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ACKNOWLEDGEMENTS

Completion of this project was dependent upon EPA’s management and the talents of numerous individuals within and outside of EPA. Special thanks is extended to EPA Region 4's Administrator, Mr. John Hankinson, for his financial support and faith in the Savannah REMAP team. Likewise, appreciation goes to Russ Wright, Director of Region 4's Science and Ecosystem Support Division (SESD), Delbert Hicks, Chief of the Ecological Assessment Branch (EAB), Antonio Quinones, Acting Chief of the EAB, and Meredith Anderson, EPA Region 4's Savannah River Basin Coordinator for their support over the life-time of the project. Trudy Stiber, Mel Parsons, Bo Noakes, and Jim Davee of the EAB contributed significantly to the graphics of this report. Jim Harrison, Dave Melgaard, Jim Greenfield, John Greis, John Deatrick, Dan Ahern and Larry Burns deserve a special thanks for their ideas and critiques of the early work. Gratitude is extended to Don Schultz and Alana Conley of the Algal Assay Laboratory who provided timely assistance. Thanks also to David Millie and Larry Boihem of USDAs Southern Regional Research Center and Lila Melendez and Arthur Burks of the Region 4 Analytical Support Branch (ASB) for their assistance in HPLC analysis. Additionally, we would like to thank Jenny Scifres, Anthony Carroll, Tom Sack, and Pam Betts of ASB for phosphorus and solids analyses. Kent Thornton, Don Stevens Jr., Steve Paulsen, Steve Weisberg, Gary Saul, and Christina Laurin of the the Office of Research and Development’s EMAP team provided invaluable assistance during the planning and data evaluation stages. Special acknowledgement is due Jim Maudsley and his team who assisted in the field sampling and development of guidelines for locating and accessing the sites. Likewise, a special debt of gratitude is extended to Mike Van Den Avayle of the National Biological Survey who worked with us on an interagency agreement that provided the services of Dr. Steven Rathbun of the University of Georgia. Dr. Rathbun was invaluable in providing statistical guidance and significant work products during the study. Likewise, the expertise of Dr. Bud Freeman of the University of Georgia was most helpful during confirmation of fish species.

The cooperation of the state’s of Georgia and South Carolina was the key to accomplishing numerous tasks from the planning stage through the field work and review of reports. We especially extend our thanks to Alan Halum, Mork Winn, Trish Foster, David Kamps and Bill Kennedy of the Georgia Environmental Protection Division and Lonnie Dorn of the Georgia Department of Natural Resources; Butch Younginer, Kathy Stecker, Harry Gaymon, Rick Renfrow, Jim Glover,Scott Castleberry, Chad Altman,and Dave Chestnut of the South Carolina Department of Health and Environmental Control for their steadfast assistance.

Finally, we owe a debt of gratitude to the many private homeowners, lumber/paper companies, and forest mangers who permitted access through their properties to the sites.

SUMMARY

The Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) is an outcome of EPA's National Eutrophication and Acid Lake Monitoring Programs of the 1980s. EMAP is a statistical sampling program that has adopted a uniform approach for national and regional monitoring assessments across ecosystem types. EMAP uses a serially alternative probability-based sampling design that systematically allocates sampling effort over space and time to ensure adequate coverage followed with randomization to ensure unbiased estimates of status throughout the life of a project. The design does not rely on assumptions of population distribution, but describes the underlying structure of the population of interest. The approach is flexible and applicable to all landscape media. It has the ability to increase or reduce sampling density down to the ecoregion level, respond quickly to environmental problems, maintain representative coverage of environmental resources, and provide for sampling of fewer sites in an area but over rotating cycles. Through this project, an interval-overlap technique is presented that minimizes the loss of monitoring data when the EMAP approach is incorporated into a fixed station (judgement) monitoring program. The technique uses a back-prediction method with a bias-corrective factor to best fit the two types of monitoring derived data.

In cooperation with EMAP's desire to transfer this monitoring approach to the EPA regions and states, Region 4 established the Regional Environmental Monitoring and Assessment Program (REMAP). Region 4 teamed with scientists and managers in EPA's Office of Research and Development and the states of Georgia and South Carolina to conduct a demonstration of the new monitoring approach, answer questions about probability sampling and analysis, and address the concerns about the ecological condition of streams and large lake tributary embayments in the Savannah River Basin.

From a basin perspective, the tributary embayments with regard to trophic condition are in good condition. At worst, only about 5% of the acreage exhibited less than desirable conditions. There appeared to be a general decline southward with respect to stream EPT Index, dissolved oxygen, and conductivity. Average stream temperatures increased southward. Water quality violations were noted for dissolved oxygen and pH. A dissolved oxygen violation was noted on an unnamed tributary to Cliatt Creek in Columbia County, Georgia. Likewise about 8% of the stream miles were less than both state's pH standard of 6.0 and 2% of the miles were greater than the allowable South Carolina standard. An examination of basin-wide stream conditions over a two-year period indicated that up to 52% of the

stream miles were in poor ecological condition.

Because of a sufficient number of reference and sampling stations in the Lower Piedmont Ecoregion, EPA scientists focused on that scale in assessing stream condition over a four-year period. Consolidating information from an EPT Index, Fish Index, and Habitat Score, scientists developed a Lower Piedmont Ecological Index (LPEI). The LPEI showed that 69% of the Ecoregion’s stream miles are in fair to poor ecological condition. Most of this adverse impact is attributed to habitat degradation in the form of excessive sedimentation. One area of the landscape along the I85 corridor showed an unusually high number of poor stream sites and it is the conclusion of the scientists that this area is in need of further study.

1.0 INTRODUCTION

1.1 PURPOSE

Responding to increased population growth and demands for multiple uses of natural resources, The Environmental Protection Agency (EPA) established the Watershed Protection Approach (WPA) in 1991 (EPA, 1991; 1996). The WPA is a program for identifying and preventing environmental problems, setting priorities, and developing solutions through an open, inclusive process with the people (stakeholders) who live in a geographical setting. Consideration of economic prosperity and environmental well-being is the cornerstone of WPA. The Savannah River Basin was one of two areas selected in 1993 for the WPA in Region 4 because of its high public use, known environmental problems, susceptibility for further degradation, interest in participation by the users, and the likelihood of success. Through the WPA initiative, EPA Region 4 brought together scientists and stakeholders who developed a strategy to provide an ecological focus for resolving problems. This strategy gave birth to the Savannah River Basin Watershed Project (SRBWP) (Management Committee, 1995). The goal of the SRBWP is to develop and implement a multi-agency environmental protection management project which incorporates the authorities and expertise of all interested parties in an effort to accomplish the vision of conserving, restoring, enhancing, and protecting the Basin’s ecosystems in a way that allows the balancing of multiple uses. Further details on objectives and issues within the basin can be found in Volume I of the “SRBWP Initial Assessment and Prioritzation Report” by the Management Committee (1995). Part of the SRBWP strategy included a monitoring component, The Regional Environmental Monitoring and Assessment Program (REMAP)(FTN et al., 1994).

Environmental monitoring programs have developed in response to specific needs, such as compliance monitoring by regulating agencies responsible for the condition of surface waters, or fixed-station monitoring networks that primarily address indicators of exposure and stress. Some of the monitoring programs are driven by mandates in the Clean Water Act (CWA). The reports required by Sections 305(b) and 314 of the CWA are an example. Programs that collect data on other ecosystem types have also been established. For example, the U. S. Department of Agriculture (USDA) National Agricultural Statistical Survey collects data for agricultural resources; The Forest Service’s Inventory and Analysis Surveys analyze forest resources; and the U. S. Geological Survey’s National Water Quality Assessment (NAWQA) program monitors water quality in selected basins. None of the programs, however, have adopted a uniform approach for national and regional assessments across and among ecosystem types. The Environmental Monitoring and Assessment Program (EMAP) and its counterpart, REMAP, is intended to fill that gap by providing the U. S. EPA Administrator, Congress, and the public with statistical data summaries and periodic interpretative reports on ecological status and trends. Because knowledge about uncertainty is important for interpreting quantitative environmental data, EMAP is designed to make rigorous uncertainty estimates as well (Larsen et al., 1991).

The REMAP was developed as a partnership between EMAP, EPA's Regional Offices, and States to promote the use of EMAP science. The objectives of REMAP follow:

1. **To evaluate and improve EMAP concepts for State and local use.**

2. **To assess the applicability of EMAP indicators and the EMAP approach at differing spatial scales.**

3. **To demonstrate the utility of EMAP for resolving issues of importance to the EPA, Regions, and States.**

The REMAP strategy lends itself to the benefits of a full partnership between states and federal agencies because both national and state monitoring needs can be met in a cost-effective manner. The EMAP approach can provide a cost-effective approach for assessing ecological data and reporting estimates of status and trends in indicators of condition with known confidence. State reporting requirements under several sections of the Clean Water Act (CWA) can be accomplished using an EMAP monitoring approach. Section 305(b) of the CWA requires states to submit biennial reports that include analysis of water quality data of all navigable waterways to estimate environmental impacts. The Clean Lakes Section 314 requires states to submit biennial reports that identify, classify, describe, and assess status and trends in water quality of publicly owned lakes. REMAP projects are being designed to provide meaningful information to decision-makers within a 1- to 2-year period.

1.2 POLICY-RELEVANT QUESTIONS

The Science and Ecosystem Support Division (SESD) of EPA Region 4 was asked by the Savannah River Watershed Project Policy Committee to implement the REMAP strategy as a demonstration project for the states of South Carolina and Georgia. These states were interested in reducing sampling frequency and analyses, having the ability to reduce or increase sampling density, responding quickly to emerging environmental problems, and maintaining representative coverage of environmental resources through a systematic-random means of sampling. Before the monitoring study, a set of questions was posed by the states of Georgia and South Carolina to provide direction for the monitoring design. The following policy-relevant questions were identified to guide the development of a plan of study and subsequent monitoring efforts.

- **What is the status of condition of the water resources of the Savannah River Basin?**
- **What proportion of the Savannah River Basin surface waters are attaining designated uses?**
- **What are the changes of ecological condition over time?**
- **What factors might be associated with changes?**
- **Is there a tendency for distribution of condition in a specific direction (spatial gradient) over the basin landscape? What are the possible reasons for these gradients?**
- **What resources are at risk in the Savannah River Basin?**

1.3 PROGRAM OBJECTIVES

In response to the needs of the states and policy-relevant questions posed, The Ecological Assessment Branch (EAB) of the SESD developed the following study objectives with the concurrence of the Policy Committee of the Savannah River Watershed Project.

- **Estimate the status and change of the condition of water resources in the Savannah River Basin;**
- **Identify water quality spatial gradients that exist within the Savannah River Basin and associate current and changing condition with factors that may be contributing to this condition and spatial gradients;**
- **Demonstrate the utility of the REMAP approach for ecoregion and river basin monitoring and its applicability for state monitoring programs;**

- **Incorporate the REMAP approach in the formulation and accomplishment of the State River Basin Management Plans; and**

- **Provide baseline information required to conduct comparative risk assessments in the Savannah River Basin.**

1.4 DESCRIPTION OF THE SAVANNAH RIVER BASIN

The Savannah River originates in the mountains of Georgia, South Carolina, and North Carolina and flows south-southeasterly 312 miles to the Atlantic Ocean near the port city of Savannah, Georgia (Figure 1.1). The Savannah River is formed at Hartwell Reservoir by the Seneca and Tugaloo Rivers.

Headwater streams of the Seneca River are the Keowee River and Twelve-Mile Creek. The Tugaloo River is formed by the confluence of the Tallulah and Chattooga Rivers. The Savannah River flowing in a south-southeasterly direction forms the border between the states of Georgia and South Carolina. The river’s entire length of 312 miles is regulated by three adjoining Corps of Engineers multipurpose reservoirs, each with appreciable storage. The three lakes, Hartwell, Russell, and Thurmond, form a chain along the Georgia-South Carolina border 120 miles long. Six power developments that are part of the Georgia Power Company hydropower network exist upstream of Hartwell Lake on the Tugaloo River system; Yonah and Tugaloo lakes on the Tugaloo River, and Tallulah Falls, Rabun, Seed, and Burton lakes on the Tallulah River. Upstream of Lake Hartwell, on the Seneca River, is Duke Power Company’s Keowee-Toxaway Project. The project is composed of three adjoining reservoirs, the most downstream of which is Keowee Lake, and the other two, Jocassee and Bad Creek Lakes are pump storage projects(Figure 1.2).

The Savannah River Basin has a surface area of 10,577 square miles, of which 4,581 square miles are in South Carolina, 5,821 square miles are in Georgia, and approximately 175 square miles are in North Carolina. Like other basins of large rivers in the Southeast which flow into the Atlantic Ocean, the Savannah River Basin embraces three distinct areas: the Mountain Province, the Piedmont Province, and the Coastal Plain (Figure 1.3). The mountains and Piedmont are part of the Appalachian area. The division between the Mountain and Piedmont is an irregular line extending from northeast to southwest, crossing the Tallulah River at Tallulah Falls. The Fall Line, or division between the Piedmont Province and the Coastal Plain, also crosses the basin in a generally northeast to southwest direction, near Augusta, Georgia. Elevations within the Mountain Province of the basin vary from 1,500 feet National Geodetic Vertical Datum (NGVD) on the Tallulah River to 5,030 feet NGVD for the highest peak, Little Bald Mountain, in North Carolina along the watershed divide. The Blue Ridge is characterized by mountains covered naturally with Appalachian oak. Forests and ungrazed woodlands are the predominant land uses with some cropland and pastures. The Piedmont Province, due to its great width of over a hundred miles, is truly Piedmont only in the upper parts, and gives way to a midland area before reaching the Coastal Plain. Exclusive of river valleys, its elevation generally varies from 500 feet NGVD at the Fall Line to about 1,800 feet NGVD at its upper extremity. The Piedmont is characterized by gently sloping hills and smooth to irregular plains. This province is underlain naturally with nutrient poor soils supporting oak/hickory/pine and southern mixed forests. Land use is a mixture of crop lands, pasture, and woodlands with some urban areas. Within the Coastal Plain, elevations vary from 500 feet NGVD at the Fall Line to sea level at the Atlantic Ocean. Flat plains dominated naturally by oak/hickory/pine forests, pocasin (pine, holly) forests, southern flood plain forests (oak/tupelo, bald cypress), and southern mixed forests (beech, sweetgum, magnolia, pine and oak) are characteristic of the Coastal Plain.

Within the three physiographic provinces there exist distinct ecosystems based on the interrelationships between organisms and their environment. These distinct ecosystems are defined as ecoregions. Ecoregions are ecologically distinctive areas that result from the mesh and interplay of the geologic landform, soil, vegetative, climatic, wildlife, water and human factors which may be present (from Wilken, 1986) While physiographic provinces may prove suitable for regional or national assessments, definition of ecoregions among broad physiographic areas is necessary to accurately assess ecological condition or health. Ecoregions are distinct areas grouped by climate, soils, land forms, and vegetative cover. The Blue Ridge physiographic province stands alone as a separate ecoregion as does the Piedmont physiographic province. However, the Coastal Plains physiographic province is composed of three distinct ecoregions: the Fall Line Hills (or Sand Hills), the Southeastern Plains and Hills, and the Coastal Plains.

Land use in the basin is agriculturally oriented. Sixty-six percent of the basin is considered timberland and 34.1% is nonforested. The number of acres farmed remains constant. Between 1987 and 1992 there was little change in the total farm acreage in the basin. However, Georgia had 330 fewer farms and lesser acreage in 1992 than in 1987 while South Carolina had an increase of 931 farms and an increase of 110,134 acres in farm land. There was a shift over the same five-year period in the types of crops grown. An increase in the number of acres cultivated have occurred in corn (18%), cotton (86%), peanuts (12%), and tobacco (31%). These gains have been made with corresponding decreases in primarily wheat (-30%) and soybeans

(-32%).

The Savannah River Basin contains all or part of 43 counties in Georgia, South Carolina, and North Carolina. Four of the counties are in North Carolina, thirteen in South Carolina, and twenty-six in Georgia. The population of the basin in 1990 was about 1,500,000 and is expected to grow to 1,800,000 by the year 2030. About 53% of the population resides in Georgia, 42% in South Carolina, and 5% in the headwaters located in North Carolina. Four metropolitan areas contain 62% of the basin’s population. Savannah, Georgia is the largest city with 137,560 persons followed by Augusta, Georgia with a population of 44,619 (FTN _et_ _al_., 1994; SRBWP, 1995; EPA, 1991; EPA, 1996).

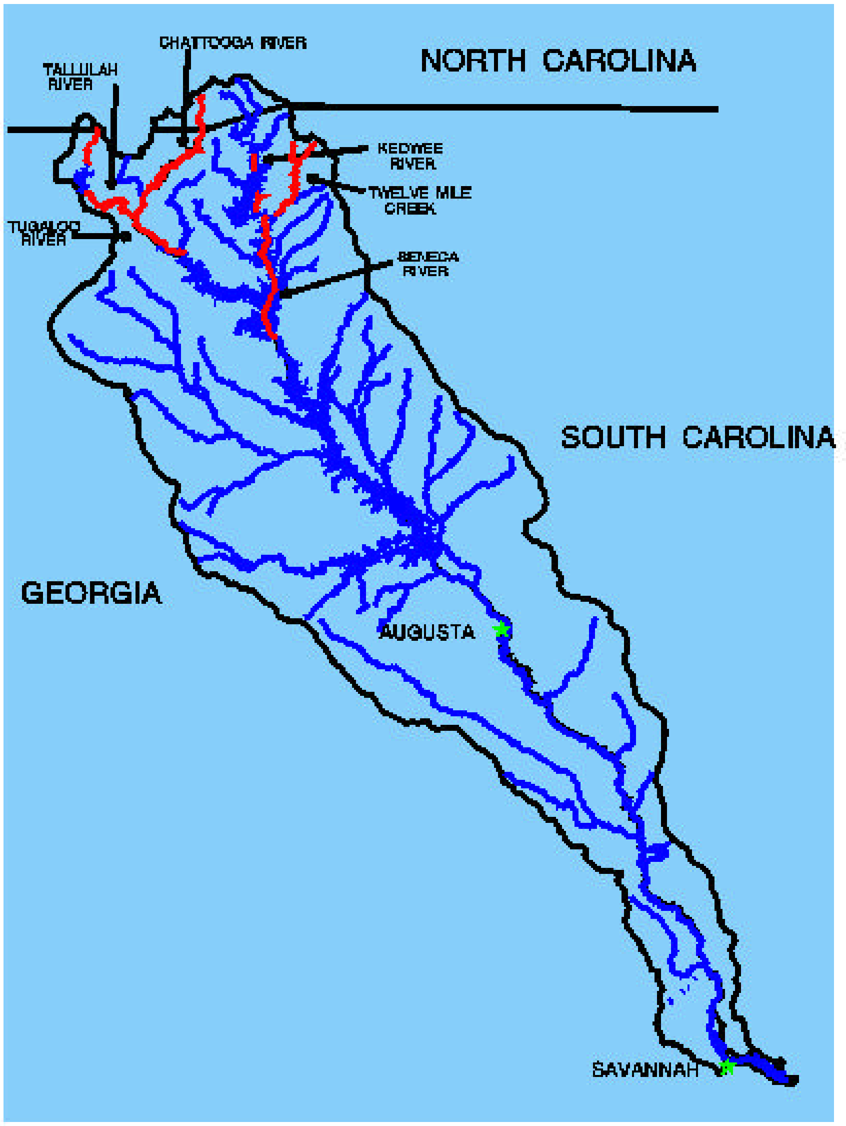

Figure 1.1 Savannah River Basin.

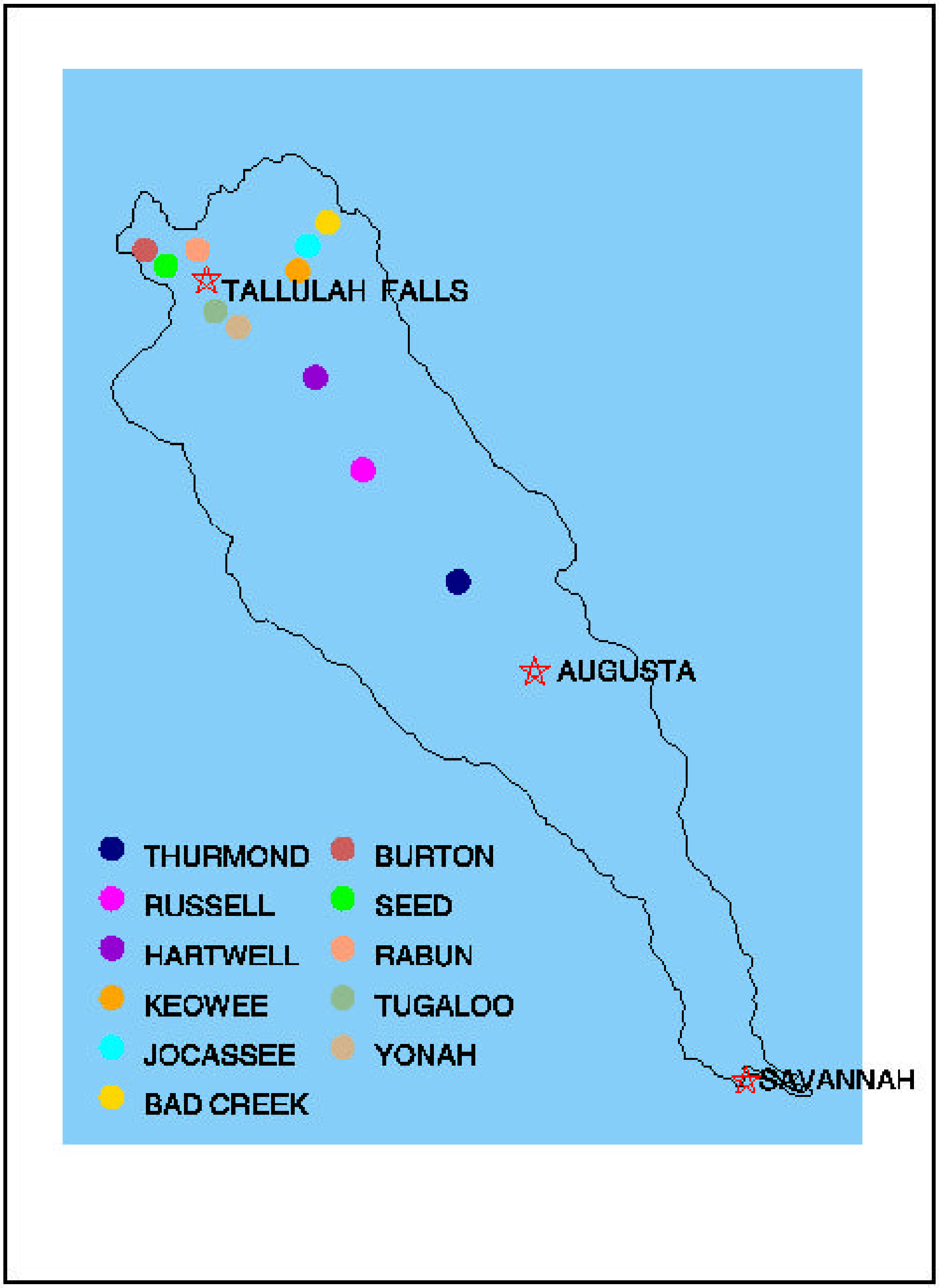

Figure 1.2 Location of Major Lakes in the Savannah River Basin.

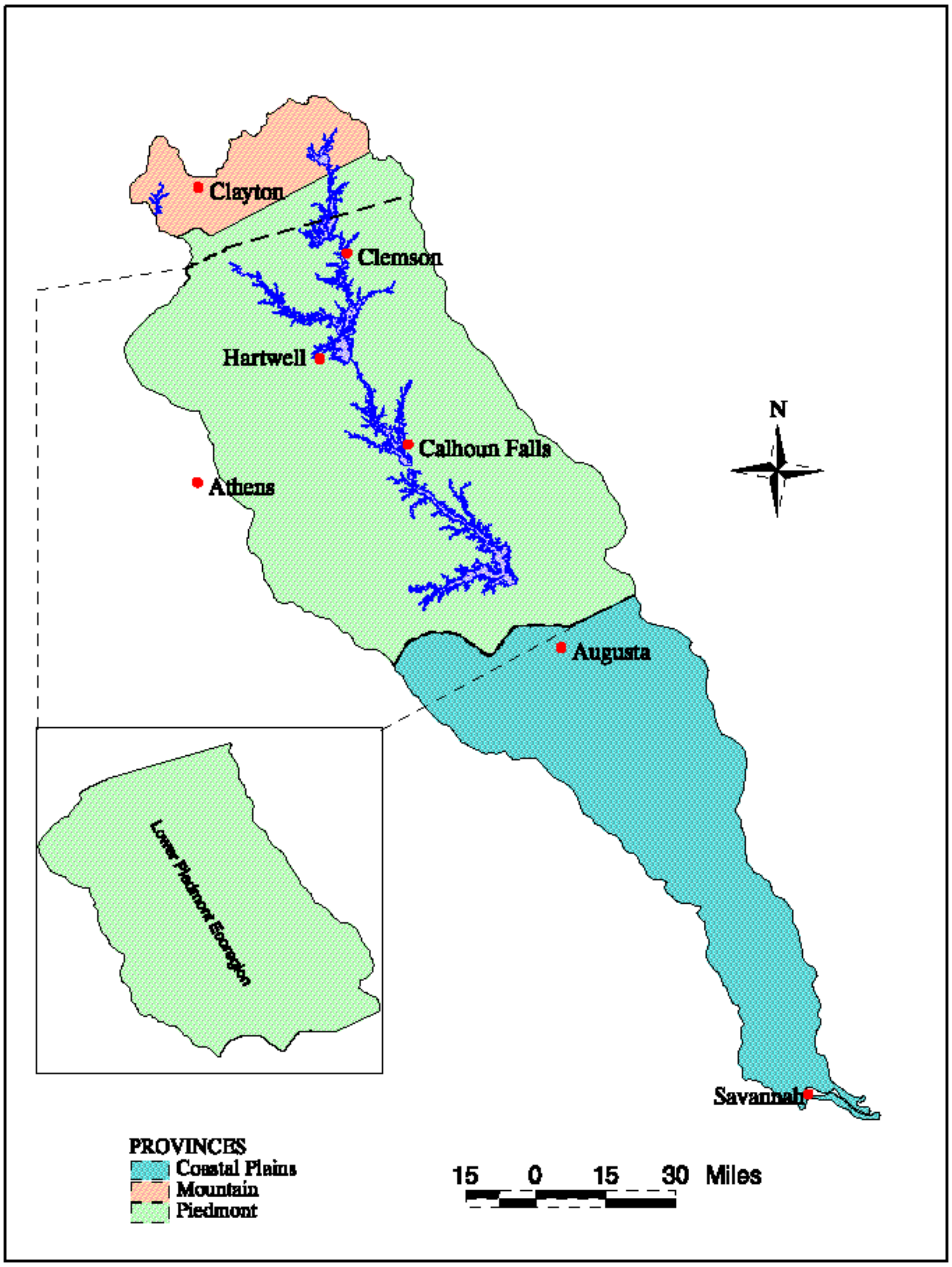

Figure 1.3. Physiographic Provinces and the Lower Piedmont Ecoregion of the Savannah River Basin.

2.0 STUDY DESIGN

2.1 Resources of Interest

2.1.1 Streams

Within the basin’s 10,579 square miles, there are 17,354 stream miles. An estimated 1,503 stream miles or 5.4% are wadeable (first through third order) stream miles. The population of wadeable streams of interest is those permanent streams as indicated by a blue-line segment on a USGS 1:100,000-scale topographic map series in digital format (DLGs) and the modification of the DLGs represented by the U.S. EPA River Reach File (RF3). Streams typically exhibit unilateral gravity flow that under normal conditions are confined to a channel. All permanent wadeable streams from Strahler first order to third order (Chow, 1964) were included in the target population.

2.1.2 Large Lake Embayments

The statistical population of interest included all tributary embayments >20 hectares associated with lakes >500 hectares. A tributary embayment is defined as a body of water associated with, but offset from, the main lake that has a permanent, blue-line stream at its headwaters. The embayment begins at the plunge point, the stream stretch where the inflow water density is greater than the density of the lake surface water, and it joins the main body of the lake at the plane created by intersecting break points of the shoreline of the embayment with the main body. Tributary embayments are associated only with lakes that have a shore line development ratio >3.0 and a surface area >500 hectares (FTN et al., 1994).

Shore line development is the ratio of the actual length of shore line of a lake to the length of the circumference of a circle the area of which is equal to that of a lake. If a lake had a shoreline in the form of a circle, the shore line development would be 1.0 (Welch, 1948).

Tributary embayments of six major lakes were studied over a three-year period (1995 to 1997). These lakes were Burton, Jocassee, and Keowee, located in the Mountain Province. The other three lakes, Hartwell, Russell, and Thurmond, were located in the Piedmont Province.

Lake Burton, controlled by Georgia Power Company, is located near Clayton, Georgia. It is an old reservoir impounded in 1919. The lake has a shoreline length of 62 miles surrounding 2,775 acres containing 1,000,080 acre-feet of water.

Hartwell Lake is 7 miles east of Hartwell, Georgia. A dam is located at river mile 305.0. When the lake level is at elevation 660 ft. NGVD, the top of the conservation pool, the lake extends 49 miles up the Tugaloo River in Georgia, and 45 miles up the Seneca and Keowee Rivers in South Carolina, covering 55,900 acres. The shoreline at elevation 660 NGVD is about 962 miles long, excluding island areas. The lake has a total storage capacity of 2,550,000 acre-feet below elevation 660 NGVD. Hartwell dam began operation in 1963.

Russell dam is at River Mile 275.2 in Elbert County, Georgia and Abbeville County, South Carolina. The dam is 18 miles southwest of Calhoun Falls, South Carolina, and 40 miles northeast of Athens, Georgia. At the top of conservation pool elevation of 475 NGVD, the lake has a useable storage capacity of 126,800 acre-feet and a shoreline of 523 miles encompassing 26,000 acres. Operation of the project began in January 1984.

Thurmond Lake is 22 miles upstream of Augusta Georgia. At elevation 330 NGVD, at the top of the lake pool, the lake extends 40 miles up the Savannah River and about 30 miles up the Little River in Georgia. The lake has about 1,050 miles of shoreline, excluding island areas. At the top of the flood control pool (elevation 335 NGVD), the lake has an area of 78,500 acres with a total storage capacity of 2,510,000 acre-feet.

The three-project system is authorized and operated by the U.S. Corps of Engineers for fish and wildlife, flood control, hydro power, navigation, recreation, water quality, and water supply.

Duke Power Company built and controls Lakes Jocassee and Keowee. The upper lake, Jocassee, was built in 1973. It contains an area of 7,318 acres holding 1,077 acre-feet of water with a shoreline length of 75 miles. Lake Keowee, built in 1971, has a shoreline length of 300 miles encompassing 18,373 acres with a storage holding capacity of 955 acre-feet.

2.2 Statistical Sampling Design

A probabilistic sampling survey strategy was used to characterize the wadeable streams and tributary embayments of the Savannah River Basin. The sampling design was derived from the approach used in EMAP (Messer et al., 1991; Overton et al., 1990; Stevens et al., 1992).

Probability sampling designs use randomization in the sample site selection process. Probability sampling is the general term applied to sampling plans in which

- **every member of the population (i.e., the total assemblage from which individual sample units can be selected) has an equal chance of being included in the sample;**

- **the sample is drawn by some method of random selection**

consistent with these probabilities; and

- **the probabilities of selection are used in making inferences from the sample to the target population (Snedecor and Cochran, 1967),**

One advantage of probability-based surveys is their minimal reliance on assumptions about the underlying structure of the population (e.g., normal distribution). In fact, one of the goals of probability-based surveys is to describe the underlying structure of the population. Randomization is an important aspect of probability-based surveys. Randomization ensures that the sample represents the population. Without probability sampling, each sample often is assumed to have equal representation in the target population, even though selection criteria clearly indicate this is not the case. Without the underlying statistical design and probability samples, the representativeness of an individual sample is unknown. Drawing inferences from samples selected without randomization and without incorporating inclusion probabilities can lead to misleading conclusions.

One can study conditions of streams in two ways. The first is by census, which entails examining every point on the streams. This method is impracticable. A more practicable approach is to examine some points systematically to ensure adequate coverage of the basin, and randomly to prevent bias in selection of stream points. For example, we would not obtain a good estimate of the percent of all students in a region with hepatitis if we polled only students in small towns of less than two thousand people. This preferential or biased sample would most likely include a much lower proportion of students with hepatitis than the general population of students. Similarly, in a stream study, preferential sampling occurs if the sample includes only sites, for example, downstream of sewage outfalls where sewage outfalls affect only a small percentage of total stream length. This kind of sampling program may provide useful information about conditions downstream of sewage outfalls, but it will not produce estimates that accurately represent conditions of the whole basin. Preferential selection can be avoided by collecting random samples.

Randomization can be thought of as a kind of lottery drawing to determine which points are included in the sample. Randomization is important. When used, it is possible to estimate condition of streams with a known degree of confidence. In REMAP, hexagons are used to add the systematic element to the design. The hexagonal grid is positioned randomly over the basin map, and sampling points from within each hexagon are selected randomly. The grid ensures spatial separation of selected sampling points. This design's sampling requirements reduce sampling locations to a logistically and economically feasible number. It allows fewer sites to be sampled annually, but provides for sampling of all randomly selected sites over a rotating year period.

2.2.1 Frame Material

A sampling frame is an explicit representation of a population from which a sample can be selected. The sampling frame for wadeable streams and tributary embayments is the USGS 1:100,000-scale map series in digital format (DLGs) and the modification of the DLGs represented by the U.S. EPA River Reach File (RF3), which established edge matching and directionality in the DLG files.

2.2.2 Sample Site Selection

The survey design follows the general design strategy proposed for EMAP (Overton et al.,1990; Messer et al.,1991). The EMAP sampling design (Overton et al., 1990) achieves comprehensive coverage of ecological resources through the use of a grid structure. White et al. (1992) describe the construction of the underlying triangular point grid and its associated tessellation of hexagonal areas.

A two stage sampling approach was used to select the sample units. The same general approach was used to select the Stage I samples of wadeable streams. A 7x7x7 fold enhancement of the random EMAP base grid was placed over the Savannah River Basin (Fig. 2.1). Each grid point was circumscribed by a hexagonal area 1.86 km^2. These 1.86-km^2 hexagons are aggregated into groups of seven, one central hexagon surrounded by six other 1.86 km^2 hexagons. These seven hexagons form a rough, crenulated hexagon, or hexal of about 13 km^2. Seven 13-km^2 hexals comprise one 90-km^2 hexagon and there are seven 90-km^2 in the EMAP base grid hexagon which covers 640 km^2 (Fig.2.1). This results in the 7x7x7 fold enhancement of the Savannah River grid over the original EMAP base grid. There are about forty-three 640 km^2 hexagons (hex) located within the Savannah River Basin.

Stage I sampling selected three 13-km^2 hexals at random within each EMAP 640-km^2 hexagon (Fig. 2.2). The process constituted a probability sample and preserved the spatial distribution of samples throughout the basin. Every stream reach within each of the selected 13-km^2 hexals was identified and designated with a unique code. These streams constituted the elements for the Stage II sample.

Stage I samples streams in direct proportion to their occurrence on the landscape. There are orders of magnitude of more small streams than there are large streams. Different weights were assigned to the streams based on stream order. If these sampling units are not weighted for size, random selection will result in a preponderance of smaller streams in the monitoring program.

The exact weighting procedure is based on the population distribution of the streams. For streams in the Savannah River Basin, a weight of 1.0 was assigned to first order streams (i.e., the smallest streams), a weight of 3.5 was assigned to second order streams and a weight of 6.0 was assigned to third order streams.

The selection process for streams illustrates the randomization and spatial distribution preservation inherent in the EMAP approach: For each stream segment located within each 13 km^2 hexal, the length (km) of the segment and its classification (e.g., first order, etc.) are transposed onto a line that constitutes the total length (km) of streams of all stream orders located within the hexal (Fig. 2.3). The individual stream length segments are then multiplied by an appropriate weight. All first order segments, all second order segments, etc. are added to this line until the line contains all segment lengths for the subject hexal. The total stream length contained within a hexal is the sum of the stream reaches in the hexal (Fig.2.3). The order of the segments on the line is randomized but the location of each uniquely identified segment is preserved. Following this same pattern, hexals within the EMAP 640-km^2 hexes are randomized (Fig. 2.4). The final line represents the total length of all wadeable streams selected in the Stage I sample. Spatial distributions are preserved through the randomization process (all stream segment lengths randomized within a hexal, hexals randomized within an EMAP 640-km^2 hex and the 640-km^2 hexes randomized). Once the sample size has been determined, the total wadeable stream length (weighted) is divided by the required sample number to derive a length interval for sample selection. A random start location on the weighted line is selected and sample sites are systematically drawn using the derived length interval. For example if the weighted line is 200 km long and the sample size is 50 (200/50=4km), then a station is selected every 4 km along the line beginning from the random start point (Fig. 2.4).

In a similar manner large lake embayment stations were selected for sampling. The hexagonal tessellation was randomonly located over the area covered by the embayment population. Within each hexagon, a point was randomonly selected. If the point fell within one of the embayments, then that point became a sample point. The selection process ensured that each location in the embayment population was equally likely to be sampled, and that the set of sites was spatially distributed throughout all embayments (Stevens, 1997).

2.3 Temporal Sampling Rationale

The EMAP has developed an approach that permits fewer sites to be sampled annually, but provides for sampling all sites over a rotating year period. Currently, this rotation period, or interpenetrating cycle, is four years for the wadeable streams and two years for the lake embayment sampling, but it can be two, three, five years etc. This approach preserves the spatial distribution of the samples throughout the Basin and randomonly assigns similar numbers of streams or embayments in each year. This reduces the sampling requirements in any year to a logistically or economically feasible number while still permitting estimates of resource condition. The design is well adapted for detecting persistent, gradual change on dispersed populations or sub populations and for representing patterns in indicators of condition. The period for rotation is based on the desired precision of estimates for any given year. For this demonstration project, precision was set at +/-10% with a 95% confidence Interval (CI).

The large lake embayment study extended over a period of three years. Two independent systematic random samples were selected - one for each year. A total of 111 embayment sample locations was selected such that 52 were allocated in 1995 and 59 in 1996. During the third year, we cycled back to the first set of samples allocated for the embayments. For the three-year period, 126 embayment stations out of 163 (77%) were sampled. Those stations not sampled were non-targets, that is, the location was on land, less than one meter deep, or inaccessible.

Sixty sites per year for a total of 240 sites over a four-year period were selected for stream sampling. Only 119 sites were sampled because of access denial, some were intermittent streams, some were ponds or embayments, some were on dry land, some were in wetlands, and a few did not meet our criteria of <½ hour to walk to the site.

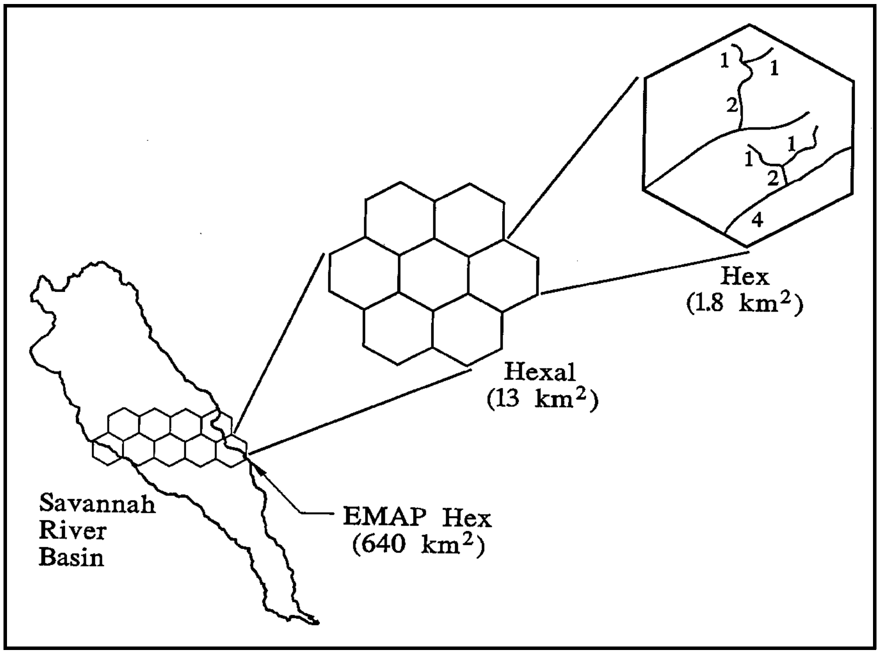

Figure 2.1. Illustration of Base Grid for the Savannah River Basin

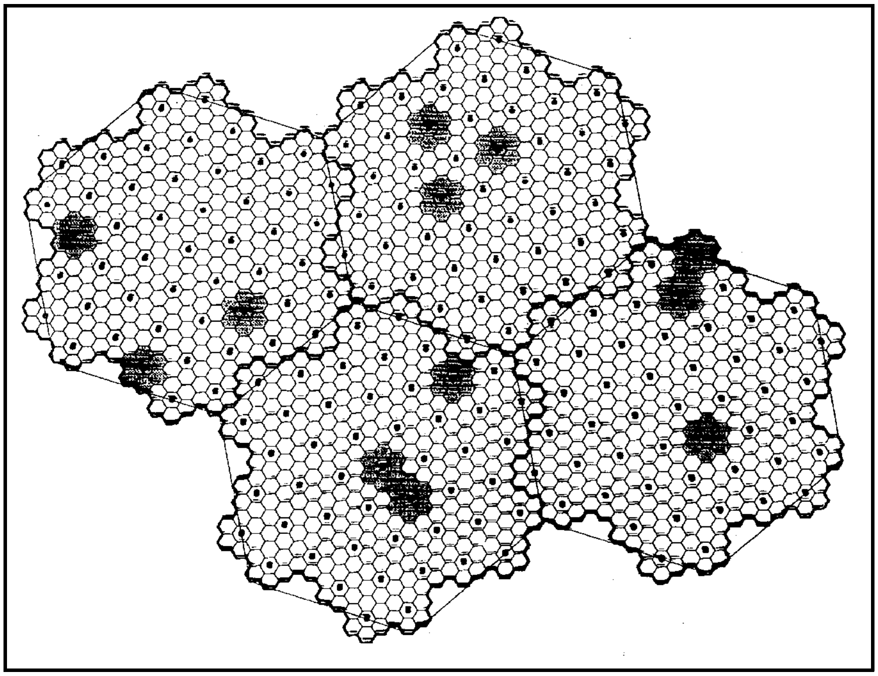

Figure 2.2. Illustration of Random Selection of Hexals from 640-km^2 Hexagon

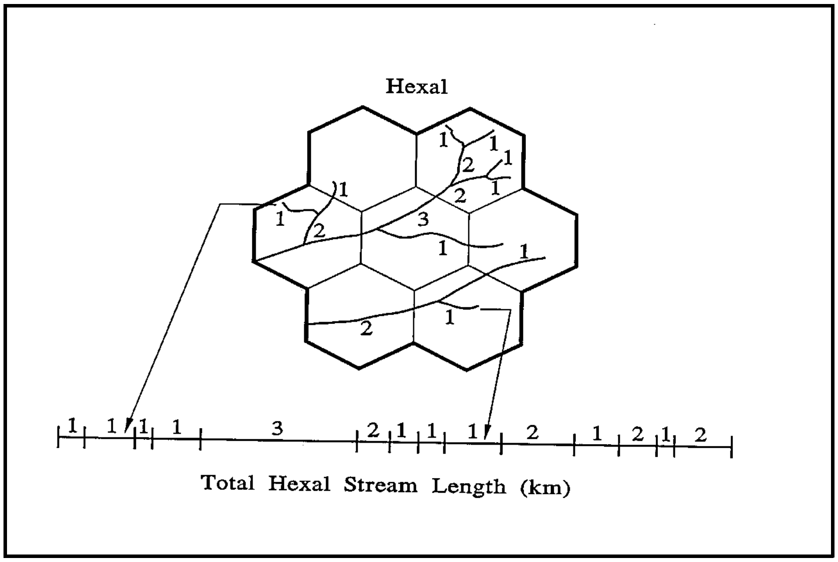

Figure 2.3. Weighted Hexal Stream Length

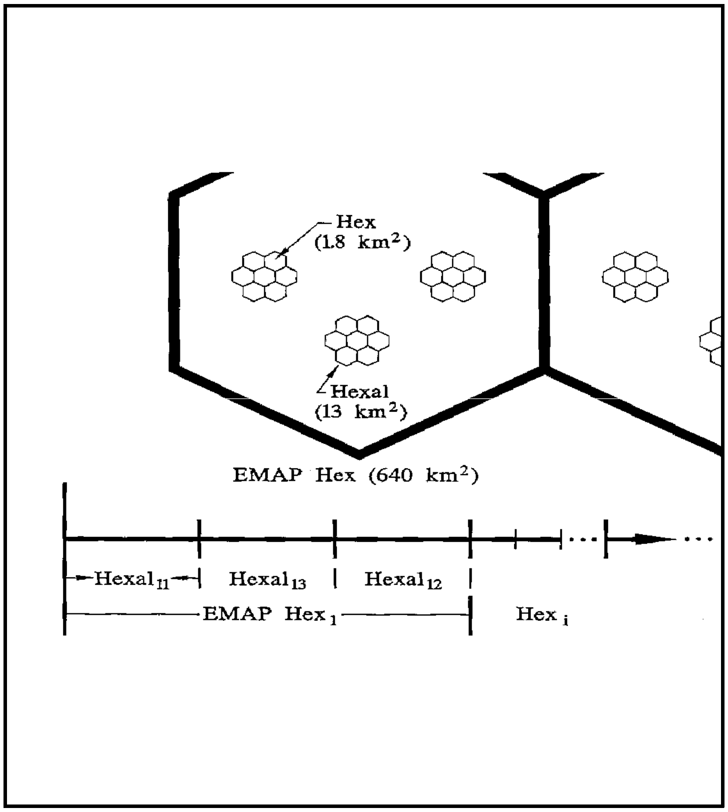

Figure 2.4. Total Weighted Stream Length Selected in Stage I Sample

3.0 INDICATORS

REMAP monitors ecological indicators to assess status, trends, and changes in the condition and extent of the Region’s ecological resources (Bromberg, 1990, Hunsaker and Carpenter, 1990; Hunsaker et al., 1990). Indicators are defined as any characteristic of the environment that estimates the condition of ecological resources, magnitude of stress, exposure of a biological component to stress, or the amount of change in condition.

Ecological principles state that ecosystem responses and condition are determined by the interaction of all the physical, chemical, and biological components in the system. Because it is impossible to measure all these components, REMAP’s strategy emphasizes indicators of ecological structure, composition, and function that represent the condition of ecological resources relative to societal values. The challenge is to determine which ecological indicators to monitor. One approach for selecting these indicators starts with those attributes valued by society and determines which indicators might be associated with these values.

3.1 Societal Values

To be effective, information from the monitoring program must prompt action when required. This means the information produced must be related to perceptions of aquatic health and represent issues and values of concern and importance to the public, aquatic scientists and decision makers. The selection of these societal values drives the selection of appropriate indicators. After extensive discussions with resource managers, decision makers and the scientific community by members of the EMAP - Surface Waters Resource Group (Larsen and Christie 1993), an initial set of societal values and concerns were identified for evaluation in EMAP. These values are:

- **Biological Integrity,**
- **Trophic Condition, and**
- **Fishability.**

Biological integrity can be defined as the ability to support and maintain a balanced, integrated, adaptive community with a biological diversity, composition, and functional organization comparable to those of natural lakes and streams of the region (Frey 1977; Karr and Dudley 1981) and includes various levels of biological, taxonomic and ecological organization (Noss

1990). Biological integrity incorporates the idea that all is well in the community. That is, the different groups are stable and working well with little if any external management of the community, whether it is a township, coral reef, or stream. Waters in which composition, structure and function have not been adversely impaired by human activities have biological integrity (Karr _et_ _al_. 1986). Karr and others (1986) also defined a system as healthy "when its inherent potential is realized...and minimal external support for management is needed." This value or ethic differs considerably from values oriented toward human use or pollution that are traditionally assessed in water quality and fisheries programs, in which production of a particular species of game fish is the goal (e.g., Doudoroff and Warren, 1957), and may conflict with these definitions (Callicott 1991; Hughes and Noss, 1992; Pister, 1987).

Fishability is defined as the catchability and edibility of fish and shellfish by humans and wildlife (Larsen and Christie 1993). Fish represent a major human use of an aquatic ecosystem product. Protecting fish is the goal of many water quality agencies, and fish drive their water quality standards.

Trophic condition has been defined in EMAP as the abundance of production of algae and macrophytes (Larsen and Christie 1993). Trophic condition involves both aesthetic (water clarity) and fundamental ecological (production of plant biomass) components. It is a key aspect in determining both a lake's relative desirability to the public, its production of fish and its ecological character or classification by limnologists (e.g.,eutrophic or oligotrophic). Because of limited resources, a decision was made to concentrate on trophic condition indicators for lakes over a three-year period; and for streams, we emphasized integrity all four years and trophic condition (algal growth potential) only for two years.

3.2 Types and Selection of Indicators

EMAP defines two general types of ecological indicators, condition and stressor indicators. A condition indicator is any characteristic of the environment that estimates the condition of ecological resources and is conceptually tied to a value. There are two types of condition indicators: biotic and abiotic. Condition indicators relate to EMAP's first and second objectives: estimating the status, trends, and changes in ecological condition; and the extent of ecological resources.

Stressor indicators are characteristics of the environment that are suspected to elicit a change in the condition of an ecological resource, and they include both natural and human-induced stressors. Selected stressor indicators are monitored in EMAP only when a relationship between specific condition and stressor indicators are known, or a testable hypotheses can be formulated. Monitoring selected stressor and condition indicators addresses the third EMAP objective of seeking associations between selected indicators of stress and ecological condition. These associations can provide insight and lead to the formulation of hypotheses regarding factors that might be contributing to the observed condition. These associations can provide direction for other regulatory, management, or research programs in establishing relationships.

3.2.1 Streams

In concert with the EMAP approach, the Savannah REMAP Project considered a suite of indicators to evaluate the condition of ecological resources of streams in the Savannah River basin. Selection of specific ecological indicators was based on societal values. Upon consideration of the type of streams (wadeable) to be investigated, a set of societal values were first identified. They were **biological integrity** and **trophic condition**. After identification of the values, four indicators were selected to assess biological integrity and trophic condition - benthic macroinvertebrates, fish, habitat, and algal growth potential (AGP).

Benthic macroinvertebrate insects represent the first consumer level in streams. They are important as processors of organic matter, like leaves and sewage, that find their way into a stream. By fragmenting or breaking down this organic matter, stream insects prepare it for decomposition by bacteria that attach too or colonize the organic matter. In turn, bacteria may serve as a food source for other stream insects that seek out and graze on the organic matter. Because of their limited mobility and relatively long life span, stream insects provide a "window" of cumulative impacts on ecological or resource condition. This community is sensitive to changes; they have for many years been used as a reliable barometer of water quality conditions. Some groups of insects are very sensitive to stresses, like man-made pollution, while others are tolerant. By focusing on the presence or absence of different groups of insects, an aquatic biologist is provided insight about the ecological health of a stream. Sometimes pollution effects may stem from discharges of chemicals, pesticides, or nutrients that are of a manmade origin. Often, sediments from erosion and attributable to land clearing or silviculture practices may adversely affect the stream habitat. The materials that constitute a stream bottom are very important to both fish and stream insects. For example, very fine sediments, like silt, clay, or very fine sand, are detrimental to the reproduction of fish and eliminate preferable habitat for stream insects (Plafkin _et al_., 1989; Barbour _et al_., 1998). Silt, especially, can interfere with a fish's or stream insect's ability to breathe. Assessment of the insect community was accomplished by using a standard field survey technique known as Rapid Bioassessment Protocol II(RBPII)(Plafkin _et_ _al_, 1989; Barbour _et_ _al_., 1998). With the RBP II protocol, most sites can be surveyed with relatively limited time and effort in the field and laboratory. Although RBP II is not the most intense level of bioassessment (RBP III is the most intense effort), it serves well the goal of the Savannah REMAP Project of characterizing the ecological health of streams in a large geographic area with a minimum of laboratory time and support coupled with efficient turn-around of study results. This is accomplished because most benthic macroinvertebrates can be identified in the field to the family level. RBP II provides a basis for ranking and prioritizing impaired sites for further study.

The biological metric of choice utilized for benthic macroinvertebrates was the family level EPT Index (Barbour _et_ _al_., 1998). The EPT Index, as reported in the scientific literature (Barbour et al., 1992; Wallace 1996), is a useful and widely accepted biological metric for analysis of benthic macroinvertebrate data. The EPT Index is an approved biometric put forth in guidance documents used by state and federal resource agencies because of its ability to detect impairment and its defensibility in legal proceedings. The EPT Index is simply a summation of the total number of families at a sampling site in the generally pollution-sensitive orders of benthic macroinvertebrates. These orders are the mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera). The EPT Index is a richness measure which is expected to decrease in response to increasing perturbation.

Habitat is important when examining the ecological condition of sites. These evaluations focus on variables like substrate (bottom sediments) characteristics, flow regimes, impacts to the stream channel (e.g., channelization, deposition), impacts to stream side vegetation, stability of the stream banks, and available cover. Ecoregion reference sites provide a basis for the best attainable conditions for all streams with similar physical dimensions for a given ecoregion. Presently, there are two reference sites per ecoregion except for the Coastal Plain ecoregion. The process of reference site identification is still ongoing in Georgia and South Carolina.

Fish were chosen primarily for their societal value and role as a top consumer in streams. Fish are relatively easy to identify and with minimal training most fish can be collected, sorted, and identified at the field site and then released unharmed. Fishes represent a variety of feeding types. Their diet can consist of food derived from both inside the stream and outside the stream. One important food source is stream insects. Changes in the stream insect community often result in a change in the fish community. Like stream insect communities, fish communities will respond to environmental change, whether it is biological, chemical or physical. Some fishes are very sensitive to environmental change while others are not. By examining all fish groups that live in a stream, the general condition of a stream can be assessed. For example, if there are only one or two groups of fish in a stream who are very tolerant to pollution, and there are no groups that are sensitive to a pollutant, then impairment is suspected because of environmental change that has eliminated the sensitive groups.

The Environmental Protection Agency's Rapid Bioassessment Protocol V (RBP V) (Barbour et al, 1998) is an index used to assess stream condition based on the fish community. The EPA RBP V (Barbour et. al., 1998)is based primarily on the Index of Biotic Integrity (IBI) (Karr,1981; Fausch et al. 1984;Karr et al. 1986). The index consists of up to twelve measures scored to assess changes in the fish community compared to a reference stream, or a stream with least impact. For example, one of the measures assesses the proportion of fishes in a stream considered to be tolerant to environmental change. If the proportion of tolerant groups are high compared to the reference stream, then this would result in a lower score for that measure. Another measure looks at the number of fish groups. If the number of fish groups collected is similar to that of the reference stream then this would result in a high score. After all twelve measures have been given a score, the scores are totaled and the condition of the fish community is then characterized as either good, fair, or poor depending on how far the total score deviates from that of a reference stream.

The primary indicator selected to address trophic condition in streams for the first two years was the algal growth potential test (AGPT) (APHA, 1995). The AGPT is based on the premise that maximum yield of plants (e.g. algae) is limited by the amount of nutrients available to the test alga. With higher algal growth concentrations (AGPT), there is good likelihood that obnoxious plant growths can occur in a stream. The test was selected as the indicator of choice to assess trophic condition primarily because of its specific sensitivity, reliability and the ease and economy of using it as a monitoring tool.

3.2.2 Large Lake Embayments

We focused on condition indicators related to trophic condition because of limited resources. The original study plan (FTN et al., 1994) proposed sampling for fishability indicators, Fish Health Index and Fish Tissue Residues; biological integrity, phytoplankton and zooplankton identification and counts; and one other trophic condition indicator, zeaxanthin, a marker pigment for blue-green algae. Work is continuing on this pigment, but the information was not sufficient for inclusion into this report.

The trophic condition indicators measured during this study were chlorophyll _a_, total phosphorus (TP), algal growth potential (AGP), Secchi disc transparency, and total suspended solids (TSS). These indicators were selected because they provide different insights into the condition of the embayment waters.

Chlorophyll _a_ is commonly used to estimate the degree of phytoplankton bloom conditions that can affect aesthetics, fishing and swimming quality, taste and odor of fishes and drinking water, and the health of fish, waterfowl, and livestock. Chlorophyll is a measure of instantaneous standing crop, whereas TP and AGP indicate potential for blooms. Total phosphorus reveals insights about nutrient input and the potential for serious bloom conditions if we assume all of it is available. However, much of the TP is not normally available. The AGP can show how much of the TP is available for algal growth and the potential, under optimum conditions, for blooms. Secchi disc transparency is related to swimming conditions. Total suspended solids is related to transparency, but it also can be used to indicate effects upon fish production.

4.0 METHODS

4.1 Streams

4.1.1 Field Sampling

Benthic macroinvertebrate sampling and habitat evaluation followed basic guidelines put forth in the EPA document *"Rapid Bioassessment Protocols for Use in Streams and Rivers"* (Barbour et al., 1998). Multiple habitats (riffles, undercut banks, leaf packs, woody debris, and pools) were sampled with D-frame and A-frame biological dipnets according to the Ecological Assessment Branch's (EAB) Standard Operating Procedures (SOP) (EPA, 1998). In addition to the benthic macroinvertebrate sampling or biosurvey, the RBP II also includes in-situ water quality measurements (dissolved oxygen, pH, temperature, and conductivity). These parameters were measured with a multiparameter in-situ water quality device (HYDROLAB SCOUT) prior to the habitat evaluation phase according to EAB's SOP.

Stream fish sampling followed basic guidelines set forth in Barbour et al. (1998). A Smith-Root Type VII backpack electrofishing unit was used to collect stream fish. A single pass electrofishing run moving from downstream to upstream, thoroughly sampling each habitat type (pools, runs, riffles, eddies, undercut banks, etc.) was conducted at each stream sampling location. Equal effort was given at each location. Fish were identified at stream side and released. A few individuals of each species were preserved in 10% formalin and transported back to the lab for identification verification.

Based on the guidance provided in the EPA RBP V(Barbour et. al. 1998) document, nine metrics were utilized to evaluate the data to assess the condition of stream fish assemblages. The metrics were selected from a pool of metrics listed in the EPA RBP document and other studies that have been conducted in Georgia (DeVivo 1996). A list of metrics utilized and the scoring criteria for each are presented in Appendix C.

Habitat assessment was based on a matrix of nine parameters (EPA, 1989). These nine parameters fall into three principal categories: primary, secondary, and tertiary parameters. Primary parameters (bottom substrate, available cover, embeddedness, and flow regime) characterize the stream "microscale" habitat and are most influential to community structure. Secondary parameters (channel alteration, bottom scouring/deposition, and sinuosity) measure the "macroscale" habitat such as channel morphology. Tertiary parameters (bank stability, bank vegetation, and stream side cover) evaluate the integrity and composition of the riparian zone.

4.1.2 Analytical Methods

RBP II and V do not require analytical methods because the organism identifications usually are made in the field. When organisms need to be returned to the laboratory for identification, they are sorted by specialists and identified by an expert following protocols spelled out in the EAB’s SOP (1998). Algal growth potential tests conducted the first two years followed the protocols of standard methods (APHA, 1995) as modified by Schultz (1994) (EPA, 1998).

4.2 Large Lake Embayments

4.2.1 Field Sampling

Standard operating procedures (SOP) of EAB were followed as the principle means of sample collection and measurement (EPA, 1998). All lake sampling and measurements took place the weeks of 7/17 to 7/21, 1995, 6/21 through 7/5, 1996, and 7/7 through 7/10, 1997. One hundred and twenty-four stations were sampled over the three-year period. This annual sampling window was selected because it is a time of maximum recreational use, and maximum water supply use.

Secchi disc transparency was measured according to EAB’s SOP that was adopted from EPA methodology (Klessig, 1988) using a 30 cm black and white disc lowered on the shady side of the boat. Photic zone was determined by multiplying the Secchi measurement by a factor of 2.1 (Raschke, 1993).

Collection of water samples consisted of using a battery operated pump to fill a 5 gallon carboy with a composite depth integrated sample taken from the photic zone (1% light level). The water sample was mixed thoroughly and then the various individual sample containers were filled, labeled and stored on ice. Samples were collected for total phosphorus (TP), total suspended solids (TSS), algal growth potential tests (AGPT), and chlorophyll a. Field duplicates were collected at a minimum of once in every ten samples. For the field duplicate, the carboy was emptied, rinsed, and a second sample collected.

Chlorophyll a sampling followed basic guidelines set forth in Standard Methods, 19th Edition, section 10200. A 100 to 250 ml sample was filtered through a 24 mm diameter Whatman GF/F glass fiber filter. The filters were folded, blotted dry, enclosed in aluminum foil, labeled and stored in a cooler containing dry ice and returned to SESD for analyses. Samples were filtered in triplicate.

4.2.2 Analytical Methods

Total phosphorus and total suspended solids were analyzed using methods given in the EPA document " Methods for Chemical Analysis of Water and Wastes" (EPA, 1983). In 1995, Cycle 1, total phosphorus was analyzed using EPA Method 365.1. Results of most analyses were below the minimum detection level of 20 ug/L for this method. In 1996 and 1997, Cycles 2 and 3, a low detection level method was used (EPA, 1992a) that allowed for detection of phosphorus at 3 ug/L. Total suspended solids were determined by using EPA Method 160.2.

Chlorophyll samples were measured by high performance liquid chromatography (HPLC) following the basic guidelines given in Standard Methods and in EPA Method 447.0. The chlorophyll was extracted in a 90% acetone solution.

Algal growth potential test (AGPT) maximum standing crop (MSC) and limiting nutrient was determined using The Selenastrum Capricornutum Printz Algal Assay Bottle Test (Miller et al.,1978) as modified by Schultz et al.(1994).

4.3 Quality Assurance/Quality Control

Standard operating procedures of the Ecological Assessment Branch and the Analytical Support Branch of EPA's Region 4 SESD were followed as the principal means of monitoring appropriate quality assurance/quality control (QA/QC). Quality control checks were included in sample collection, physical measurements performed in the field, chemical analyses, and data gathering and processing. Data were subject to verification and validation. Verification included range checks and internal consistency checks. Validation consisted of a review of the data from a data user's perspective for consistency based on known numerical relationships.

4.3.1 Lakes

Secchi disk transparency was measured at each site to determine the photic zone for lake sampling. Prior repetitive test measurements of Secchi depth in a variety of water bodies showed that the coefficient of variation (CV) ranged from 5 to 15% among several investigators.

Water samples were collected as depth integrated samples throughout the photic zone. Samples were collected for total phosphorus (TP), total suspended solids (TSS), chlorophyll a, and algal growth potential tests (AGPT). Field duplicates were collected at a minimum of once in every ten samples. Results of precision as coefficient of variation (CV) are given in Appendix

A. In 1997, field blanks were collected along with the duplicates. In this case, each of the sample containers was filled with deionized water, preserved or filtered as appropriate, and returned to the laboratory for analyses. Results are given in Appendix A.

In 1995, (Cycle 1), TP in most of the samples was below the minimum detection level of 20 ug/L for the method used. In 1996 and 1997 (Cycles 2 and 3), a low level phosphorus method was used (EPA, 1992a). The CV for the field duplicates ranged from 0 to 71.2% with an average CV of 20.9% (Appendix A).

All of the field TSS duplicates in cycles 1 and 2 were below the laboratory's detection limit of 4.0 mg/L. For Cycle 3, ASB modified their procedure by filtering a greater volume of sample (APHA, 1995). This modification reduced the detection limit to 1.0 mg/L. The CV ranged from 0 to 23.6% with an average CV of 18.6%. Standard Methods gives the CV as 33% at a concentration of 15 mg/L TSS. Both laboratory and field precision were well within the values of Standard Methods (APHA, 1995).

Chlorophyll a and AGPT were measured to determine the trophic status of the lakes. For chlorophyll a the CV for field duplicates ranged from zero to 53.8% with an average CV of 16%. The standard method (APHA,1995) does not give any precision data for field duplicates that include a filtration step. The method does state that for multiple injections on the HPLC, the average CV for seven pigments is 10 percent.

The precision of the field duplicates for AGPT ranged from 1.3 to 53.1% with the average CV equal to 15.7%. The test gave an average CV of 26.4% for the 1.0 to 2.0 Maximum Standing Crop (MSC) level (Miller et al., 1978) which was typical for the Savannah lake samples.

4.3.2 Streams

Field measurements at each sampling station included temperature, DO, pH, and conductivity. Measurements were taken using a Hydrolab Scout. The Hydrolab was calibrated each morning and then again at the end of each day according to EAB's SOP (EPA, 1998).

Biological integrity was accomplished in part by using a standard field survey technique known as Rapid Bioassessment Protocols II (RBPII) (Barbour et al., 1998) to assess the benthic macroinvertebrate community. This is a screening procedure in which the macroinvertebrates are identified in the field to the family level. If identification is uncertain, the specimen is brought back to the laboratory for verification. No replication of sites were performed as this is a screening method.

The Rapid Bioassessment V Protocol (RBP V) (Barbour et al., 1998) was the index used to assess stream condition based on the fish community. To insure fish were properly identified during the study, all fish that were captured during the first year were preserved and sent to Dr. Byron Freeman at the Institute of Ecology at the University of Georgia for identification. In subsequent years, voucher specimens of each species collected in the field were preserved for identification verification at the US EPA SESD laboratory. At the end of the four year study, preserved fish with questionable identifications, were sent to the Institute of Ecology for verification.

The primary indicator selected to address trophic conditions in streams is the algal growth potential test. This test was also used in the lake work and the QA/QC used is the same as given in Section 4.3.1 except that limiting nutrient was not determined for the streams.

5.0 Findings

5.1 Basin Perspective

5.1.1 Large Lake Embayments

The distribution of data for each variable can be characterized by its cumulative distribution frequency (cdf). These curves show the percent of embayment acreage in the basin equal to or less than some specified measurement plus or minus a confidence level. For the purpose of this study, we have set a confidence level of 95%. This means that we are 95% sure that the acreage estimated to be equal to or less than a given measurement is within the bounds of our confidence lines on the graph (Fig. 5.1). There is a 1 in 20 chance (5% error) that the true or real percent of acreage affected at a particular measurement is not within the confidence bounds.

Chlorophyll a ranged from a low of 0.84 at Lake Hartwell to 11.56 ug/L at the most downstream lake, Lake Thurmond (Table 5.1).

Table 5.1. Range of Values for the Savannah River Lakes

Lakes	**CHL. A ug/L**	**AGPT mg/L**	**Limit NUT.**	**TP ug/L**	**SD Meters**	**TSS mg/L**
Thurmond	0.98-11.56	0.66-11.0	N+P	3-50	1.2-4.8	0.7-27
Russell	1.10-5.47	0.39-2.01	N+P	3-60	0.7-3.4	2-32
Hartwell	0.84-6.84	0.33-2.27	N+P	3-30	1.4-10	1.0-6
Keowee	0.91-2.03	0.49-5.08	N+P	3-11	2.4-5.5	0.7-5.5
Jocassee	1.35-2.59	0.66-1.95	N+P	3-10	3.3-6.0	1.2-34
Burton	1.60	1.62	N	6	2.2	2

This range of concentrations at the times of sampling exhibit trophic conditions related to classical lake classifications of oligotrophic to mesotrophic (Olem and Flock, 1990). Chlorophyll a was less than 12 ug/L over the entire basin’s large lakes (Figure 5.1). Based on experience (Raschke, 1994) over the past 30 years, generally, when chlorophyll a ranges from 0 to 10 ug/L, there is no discoloration of the water and no problems. At a range of 10 to 15 ug/L, waters can become discolored and algal scums could develop. Between 20 to 30 ug/L, the water is deeply discolored, scums are more frequent, and matting of algae can occur (Raschke, 1993). EPA Region 4 (Raschke, 1993) has shown that a mean photic zone growing season average of equal to or less than 15 ug/L of chlorophyll a should satisfactorily meet multiple uses, including drinking water supply.

One of the objectives of the Savannah River REMAP is to detect trends in important environmental variables over both time and space. One means of comparison is through the testing of the null hypothesis that the population's distributions from two or more annual cycles are identically distributed. This can be accomplished through use of the Cramer von Mises test statistic (W) which is founded on design-based methods of statistical inference (Appendix E). For design-based statistical inference, the source of random variation is the random selection of sample sites. This is in contrast to model-based statistical inference, where the source of random variation is in the assessed deviations from the statistical model (e.g., a regression model). Thus, designed-based statistical inference has the advantage that no model assumptions are required. The distribution of a population can be characterized through its cumulative distribution function (cdf). This is equivalent to testing the null hypothesis that the cdf's are identical. A test of cdf differences at alpha .05 (Table 5.2) using the Cramer-von Mises test statistic (W) showed that four variables, chlorophyll a, AGPT, total phosphorus (TP), and total suspended solids (TSS) had significantly different distributions from one cycle to the other. Chlorophyll Cycles 2 and 3 are intertwined and slightly different from Cycle 1 (W=1.70, k=3). The curve for Cycle 1 rises more gradually than that of Cycles 2 and 3 (Figure 5.2) culminating in a high of 11.56 ug/L thus suggesting the mean is higher for Cycle 1.

Table 5.2. Cramer-von Mises Tests for Equality of Cumulative Distribution Functions for the Savannah River Basin Embayments. Equality of Cumulative Distribution Functions Between Cycles (Years) is Tested.

Variable	W
Chlorophyll a	1.70*
Agpt	8.60*
Total Phosphorus	3.16*
Secchi Disc	0.44
Total Suspended Solids	2.84*

*Significant at alpha=.05

Chlorophyll a represents phytoplankton standing crop or yield at given time periods, whereas AGPT is representative of the potential phytoplankton production, given optimum conditions of sufficient nutrients, light, time and temperature. Algal growth potential ranged from 0.33 mg dry weight (DW)/L at Lake Hartwell to 11.0 mg DW/L at Lake Thurmond (Table 5.1)(Figure 5.3). Approximately 99.7% of the AGPT dry weights were equal to or less than 5 mg/L (Fig. 5.3), an in-lake action level that will reasonably assure protection from nuisance algal blooms and fish kills in southeastern lakes (Raschke and Schultz, 1987). The 5 mg/L of dry weight translates to a potential chlorophyll standing crop of approximately 57 ug/L of chlorophyll a based on the following equation:

$\mathbf{Log_{10}\ chl\ \underline{a} = 1.15\ Log_{10}(DW) + 0.95}$ (Raschke and Schultz,1987).

The sampled maximum chlorophyll a of 12 ug/L is much lower than the 57 ug/L of chlorophyll a derived from the 5mg DW/L AGPT action level suggesting that the present phytoplankton biomass does not pose a threat to the integrity of the lake system. Figure 5.4 depicts the AGPT cdf’s for cycles one through three. The curve for Cycle 2 rises more gradually than that for cycles one and three suggesting the mean AGPT is not only higher in Cycle 2, but also shows greater variability within this cycle. The Cramer-von Mises test statistic confirms that the difference between the three cycles at the alpha .05 level is statistically significant (W=8.60; k=3).

Total phosphorus (TP), another indicator like AGPT of potential production, ranged from 3.0 ug/L in most lakes to 60 ug/L in Lake Russell (Table 5.1). Approximately 87.0% of the embayment acreage was equal to or less than 10 ug/L TP (Figure 5.5). If all of the phosphorus were available for algal growth, at high values of 40 to 60 ug/L one could expect severe bloom conditions, but this was not the case as seen by the relatively low chlorophyll a values. This is not surprising; besides needing optimum conditions for maximum growth, the phytoplankton need sufficient nutrients that are bioavailable to them. Generally, not all of the TP in lakes is available for phytoplankton growth. Peters (1981) estimated that bioavailable phosphorus (BP) is 83% of TP in natural lakes and 18 to 57% in rivers. Since our lakes are reservoirs and thus an extension of a river system one would expect bioavailability to be much less than that found in natural lakes. Previous work on the 18 Mile Creek embayment of Lake Hartwell showed that the average percent of BP to TP was 38% (Raschke et al., 1985). Sometimes the BP portion of TP can be as low at 3% (Raschke and Schultz, 1987). At the alpha .05 level there was a significant difference (W=3.16; k=3) between Cycle 1 and the other two cycles, but higher values were observed in Cycle 1 (Figure 5.6). The significant differences between cycles for chlorophyll, AGPT, and TP suggests that other variables are influencing differences from one cycle to the other. We are not in a position with three years of data to focus on particular stress indicators at this time. Samples were collected from two to three weeks after rainfall events in the basin. Thus rainfall or unusually high stream flows would not seemingly cause the differences observed between cycles with respect to these three phytoplankton growth related indicators. Presumably the cyclic differences were caused by internal lake influences like internal nutrient cycling. Even these differences may be within the normal suite of variability experienced in a natural setting.

For water supply, a mean growing season average Secchi disc (SD) transparency of equal to or greater than 1.5 meters is desirable (Raschke, 1993). For non-water supply embayment situations a mean SD of greater than 1 meter is acceptable for fishing and swimming (Raschke, 1993). Secchi disc transparency ranged from 0.7 meters at Lake Russell to a high of 10 meters at Lake Hartwell (Table 5.1). An examination of Figure 5.7 shows that in about 2.6% of the embayment acreage, less than desirable conditions exist for recreational purposes, and only 5.3% of the acreage was less than the water supply criterion of equal to or greater than 1.5 meters. Where SD was less than one meter, measurements were located near shore or at the upper end of the tributary embayments.

The National Academy of Sciences (1973) has set TSS levels for different levels of stream protection. High protection can be maintained if the TSS is 25 mg/L or less, moderate protection is possible if the range is between 25 to 80 mg/L, low protection is from 80 to 400 mg/L, and there is very little protection from TSS at concentrations greater than 400 mg/L TSS. According to these criteria, our embayment population is highly protected in more than 95% of the embayment acreage and moderately protected in the remaining acreage (Fig. 5.8). Buck (1956) divided impoundments into 3 categories: clear with total suspended solids (TSS) less than 25 mg/L; intermediate with TSS 25-100 mg/L; and muddy with TSS greater than 100 mg/L. The mean harvest of game fish was 162 lbs/acre for clear lakes, 94 lbs/acre in intermediate lakes, and muddy lakes only yielded 30 lbs/acre. The TSS ranged from a low of 0.7 mg/L at Lakes Keowee and Thurmond to a high of 34 mg/L at Lake Jocassee, the uppermost lake in the Savannah Chain of lakes (Table 5.1). Again these high values were attributed to near shore stations receiving wind fetch at the time of sampling. Ninety-seven percent of the embayment acreage would fall into Buck’s clean category, with only 3% being intermediate with respect to water clarity (Fig. 5.8). There were significant differences between the cycles (W=2.84, k=3)(Figure 5.9). Presumably, cycle three was significantly different from the other two cycles, because there were no significant differences at alpha .05 between cycles one and two (W=0.15; k=2).

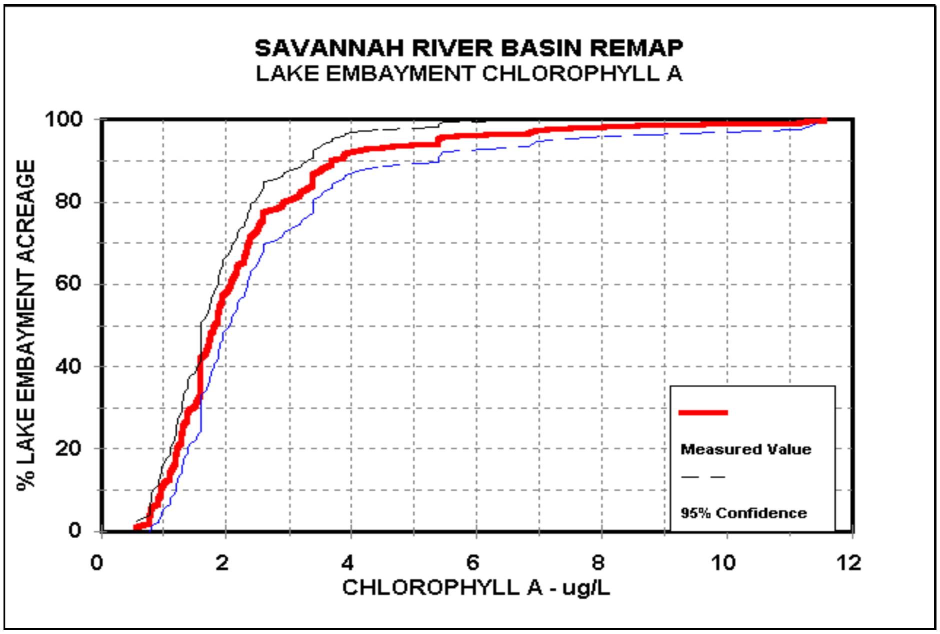

Figure 5.1. Cdf for Chlorophyll a.

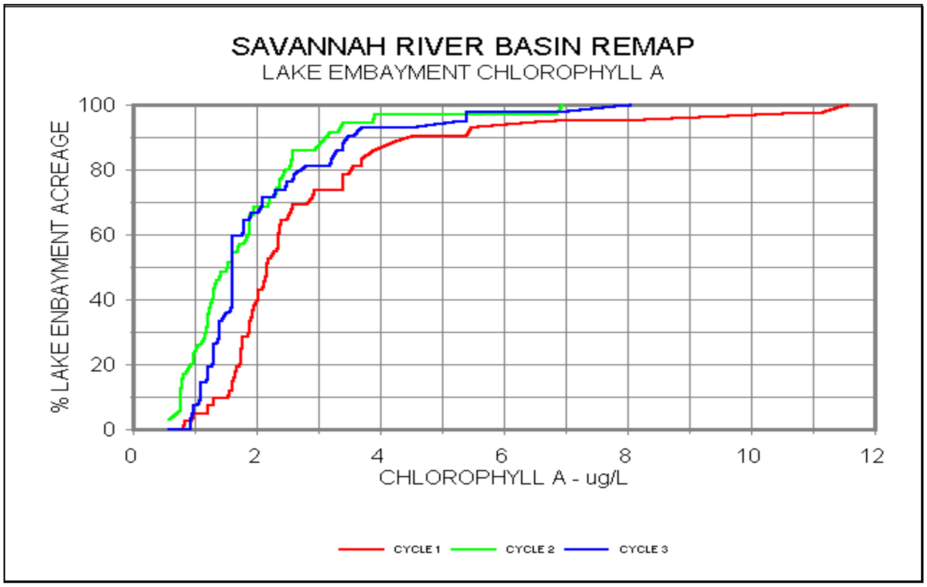

Figure 5.2. Cdf Curve Showing Differences Between Cycles.

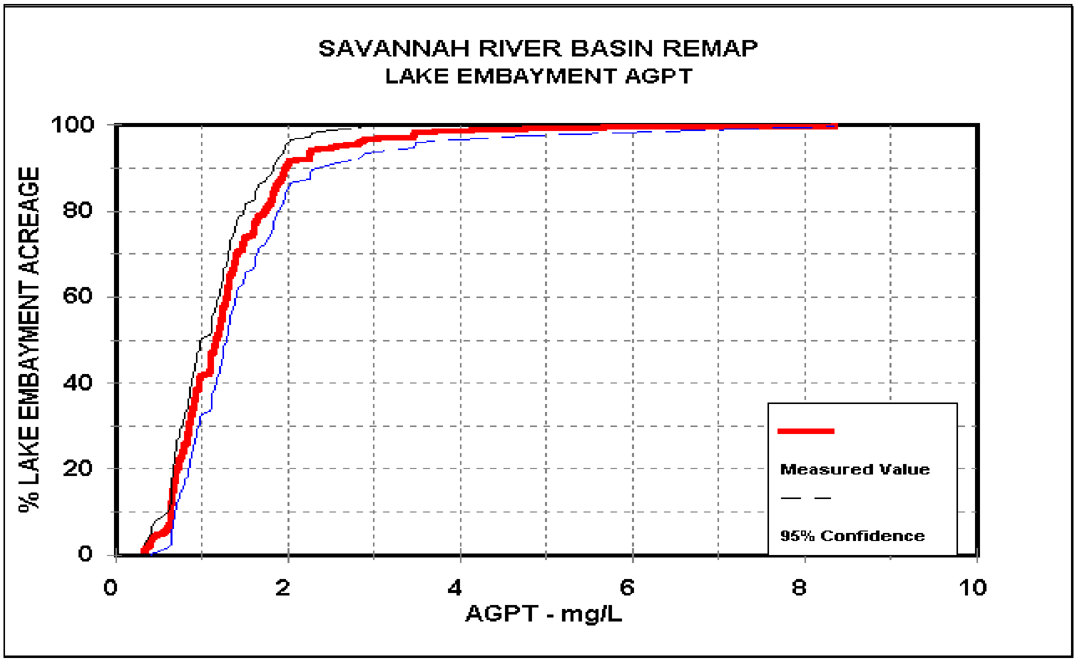

Figure 5.3. Cdf Curve for AGPT.

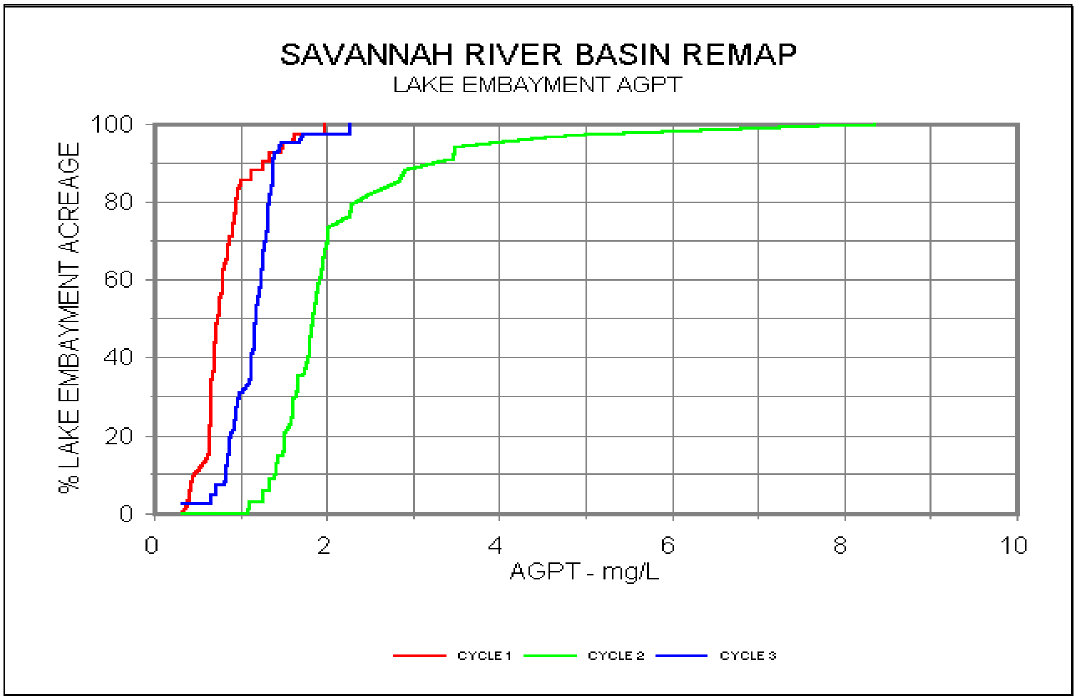

Figure 5.4. Cdf Curve Showing Differences Between Cycles.

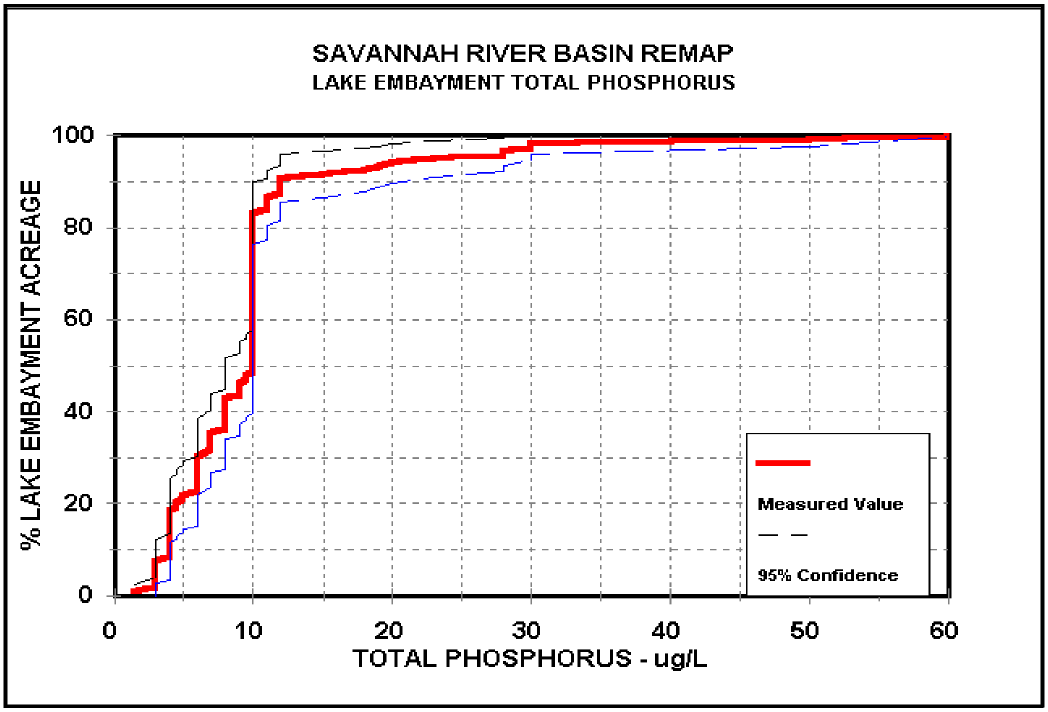

Figure 5.5. Cdf Curve for TP.

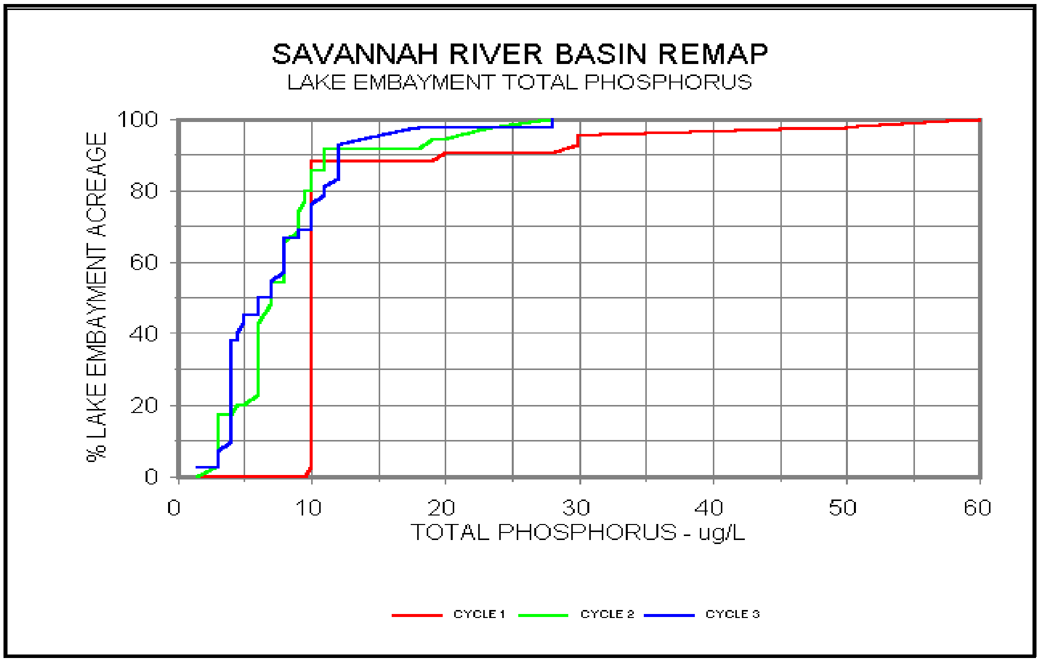

Figure 5.6. Cdf Curve Showing Differences Between Cycles.

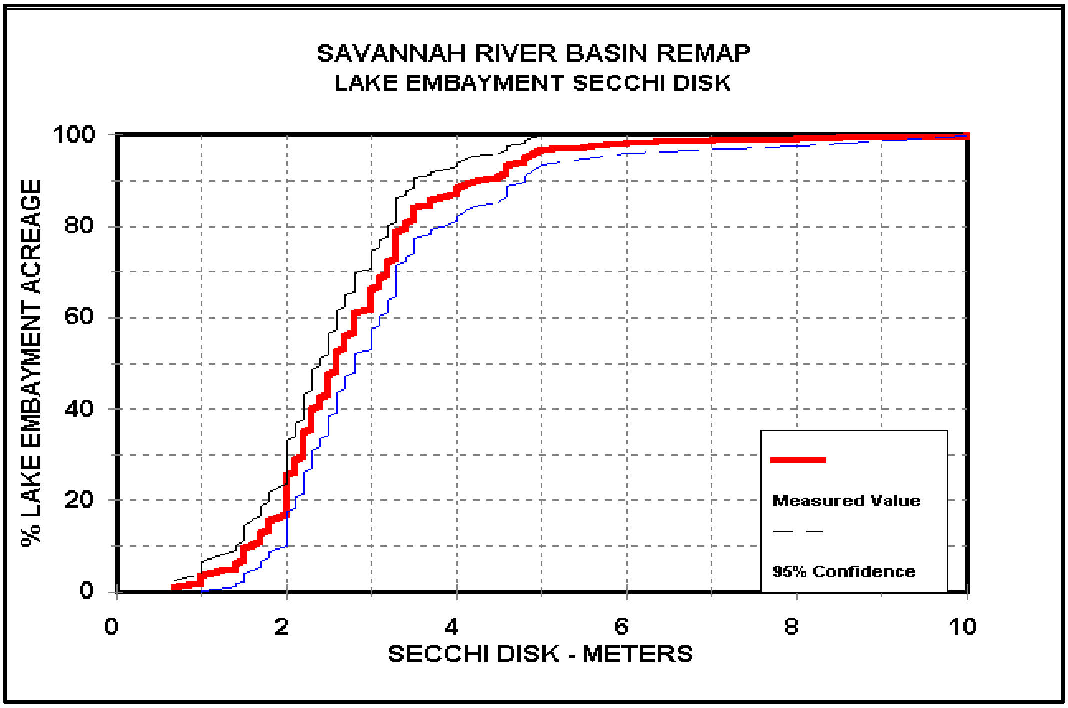

Figure 5.7. Cdf Curve for Transparency.

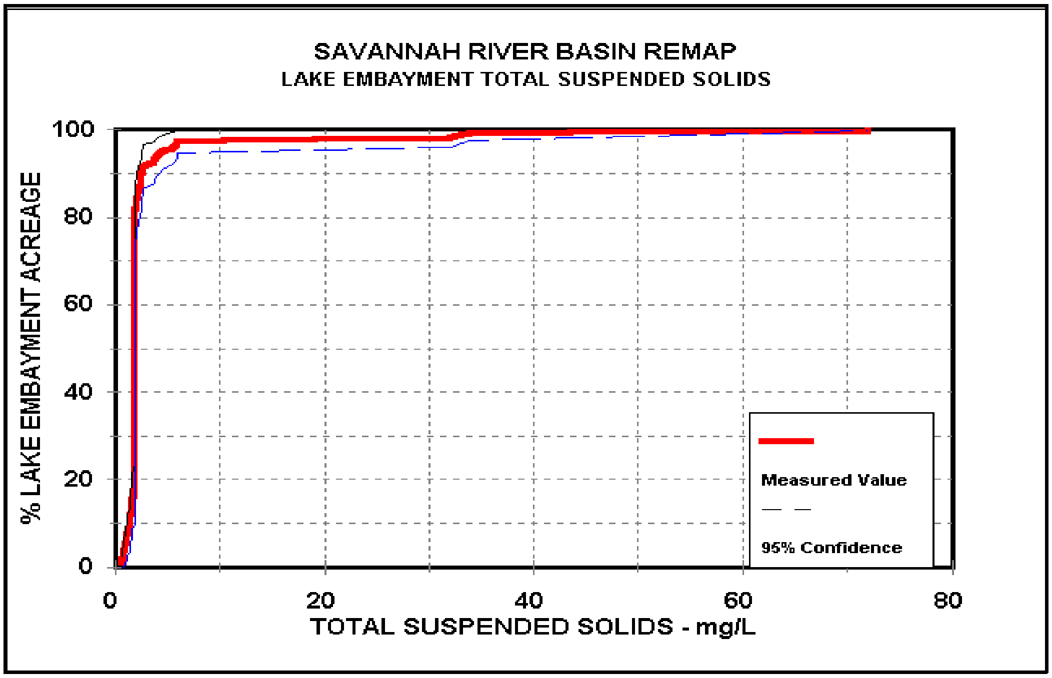

Figure 5.8. Cdf Curve for TSS.

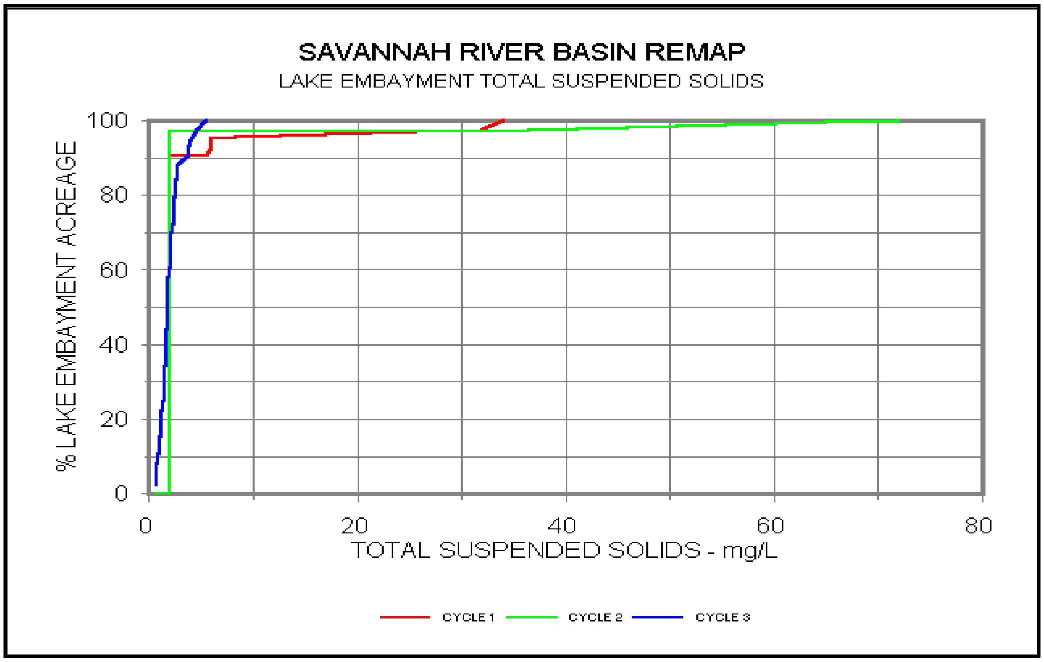

Figure 5.9. Cdf Curve Showing the Differences Between Cycles for TSS.

5.1.2 Streams

The report by Raschke et al. (1996) (Appendix H) demonstrated the applicability of the EMAP approach to stream monitoring in basins. The information in this section is a summary of four years of stream data. It is not an exhaustive analysis of basin response. Rather, we devoted our energies to demonstrating the applicability of the EMAP approach to an ecoregion and the application of modified indicators and a new index that incorporates macroinvertebrate and fish metrics (Section 5.2).

The family level EPT Index ranged from 1 - 20 across all six ecoregions (Appendix C). EPT Index scores exhibited a general decline southward along successive ecoregion belts (Fig. 5.10). However it should be pointed out that the small sample sizes within each ecoregion, with the exception of the Lower Piedmont, is inadequate to confirm this observation. The Blue Ridge Mountain Ecoregion had the highest EPT Index scores (range = 8 - 20; n = 11). Mean EPT Index value in the Blue Ridge was 15. Only 3 sampling stations were in the Upper Piedmont; EPT Index scores for the 3 Upper Piedmont stations were 9, 16, and 16. EPT Index scores in the Lower Piedmont (range = 1 - 18; n = 88) were lower than the Blue Ridge and Upper Piedmont and the mean EPT Index value of 7 was much lower than that of the Blue Ridge (15). Five stations were located in the Sand Hills where the EPT Index ranged from 3 to 11. Ten stations were located in the Southeastern Plains; the EPT Index ranged from 2 to 11 with a mean EPT Index value of 7. Only two stream stations were located in the Middle Atlantic Coastal Plain. An EPT Index value of 1 was recorded for the Middle Atlantic Coastal Plain stations.

Habitat evaluation scores for all sites ranged from 30 to 123 Figure 5.11). Habitat evaluation scores for each stream station are presented in Appendix C. Unlike the EPT Index results, habitat evaluation scores did not reveal any marked patterns from an ecoregional perspective (Figure 5.10). The Blue Ridge habitat evaluation scores(N = 11) ranged from 58 to 123 with a mean of 90. The Upper Piedmont (only 3 stations) had habitat evaluation scores of 82, 102, and 112. The Lower Piedmont’s 88 stations had a wide range in habitat scores (30 to 119) with a mean score of 71. The Sand Hills ecoregion stations (N = 5) had a range in habitat evaluation scores of 92 to 108. Habitat evaluation scores for stations in the Southeastern Plains(N = 10)ranged from 73 to 120. The two stations in the Middle Atlantic Coastal Plain had habitat evaluation scores of 96 and 99.

Of the 118 sampling stations for the Savannah REMAP Project, 88 of them are in the Lower Piedmont ecoregion. Seventy-eight of these Lower Piedmont stations had data for all three indicators

(EPT, Fish IBI, and Habitat) utilized for ecological assessment. The other ecoregions within the project area did not have a sufficient number of sampling stations to adequately assess ecological condition. Statistical analysis was therefore restricted to the 78 station data set for the Lower Piedmont ecoregion.

During the four year study period, fish were collected from 108 stream stations. Over 10,000 fish, comprising 49 different species (Table 5.3), were collected. Appendix C list the species and the number collected at each stream station.

Stream fish were collected from six different ecoregions in the Savannah Basin (Table 5.3). Eighty eight (over 75%) of the stream stations were located in the Lower Piedmont ecoregion. The Lower Piedmont is the largest ecoregion in the Savannah River Basin. Only one stream station was located in the Mid-Atlantic Coastal Plain.

Table 5.3 Summary of the number of fish collected over the four year study.

Ecoregions	Stream Stations	Number Fish Species	Number of Fish Identified
Blue Ridge	11	17	318
Upper Piedmont	3	8	267
Lower Piedmont	82	43	9103
Sand Hills	3	9	48
Southern Plains	8	26	329
Mid-Atlantic Coastal Plain	1	2	9
Total	108	49*	10074

* - Number represents total number of different species collected during the study, not the column total.

Ranges of in-situ water quality measurements (pH, dissolved oxygen, conductivity, and temperature) are presented in Table 5.4. In regard to pH, no ecoregional pattern or characteristic emerged. Although the remaining water quality parameters are lacking in number of observations for the Upper Piedmont, Sand Hills, and Middle Atlantic Coastal Plain, there appears to be a gradient from the mountains to the coast (Figure 5.11). This occurs as a decrease in dissolved oxygen and an increase in the temperature regime from the Blue Ridge to the Middle Atlantic Coastal Plain. Although not as apparent as dissolved oxygen and temperature, conductivity, with the exception of the Sand Hills, also increased along this same ecoregional gradient. Again, more data points are necessary to validate this pattern.

Table 5.4 In-situ Water Quality Data

Ecoregion	**pH**	**D.O. (mg/l)**	**Conductivity (μS/cm)**	**Temperature (°C)**
Blue Ridge	6.6 - 7.6	7.9 - 9.5	16 - 29	16.5 - 23.7
Upper Piedmont	6.3 - 7.0	8.2 - 8.5	20 - 40	22.0 - 23.2
Lower Piedmont	5.1 - 9.1	3.6 - 11.3	15 - 3260	17.5 - 28.2
Sand Hills	5.2 - 6.9	6.7 - 7.9	18 - 914	20.9 - 25.6
South Eastern Plains	6.1 - 7.5	6.3 - 8.3	36 - 184	20.9 - 25.5
Mid-Atlantic Coastal Plain	4.1 - 6.0	5.1 - 6.9	58 - 60	25.6 - 25.8

Water quality violations were noted for dissolved oxygen and pH during the in-situ water quality measurements. Dissolved oxygen at Station 98, an unnamed tributary to Cliatt Creek, in Columbia County, Georgia was measured at 3.6 mg/L which is below the two state's water quality standards of 4.0 mg/L. This translates into about 2% of the stream miles being below the minimum standard dissolved oxygen in the basin (Figure 5.12). Likewise, about 8% of the stream miles were below both state's pH standard of 6.0 and approximately 2% were greater than the allowable level for streams in Georgia (8.5) and South Carolina (8.0) (Figure 5.13).

Algal growth potential tests were conducted for the first two years and analyzed from a basin perspective. The results of that effort and interpretation of the data are in a report by Raschke, et al. (1997) (Appendix H).

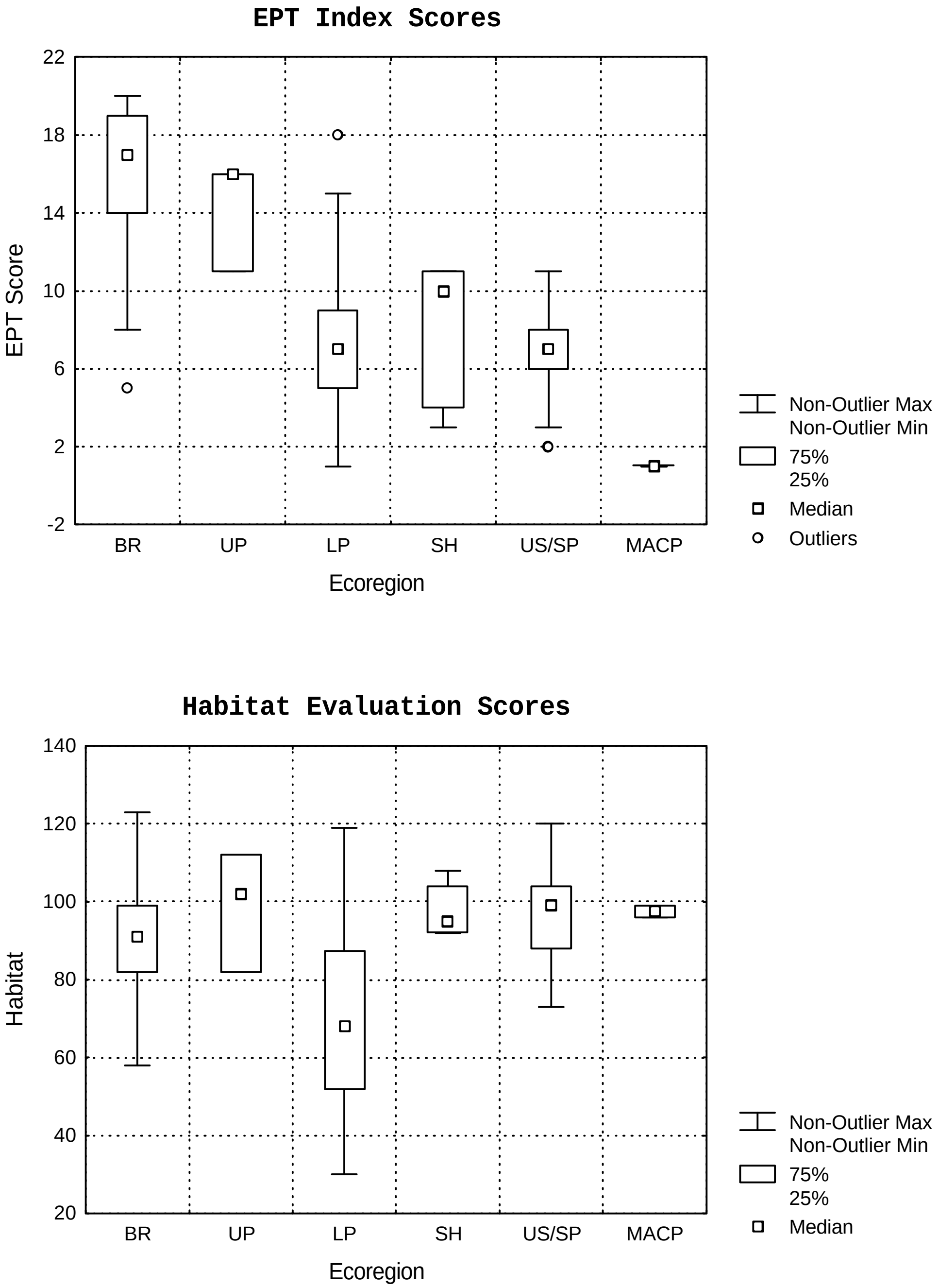

Figure 5.10 Box and Whisker Plots of Ecoregion EPT Index Scores and Habitat Scores.

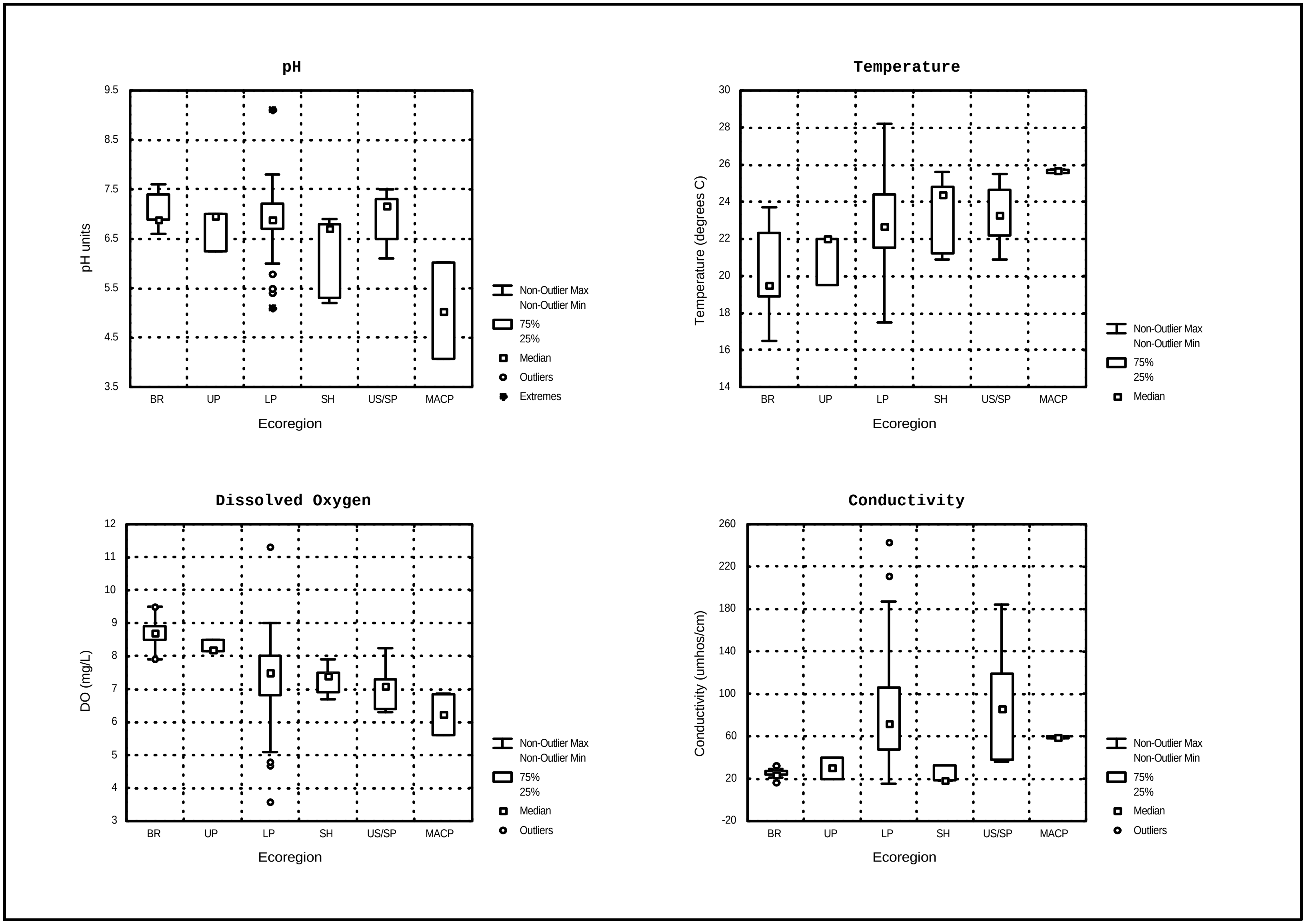

Figure 5.11. Box Whisker Plots of Ecoregion In-Situ Water Quality Parameters.

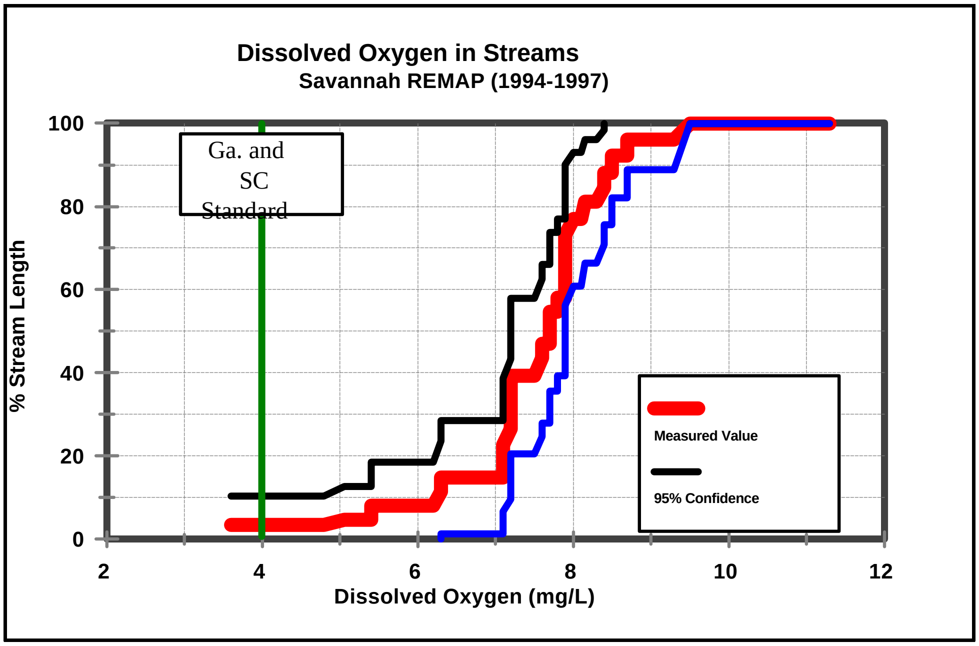

Figure 5.12 Cdf curve of Dissolved Oxygen Data.

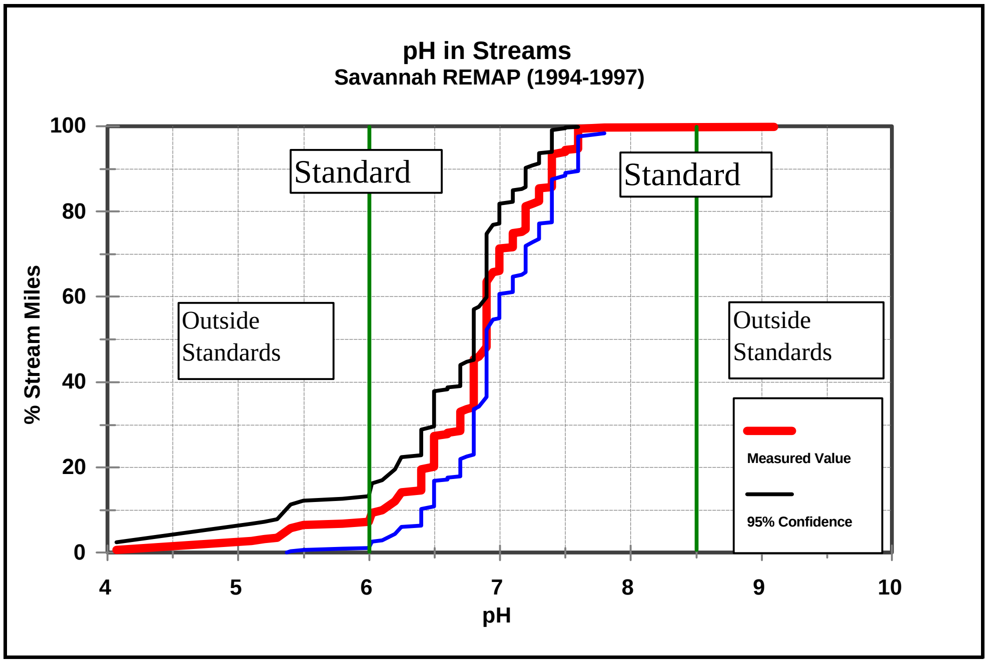

Figure 5.13 Cdf curve of pH data.

5.2 Ecoregion Perspective

Because of our original emphasis on Basin ecological condition, sampling locations were randomly selected over the whole Savannah River Basin, not by ecoregion. This skews the number of sampling locations in favor of the largest ecoregion, which was the Lower Piedmont. The Lower Piedmont ecoregion is a large geographical area that encompasses two states and many subwatersheds. There were not enough stream stations in all of the ecoregions to adequately develop an index for each ecoregion. Only the Lower Piedmont region had sufficient number of stream stations to produce enough data, in our opinion, to develop an index that realistically assesses ecological condition.

5.2.1 Development of Scoring Criteria for Ecological Health Assessment of the Lower Piedmont Ecoregion

Benthic macroinvertebrate, fish, and habitat were the basis for interpreting the ecological health of Savannah REMAP wadeable stream sites in the Lower Piedmont Ecoregion. Specifically, the EPT Index (macroinvertebrates), the fish IBI (Index of Biotic Integrity), and habitat evaluation scores were utilized to develop a scoring system for classifying Lower Piedmont streams into three categories (good, fair, poor). Sampling stations for the Savannah REMAP were located in six different ecoregions, however, 88 of the 119 were in the Lower Piedmont ecoregion which provided a sufficient database to examine ecological health in this ecoregion.

The choice of metrics was determined by correlation analysis. Correlation analysis is important in the choice of metrics because it identifies redundancy. Metrics that are very highly correlated should be interpreted with caution since they may indicate some overlap or redundancy; metrics that are highly correlated do not contribute new information to an assessment (Barbour et al., 1996). Habitat evaluation scores and EPT Index results were not significantly correlated thus both of these ecological indicators were acceptable tools for bioassessment. Although Fish IBI and habitat evaluation scores were significantly correlated ($p<.05 = 0.42$), the correlation was more on the order of moderate rather than strong correlation (Appendix C).

Descriptive statistics of all seven variables examined in all 88 Lower Piedmont stations are presented in Table 5.5. Box and whisker plots (Figure 5.15) were performed on the results for each indicator to define the boundaries for three categories (Good, Fair, and Poor). A scoring matrix based on boundaries defined by box and whisker plots was completed for the Lower Piedmont Ecoregion. The scoring matrix for the EPT Index, Fish IBI, and Habitat is provided in Table 5.6.

Table 5.5 Descriptive Statistics of the Stream Variables.

Variables	# of Stations	Mean	Minimum	Maximum	Standard Deviation
Fish IBI Scores	82	26.00	13.00	43.00	6.26
Habitat Scores	84	70.99	30.00	119.00	21.68
EPT Scores	87	7.14	1.00	18.00	3.19
pH	84	6.91	5.10	9.10	0.53
Temperature (C)	83	23.02	17.5	28.2	2.05
Dissolved Oxygen (mg/l)	75	7.29	3.6	11.3	1.14
Conductivity (μS/cm)	76	80.58	15.00	243.00	43.92

Table 5.6 Scoring Matrix for Ecological Health of Lower Piedmont Streams

Indicator	5 points GOOD	3 points FAIR	1 point POOR
EPT Index	$\geq$ 9	6 - 8	$\leq$ 5
Fish IBI	$\geq$ 31	22 - 30	$\leq$ 21
Habitat	$\geq$ 87	53 - 86	$\leq$ 52

The next step was defining a final classification system based on the total score obtained from all three indicators for the 78 station Lower Piedmont data set. Again, box plots were utilized to define the boundaries for total scores in the “Good”, “Fair”, and “Poor” categories. This final classification system is termed the Savannah Basin-Lower Piedmont Ecological Index (SB-LPEI).

5.2.2 SB-LPEI and Ecological Condition of Lower Piedmont Streams

Final ecological health classification of Lower Piedmont streams, based on total points derived from the three ecological indicators (EPT Index, Fish IBI, and Habitat), was determined by the following scheme:

Classification	**Total points**
Good	≥ 11
Fair	8 - 10
Poor	≤7

(Note: a score of 1 in either of three ecological indicators does not warrant a “Good” ranking)

Based on this scoring scheme, 69% of the stream miles indicated some degree of impairment (“Fair” and “Poor” rankings) (Figure 5.14). A complete listing, by station, of the individual ecological indicator results and the final ecological health classification from the results of the SB-LPEI is provided in Appendix C. Habitat degradation, primarily from sedimentation, is apparently the leading cause affecting the aquatic life in Lower Piedmont streams. Habitat evaluation parameters such as bottom substrate/available cover, channel alteration, and bottom scouring and deposition specifically identify sedimentation concerns. Low scores in these three sediment-related parameters of the habitat evaluation worksheet translated into less than desirable benthic macroinvertebrate and fish populations. Conversely, ecoregional reference sites scored higher in these three sediment-related parameters and supported diverse fish and macroinvertebrate communities.

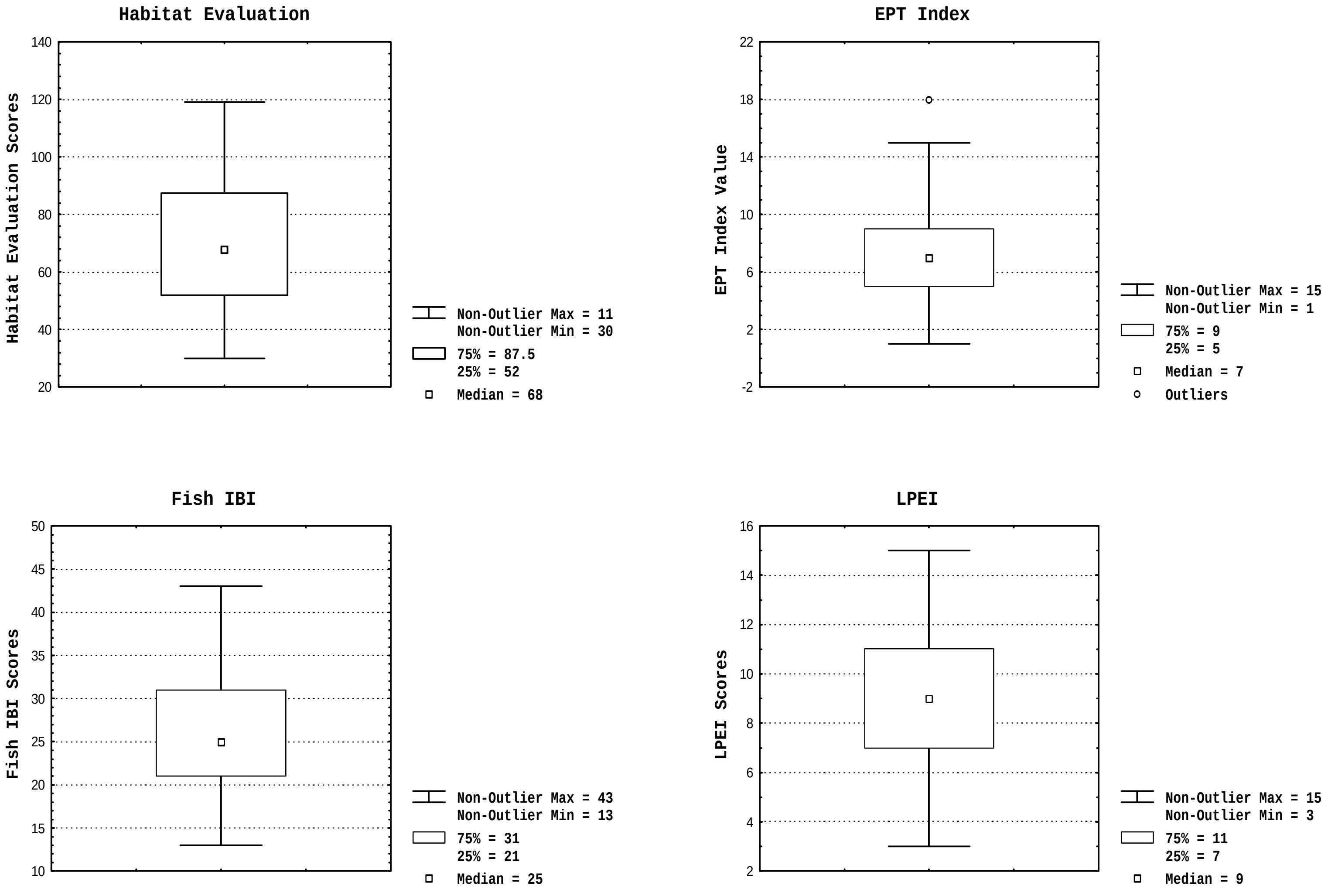

Figure 5.14. Box and Whisker Plots Used to Develop the Scoring Criteria for the Savanna Basin-Lower Piedmont Ecological Index.

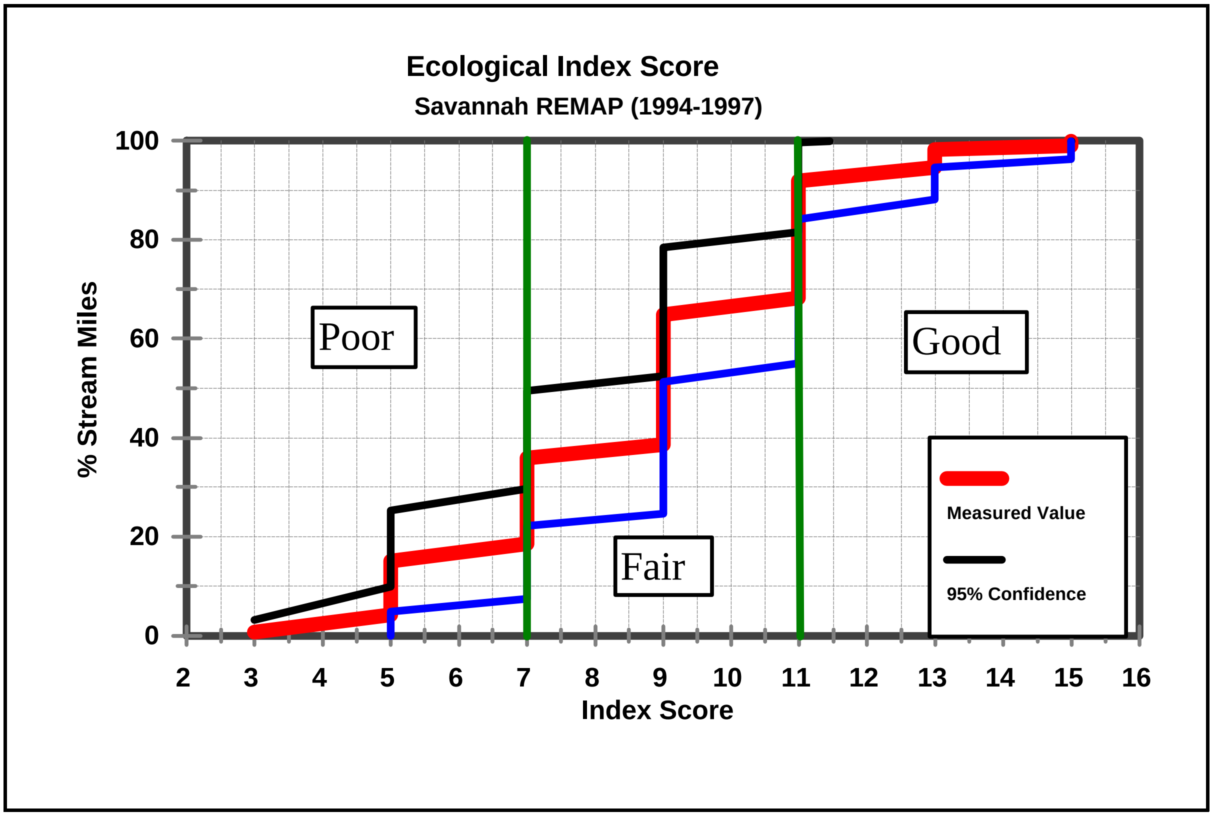

Figure 5.15. Cdf Curve of Savannah Basin-Lower Piedmont Ecological Index.

6.0 Discussion of Objectives

Estimate the status and change of the condition of water resources in the Savannah River Basin.

Based on three years of measuring trophic condition of the tributary embayments of large lakes in the basin, the data show that the lakes' embayments are in good condition. Only about 5% of the embayment acreage exhibited less than desirable conditions with respect to recreation and water supply use (Raschke, 1993). Much of that could be attributed to wind fetch at the near-shore stations. Significant changes from cycle to cycle possibly are within the realm of natural variability or some unmeasured stressor indicators within the lakes' environs. Sampling took place several weeks after rainfall events, therefore, external stream inputs were not expected to cause the observed differences between cycles.

In evaluating the status of ecological health of streams in the Savannah Basin, both biological and habitat parameters were examined to arrive at a final estimate of the ecological condition of wadeable streams. There appeared to be a general decline southward with respect to EPT Index, DO, and conductivity. The temperature gradient decreased in a northward direction. Water quality violations were noted for DO and pH. A DO violation of <4.0 was observed at Station 98 on an unnamed tributary to Cliatt Creek in Columbia County, Georgia. Likewise, about 8% of the stream miles were less than both states' pH standard of 6.0, and 2% of the miles were greater than the allowable South Carolina level of 8.0.

In-depth data analysis, as indicated in Section 5.0, was restricted to streams in the Lower Piedmont Ecoregion because there was not sufficient biological data for a thorough analysis of other ecoregions. Data analysis lead to the development of the Lower Piedmont Ecological Index (SB-LPEI). The components of the SB-LPEI were the fish IBI, macroinvertebrate EPT Index, and the RBP V habitat evaluation scores.

This SB-LPEI was successful in establishing ecological "status" of wadeable streams in the Lower Piedmont Ecoregion. Based on the SB-LPEI, sixty-nine percent of the streams were classified as "fair" or "poor" indicating ecological impairment. Impairment at these sites pointed to habitat degradation primarily from excessive sedimentation. The results of the SB-LPEI can be utilized to establish areas of concern for future evaluation.

Change in ecological condition was not established during this study. There was not enough data for all study years to confidently evaluate change over the four year study period.

Identify water quality spatial gradients that exist within the Savannah River Basin and associate current and changing condition with factors that may be contributing to this condition and spatial gradients.

Analysis of information by ORD, NERL-LasVegas (Appendix F) showed that landscape indicators like percent forest cover, forest edge, proportion of watershed area with agriculture or urban land cover(U-Index), agriculture edge, average patch, average forest patch, and agriculture on slopes >3% were significantly correlated with the stream indicators AGPT, EPT Index, Fish IBI, and Habitat Score (Appendix F). NERL-LasVegas showed that both the proportion and patterns of land use are useful in assessing potential causative effects of stream condition. Landscape indicators at the subbasin scale provided the best characterization of the basin.

In a previous Savannah REMAP report using two years of stream data, Raschke et al. (1996) identified one area that had an inordinate amount of bad sites clustered around Hart and Franklin Counties, Georgia near Interstate 85. Upon review of four years of data and taking a very conservative approach in developing criteria for poor ecological health, the information revealed that this area is much larger than expected. It has expanded into South Carolina (Figure 6.1). This area includes all or part of Hart and Elbert Counties, Georgia and Oconee, Pickens, and Anderson Counties, South Carolina. The designation of an area does not imply that every stream is in “poor” condition nor that the area has a certain confidence band. Our observations are qualitative, that is, there is an unusual number of poor areas clustered, in our professional opinion, along the Interstate 85 corridor. We believe streams in this area are most vulnerable to landscape perturbations and in need of further detailed investigation.

The landscape analysis showed that approximately 64% of this “poor” area is forest, 22.3% agriculture, 2.6% urban, and 3% barren. Two percent of the area is in agriculture on slopes >3%, there is approximately 21% agriculture on moderately erodible soils, and approximately 1% on highly erodible soils, and <0.1% agriculture on slopes >3% in highly erodible soils.

This area has been subjected to a considerable increase in population growth because of the large impoundments in the upper part of the Savannah River Basin. Furthermore, examination of GIS information shows that it has a high density of chicken production, extensive agriculture in large blocks, and the headwaters of streams in the subbasins have a high density of roads. In some subbasins of this “poor” area, the forest land is highly fragmented and the land has been opened up to industrial/urban/and agriculture development in the headwaters of some of the streams.

Demonstrate the utility of the REMAP approach for ecoregion and river basin monitoring and its applicability for state monitoring programs.

In the arena of state monitoring, the concept of probability sampling is like the “new kid on the block” - the one who dresses differently and acts differently. And we, the regions and states, mirroring real life, have been slow in warming up to this “kid,” and rightfully so! For he embraces a new way of thinking that threatens stability, cultural traditions, and the past historical record. From the inception of this project, we were aware of the potential disruption that probability sampling could create among our state partners. So we diligently set a course of testing the EMAP approach and determined how we could best incorporate it into state monitoring schemes with as little disruption as possible. We sought out and found Dr. Steve Rathbun of the University of Georgia Statistical Department. He is a statistician who has experience in different types of probability sampling approaches and experience with the problems of incorporating the “new kid on the block” into traditional state monitoring programs. Rathbun addressed concerns regarding probability-based designs posed by the “Assessment Design Focus Group of the 305(b) Consistency Workgroup (Appendix G). His full report in Appendix G is an important first step in the integration of judgement and probability monitoring data without losing most of the historical data.

States and the federal government historically have established monitoring networks based on judgmental sampling. That is, stations were usually located where there were pollution problems or the area was vulnerable to pollution because of man’s activities. Unfortunately, this type of site selection is biased and it is virtually impossible to relate to a whole population of streams/lakes, watersheds, basins, ecoregions etc. Sampling designs based on judgement sampling are not likely to yield representative samples.

With the need for preserving historical monitoring data and marrying it to a probability-based design, Rathbun (Appendix G) tested an approach using an interval overlap technique with historical judgement sites and probability-based sites located near judgement sites. The technique uses a back-prediction method that determines what the historical data should have been had a probability-based sample design been implemented from the very beginning of the program. If the above methods shows there is still some bias in the data, then a bias-corrective factor is calculated to best fit the data.

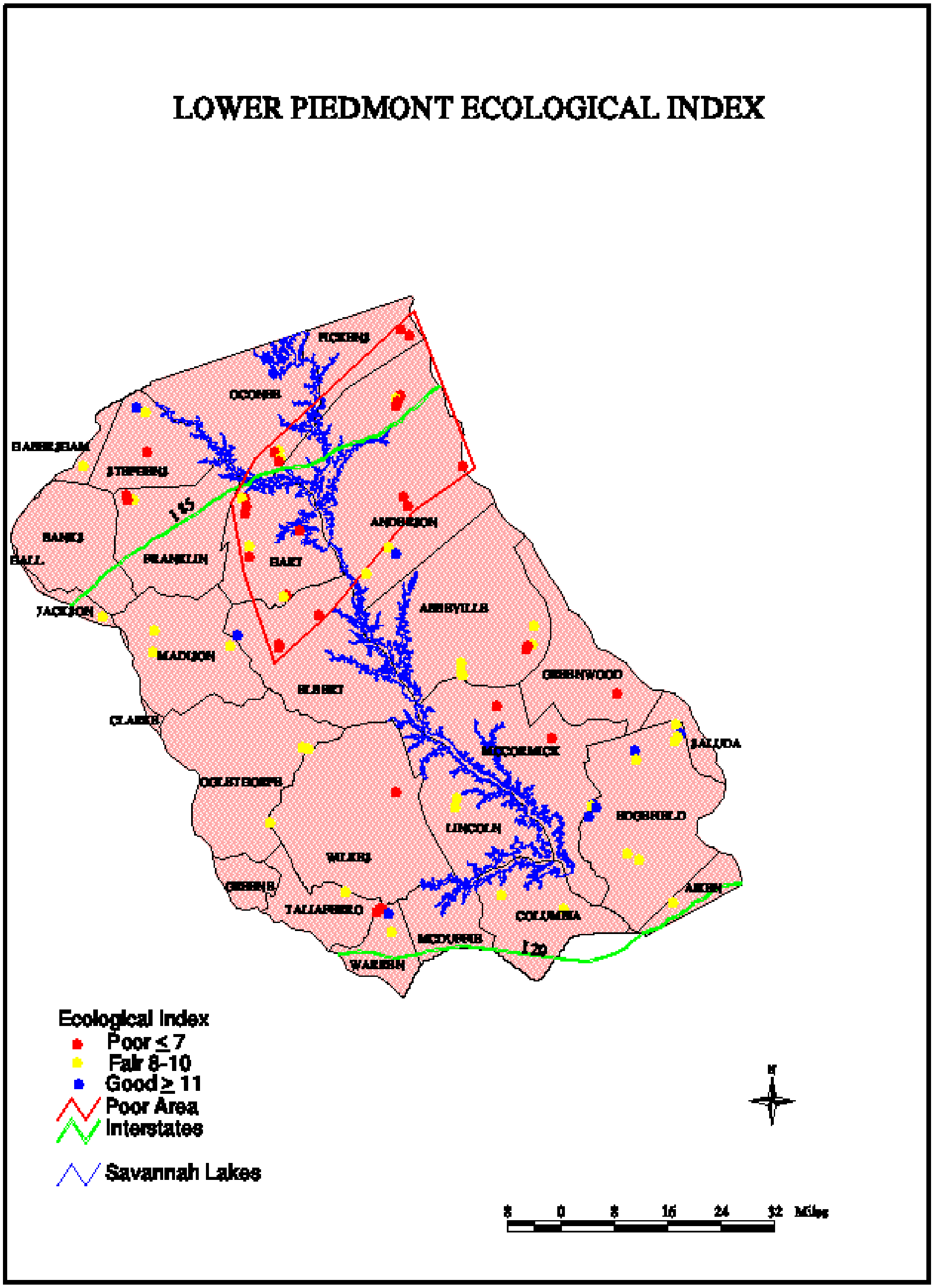

Figure 6.1. Area in the Lower Piedmont with an Unusual Amount of Poor Sites.

Incorporate the REMAP approach in the formulation and accomplishment of the state river basin management plans.

Most states are monitoring their basins on a cyclic schedule rather than doing state-wide monitoring every year. This report shows that it is possible to incorporate probabilistic sampling (the EMAP approach) into state monitoring programs at the basin level and even the ecoregional level. Rathbun (Appendix G) presents a method of incorporating historical judgement station data into a probabilistic design. This is important because the states can better estimate stream miles impacted etc. and have sufficient data for trend analysis. We can’t predict to what degree each state will incorporate probability sampling into their monitoring programs. As of the distribution of this report, we have had a workshop on integration of judgement data with probability data. The workshop addressed state concerns and opened the door for joint discussions. Likewise, the Office of Water has directed the states to move toward probability sampling for purposes of including better estimates of ecological condition into the 305(b) reports. South Carolina is moving toward probability sampling, Alabama has partially incorporated it into their monitoring program and Kentucky is evaluating it presently.

Provide baseline information required to conduct comparative risk assessments in the Savannah River Basin.

REMAP is not a problem-specific program. It focuses on monitoring the condition or system response, and changes in the condition of the ecological resource; not specific physical alterations, chemical species or associated problems. Biological indicators are the focus of monitoring in REMAP, but selected abiotic indicators can be monitored to provide directional diagnostic ability if changes in condition are detected or existing condition of the resource is degraded. Additional and/or more intensive monitoring in a given region likely will be required to specifically determine problem causes and determine the existing or potential risk to the resource. A risk analysis consists of three phases: Problem Formulation, Analysis, and Risk Characterization (EPA, 1992b).

REMAP contributes primarily to problem formulation by providing comparable information on the condition of multiple resources in a region, basin, or ecoregion. As shown in the data analysis, it can highlight areas, stream miles, etc. that are affected. It can show areas in a basin or ecoregion that might be under man-induced assaults, thereby needing further investigation like the area along I-85 in Georgia and South Carolina (Figure 6.1; Appendix F).

7.0 REFERENCES

APHA. 1995. Standard Methods for the Examination of Water and Wastewater, 19th Edition. American Public Health Association, Washington, D.C.

Buck, D. H. 1956. Effects of turbidity on fishing. Transactions of the American Wildlife Conference 21:249-261.

Barbour, M. T., J. L. Plafkin, B. P. Bradley, C. G. Graves, and R. W. Wiseman. 1992. Evolution of EPA's Rapid Bioassessment Benthic Metrics: Metric Redundancy and Variability Among Reference Stream Sites. Environmental Toxicology and Chemistry 11:437-449.

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1998. Draft Revision to Rapid Bioassessment Protocols for Use in Streams and Rivers. EPA 841-D-97-002, Office of Water, Washington, D. C.

Bromberg, S. M. 1990. Identifying ecological indicators: An environmental monitoring and assessment program. Journal of the Air Pollution Control Association 40:976-978.

Callicott, J. B. 1991. Conservation ethics and fishery management. Fisheries 16:22-28.

Chow, Ven te (Editor). 1964. Handbook of Applied Hydrology: A Compendium of Water-Resources Technology. McGraw-Hill Book Co. New York, New York.

Doudoroff, P., and C. E. Warren. 1957. Biological indices of water pollution with special reference to fish populations. Pages 144-163. In: Biological Problems in Water Pollution. U. S. Public Health Service, Cincinnati, Ohio.

EPA. 1983. Methods for the Chemical Analysis of Water and Wastes. EPA-600/4-79-020. Revised March, 1983. U.S. Environmental Protection Agency, Cincinnati, OH.

EPA. 1991. The Watershed Protection Approach, an Overview. EPA 503/9-92/002. U. S. Environmental Protection Agency, Washington, D. C.

EPA. 1992a. Methods for the Determination of Chemical Substances

in Marine and Estuarine Environmental Samples. U.S. Environmental Protection Agency, Cincinnati, OH.

EPA. 1992b. Framework of Ecological Risk Assessment: Risk Assessement Forum. EPA 630/ R-92/001. EPA, Washington, D. C.

EPA. 1996. Watershed Approach Framework. EPA 840/S-96/001. Office of Water. U. S. Environmental Protection Agency, Washington, D. C.

EPA, 1998. EPA Region 4, Science and Ecosystem Support Division, Ecological Assessment Branch SOP and QA Manual. Athens, GA.

Frey, D. G. 1977. Biological integrity of water - A historical approach. Pages 127-140. In: R. K. Ballentine and L. J. Guarria (Eds.). The Integrity of Water. U. S. Environmental Protection Agency, Washington, D. C.

FTN Associates, R. L. Raschke, H. Howard. 1994. Plan of Study for Characterizing Ecological Condition in the Savannah River Basin. U. S. Environmental Protection Agency, Region 4, Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, Georgia.

Hughes, R. M., and R. F. Noss. 1992. Biological diversity and biological integrity: Current concerns for lakes and streams. Fisheries 17:11-19.

Hunsaker, C. T., D.E. Carpenter, and J. Messer. 1990. Ecological indicators for regional monitoring. Bulletin of the Ecological Society of America 71(2):165-172.

Hunsaker, C. T., and D. E. Carpenter. 1990. Environmental Monitoring and Assessment Program - Ecological Indicators. EPA 600/3-90/060. U. S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing Biological Integrity in Running Waters: A Method and its Rationale. Publication No. 15. Illinois Natural History Survey, Champaign, Illinois.

Klessig, L. 1988. Problem Identification. In: The Lake and

Reservoir Restoration Guidance Manual. EPA 440/5-88-002. Criteria and Standards Division, Washington, D. C.

Larsen, D. P., D. J. Stevens Jr., A. R. Selle, and S. G. Paulsen. 1991. Environmental Monitoring and Assessment Program, EMAP - surface waters, a Northeast lakes pilot. Lake and Reservoir Management 7(1):1-11.

Larsen, D. P., and S. J. Christie (Eds.). 1993. EMAP-Surface Waters. 1991 Pilot Report. EPA 620/R-93/003. Office of Research and Development, U. S. Environmental Protection Agency, Washington, D. C.

Management Committee. 1995. Savannah River Watershed Project: Initial Assessment and Prioritization Report for the Savannah River Basin. Volumes 1 and 2. Prepared by the Management Committee of the Savannah River Basin Watershed Project.

Messer, J. J., R. A. Linthurst, and W. S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environmental Monitoring and Assessment 17:67-78.

Miller, W., J. Green, and T. Shiroyama. 1978. The Selenastrum capricornutum Printz Algal Assay Bottle Test. EPA-600/9-78-018.

National Academy of Sciences and National Academy of Engineering. 1973. Water Quality Criteria 1972. Superintendent of Documents, U. S. Government Printing Office. Washington, D. C.

Noss, R. F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

Olem, H. and G. Flock (Eds.). 1990. Lake and Reservoir Restoration Guidance Manual. EPA 440/4-90/006. Second Edition Prepared by The North American Lake Management Society for the U. S. Environmental Protection Agency, Washington, D. C.

Overton, W. S., D. Stevens Jr., D. White 1990. Environmental Monitoring and Assessment Program - Design Report for EMAP. EPA 600/3-91/053. U. S. Office of Research and Development, Environmental Protection Agency, Washington, D. C.

Peters, H. 1981. Phosphorus availability in Lake Memphrenagog and its tributaries. Limnology and Oceanography 26:1150-?

Pister, E. P. 1987. A pilgrims progress from Group A to Group B. Pages 221-232. In: J. B. Callicott (Ed.). Companion to Sand County Almanac. University of Wisconsin Press, Madison, Wisconsin.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrate and Fish. EPA 440/4-89-001. Office of Water, U. S. EPA.

Raschke, R. L. 1994. Phytoplankton bloom frequencies in a population of small southeastern impoundments. Lake and Reservoir Management 8(2):205-210.

Raschke, R. L. 1993. Guidelines for Assessing and Predicting Eutrophication Status of Small Southeastern Piedmont Impoundments. U. S. Environmental Protection Agency, Region 4, Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, Georgia.

Raschke, R. L., and D. A. Schultz. 1987. The use of the algal growth potential test for data assessment. Journal of the Water Pollution Control Federation 59(4):222-227.

Raschke, R. L., B. Cosgrove, and M. Koenig. 1985. Phosphorus loading effects upon phytoplankton standing crop in a tributary embayment of a southern piedmont reservoir. Pages 139-148. In: Lake and Reservoir Management: Practical Applications. North American Lake Management Society, Madison, Wisconsin.

Raschke, R. L., H. S. Howard, J. R. Maudsley, and R. J. Lewis. 1996. The Ecological Condition of Small Streams in the Savannah River Basin: A REMAP Progress Report. EPA Region 4, Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, GA.

Raschke, R. L., R. Quinn, T. Olsen, and D. Stevens Jr. 1997. Savannah River Basin REMAP Interim Report: Large Lake Embayments. EPA Region 4, Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, GA.

Rathbun, S. C., R. Houghton, and C. Laurin. 1996. Cramer-von Mises Tests for Environmental Monitoring Data. A report for the U. S. Environmental Protection Agency, Science and Ecosystem Support Division, Ecosystem Assessment Branch, Athens, Georgia.

Schultz, D., R. Raschke, and R. Jones. 1994. A shortened algal growth potential test. Environmental Monitoring and Assessment 32:201-205.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. Sixth Edition. The Iowa State University Press, Ames, IA.

Stevens, D. L. Jr. 1994. Implementation of a national environmental monitoring program. Journal of Environmental Management 42:1-29.

Stevens, D. L. Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8:165-197.

Stevens, D. L. Jr., A. R. Olsen, and D. White. 1992. Integrated Sampling Design: Environmental Monitoring and Assessment Program. EPA 600/xxx/xxx. U. S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Urquhart, M. S., W. S. Overton, and D. S. Birkes. 1993. Comparing sampling designs for ecological status and trends: Impact of temporal patterns. In: V. Barnett and K. F. Turkman (Eds.). Statistics for the Environment. Wiley, New York.

Wallace, J. B., J. W. Grubaugh, and M. R. Whiles. 1996. Biotic Indices and Stream Ecosystem Resources: Results from an Experimental Study. Ecological Applications 6(1):140-151.

Welch, P. S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc., New York.

White, D., A. J. Kimerling, and W. S. Overton. 1992. Cartographic and geometric components of a global sampling design for environmental monitoring. Cartography and Geographic Information Systems 19:5-22.