15.6	1.6	27.6	2
STEWA018.2RU	2/1/00	1020	10.08	60	10.0	4.0	111	1.11	0.020	100	110	8.94	90	12.8											
STEWA018.2RU	4/10/00	0750	30.05	50	7.0	3.0	109	0.53	0.030	56	63	7.94	76	13.1	SQB	30	37	6	12.5	34.3	8.82	23.1	13.9	45.8	2
STEWA018.2RU	7/10/00		2.12	60	14.0	2.0	123	2.58	0.090	770	870	4.13	44	16.0											
STEWA018.2RU	5/29/01	1200		1	12.0	7.0	118	1.11	0.070	310	310	8.26	77	15.0	SQB	24	29	2	8.3	33.2	6.04	22.4	18.0	40.0	2
SUGGS007.7WS	1/6/00	1300	46.80	5	6.0	4.0	69	0.90	0.020	1700	1000	11.67	96	6.2											
SUGGS007.7WS	5/1/00	1220	17.30	20	9.0	2.0	91	0.12	0.002	150	120	9.12	92	16.0	SQB	18	27	2	1.2	73.7	5.76	31.7	4.8	73.6	3
SUGGS007.7WS	6/12/01	1020	0.76	23	11.0	2.0	101	0.20	0.020	130	130	9.50	109	22.3	SQB	20	29	2	2.8	38.8	6.42	23.6	3.9	38.2	3
THICK002.0ML	1/24/00	0800	1.87		13.0	8.0	136	0.47	0.040	230	230	12.65	91	1.6											
THICK002.0ML	4/12/00	0745	13.46	10	15.0	4.0	131	0.18	0.083	2000	2800	9.96	10	11.7	SQK	12	14	1	2.8	8.4	7.59	73.6	5.1	89.3	3
THICK002.0ML	5/29/01	1015	0.01	86	15.0	11.0	98	0.24	0.090	120	180	8.90	99	19.6	SQK	12	13	1	0.5	3.8	7.71	72.7	0.5	89.6	2
WALLA000.8WI	2/7/00	1145	0.17	30	3.0	5.0	97	0.19	0.070	55	27	16.74	136	6.3											
WALLA000.8WI	4/12/00	1140	4.68	75	9.0	4.0	120	0.30	0.080	2400	4100	11.66	115	14.4	SQK	30	22	8	25.4	23.2	5.27	46.4	22.3	53.6	4
WEAKL005.2BE	1/10/00	1040	12.46	2	6.0	2.0	103	2.54	0.100	2400	2100	9.67		9.5											
WEAKL005.2BE	4/17/00	1140	9.29	2	4.0	2.0	109	1.51	0.019	260	300	13.37	136	16.0	SQK	14	14	3	8.1	69.4	5.48	62.4	4.6	77.4	3
WEAKL005.2BE	5/8/01	1330	0.04	45	4.0	0.0	98	0.19	0.050	800	770	6.90	77	19.5	SQK	18	31	3	2.7	66.5	7.77	33.0	5.5	49.4	3
WFSTO013.6RU	1/27/00	1200	81.70	10	19.0	19.0	137	1.62	0.002	1	3	14.54	108	2.7											
WFSTO013.6RU	4/19/00	1310	218.3	30	14.0	20.0	128	0.65	0.020	28	21	14.35	150	16.7	SQB	22	37	4	6.4	47.9	7.06	19.7	5.3	27.6	3
WFSTO013.6RU	7/26/00	1215	3.27		14.0	19.0	126	0.14	0.018	20	4	9.00	112	26.7											
WFSTO013.6RU	10/18/00	1320	0.77	21	18.0	12.0	117	0.13	0.002	140	120	6.94	75	18.6	SQB	22	20	2	2.2	4.0	7.37	37.4	26.0	22.0	2
WFSTO013.6RU	6/1/01	0945	21.70	51	17.0	18.0	133	0.49	0.002	64	83	9.44	112	22.9	SQB	30	36	5	8.8	10.6	7.26	22.0	16.7	14.1	2
WFSTO023.2RU	2/2/00	1240	52.26	20	15.0	13.0	120	1.91	0.002	17	5	14.40	120	6.5											
WFSTO023.2RU	4/10/00	1130	108.0		14.0	15.0	121	0.81	0.020	72	55	12.00		13.6	SQK	24	35	3	12.1	25.1	6.34	26.4	2.9	52.9	3
WFSTO023.2RU	7/24/00	0945	0.96	20	15.0	17.0	120	0.98	0.002			5.60	61	19.1											
WFSTO023.2RU	10/16/00	0849	0.24	23	18.0	5.0	98	1.11	0.013			4.65	47	15.7	SQK	32	37	11	22.5	23.1	6.11	29.6	16.6	23.1	4
WFSTO023.2RU	6/1/01	1220	7.11	14	18.0	8.0	118	0.63	0.002	22	15	8.78	100	20.5	SQK	34	34	8	24.6	34.3	3.78	26.7	40.3	56.8	3
WILSO005.2BE	5/20/96							2.05	0.002		1100														
WILSO005.2BE	1/10/00	1225	8.66	15	5.0	3.0	82	2.95	0.060	2400	4000	8.12	77	11.2											

Station	Date	Time	Flow	Can	Veg	Rip	Hab	NO2_3	P	EC	FC	DO	Sat	Temp	Mac	TMI	TR	EPT	%EPT	%OC	NCBI	%D	%CL	%NUTOL	Algae
			cfs	%				mg/l	mg/l			ppm	%	°C											
WILSO005.2BE	4/17/00	0805	16.22	10	16.0	4.0	109	1.60	0.097	610	410	8.22	83	15.1	SQK	22	20	3	2.7	22.0	6.19	35.7	6.0	76.9	3
WILSO005.2BE	10/16/00	0945	0.03	5	6.0	0.0	64	0.99	0.037	2400	18000	6.96	67	14.0	SQK	26	26	2	9.9	29.1	6.22	33.7	18.0	48.2	2
WILSO005.2BE	5/10/01	0930	1.18	22	2.0	0.0	73	1.26	0.030	2400	3100	8.60	88	18.2	SQK	18	13	3	6.3	1.6	3.23	79.4	1.1	89.6	2

Legend

Can = Percent Canopy (measured by spherical densiometer)
Veg = Vegetative Protection Score (habitat assessment form)
Rip = Riparian Vegetation Zone Score (habitat assessment form)
Emb = Embeddedness Score (habitat assessment form)
Sed = Sediment Deposition Score (habitat assessment form)
Hab = Total Habitat Assessment Score
NO2_3 = Nitrate+Nitrite
P = Total Phosphorus
EC = *E. coli*
FC = Fecal Coliform
DO = Dissolved Oxygen
Sat = Percent Oxygen Saturation

Temp = Water Temperature
Mac = Macroinvertebrate Semiquantitative Sample (SQK = Kick or SQB = Bank)
TMI = Tennessee Macroinvertebrate Index
TR = Taxa Richness
EPT = Ephemeroptera, Plecoptera, Trichoptera Richness
%EPT = Ephemeroptera, Plecoptera, Trichoptera Abundance
%OC = Oligochaeta and Chironomidae Abundance
NCBI = North Carolina Biotic Index
%D = Percent Contribution of Dominant Taxon
%CL = Clinger Abundance
%NUTOL = Percent of Nutrient Tolerant Organisms (Kentucky SOP)
Algae = Estimated Algae Abundance

APPENDIX C

2002 WATER QUALITY ASSESSMENTS OF STREAM SEGMENTS ASSOCIATED WITH 71I PROBABILISTIC MONITORING SITES

STATION ID	SEGMENT	SUPPORT RATING	STREAM MILES	SOURCE	CAUSE
ALEXA004.0BE	TN06040002039-0300	Partial	21.1	Pasture Grazing	Siltation Pathogens
BARTO017.6WS	TN05130201055-1000	Partial	16.9	Urban Runoff/Storm sewers Land Development Collection System Failure	Nitrate Siltation Pathogens
BRADL003.8RU	TN05130203029-1000	Fully	29.0		
BROCK006.0ML	TN06040002012-1000	Fully	11.0		
BUSHM002.2RU	TN05130203023-0200	Fully	5.9		
CEDAR002.2MY	TN06040002008-1000	Fully	13.6		
CEDAR004.6WS	TN05130201011-1000	Fully	11.9		
CEDAR011.8WS	TN05130201011-1000	Fully	11.9		
CHRIS000.7RU	TN05130203018-0210	Not	12.3	Pasture Grazing	Siltation Pathogens
CLEM000.4BE	TN06040002039-0100	Partial	14.2	Pasture Grazing	Nutrients Pathogens
CRIPP003.0RU	TN05130203025-1000	Partial	7.7	Pasture Grazing	Siltation
CROOK000.2MY	TN06040003034-0700	Partial	2.5	Pasture Grazing	Habitat Alterations
DAVIS000.2BE	TN06040002024-0100	Partial	2.2	Pasture Grazing	Siltation
EFSTO026.6RU	TN05130203023-1000	Fully	19.7		
EROCK020.8BE	TN06040002012-0150	Fully	37.5		
FALL003.0BE	TN06040002038-1000	Partial	11.4	Pasture Grazing	Pathogens Nutrients Siltation Habitat Alterations
FALL003.6RU	TN05130203032-1000	Fully	14.7		
FALL018.8WS	TN05130203032-2000	Fully	16.0		
FLORI002.4WS	TN05130203032-0500	Fully	18.3		

STATION ID	SEGMENT	SUPPORT RATING	STREAM MILES	SOURCE	CAUSE
HARPE076.0WI	TN05130204018-	Fully	4.7		
HENRY001.5RU	TN05130203021-0320	Partial	4.2	Pasture Grazing	Siltation
HURRI002.0RU	TN05130203036-1000	Partial	8.5	Industrial Point Source Land Development Hwy/Rd/Bridge Construction	Nutrients Siltation Organic Enrichment/Low DO
HURRI004.2BE	TN06040002038-0300	Partial	29.4	Pasture Grazing	Pathogens Nutrients Siltation Habitat Alterations
JOHNS000.4WS	TN05130201015-0200	Partial	7.6	Pasture Grazing	Pathogens
LFLAT003.6MY	TN06040002049-0200	Fully	18.3		
LITTL001.8WS	TN05130201001T-1500	Fully	4.2		
LSINK001.0BE	TN06040002021-0100	Partial	7.6	Pasture Grazing	Siltation Habitat Alterations
LYTLE000.6RU	TN05130203022-1000	Not	9.0	Urban Runoff/Storm Sewers Hydromodification	Siltation Oil & Grease Habitat Alterations
MCKNI001.2RU	TN05130203026-0200	Partial	18.8	Pasture Grazing	Habitat Alterations
MILL012.4DA	TN05130202007-3000	Partial	5.9	-Collection System Failure Urban Runoff/Storm Sewers	Siltation Organic Enrichment/Low DO Pathogens
MILL021.2DA	TN05130202007-5000	Partial	8.1	Minor Municipal Point Source Livestock in Stream	Nutrients Siltation Organic Enrichment/Low DO
NFORK007.7BE	TN06040002039-2000	Partial	4.0	Agriculture	Pathogens
NFORK016.4BE	TN06040002039-3000	Partial	9.2	Agriculture	Siltation Pathogens
OVERA009.4RU	TN05130203015-2000	Fully	10.9		

STATION ID	SEGMENT	SUPPORT RATING	STREAM MILES	SOURCE	CAUSE
RICH000.5ML	TN06040002010-0100	Fully	22.3		
SINKI001.2BE	TN06040002021-1000	Partial	12.0	Pasture Grazing	Siltation Habitat Alterations
SINKI004.0WS	TN05130201055-0250	Not	10.0	Collection System Failure Pasture Grazing Urban Runoff/Storm Sewers	Habitat Alterations Pathogens
SINKI008.9BE	TN06040002021-2000	Partial	14.4	Pasture Grazing	Siltation Habitat Alterations
SPENC005.0WS	TN05130201001T-1400	Partial	11.6	Pasture Grazing	Nutrients Pathogens
SPRIN004.4WS	TN05130201013-2000	Fully	10.0		
SPRIN016.0WS	TN05130201013-3000	Fully	8.7		
SPRIN027.0WS	TN05130201013-4000	Partial	9.0	Pasture Grazing Livestock in Stream	Pathogens
STEWA018.2RU	TN05130203010-2000	Fully	7.1		
SUGGS007.7WS	TN05130203232-1000	Partial	18.1	Pasture Grazing	Siltation
THICK02.0ML	TN06040002048-0100	Partial	13.4	Pasture Grazing	Siltation Habitat Alterations Pathogens
WALLA000.8WI	TN06040002049-0400	Partial	3.8	Pasture Grazing	Pathogens
WEAKL005.2BE	TN06040002039-0250	Partial	13.1	Agriculture	Siltation Pathogens
WFSTO013.6RU	TN05130203018-2000	Partial	5.1	Land Development	Siltation
WFSTO023.2RU	TN05130203018-3000	Partial	15.2	Pasture Grazing Land Development	Siltation
WILSO005.2BE	TN06040002046-1000	Partial	19.5	Pasture Grazing	Pathogens Nitrate Habitat Alterations