Tennessee Valley Authority

Water Management
Chattanooga, Tennessee

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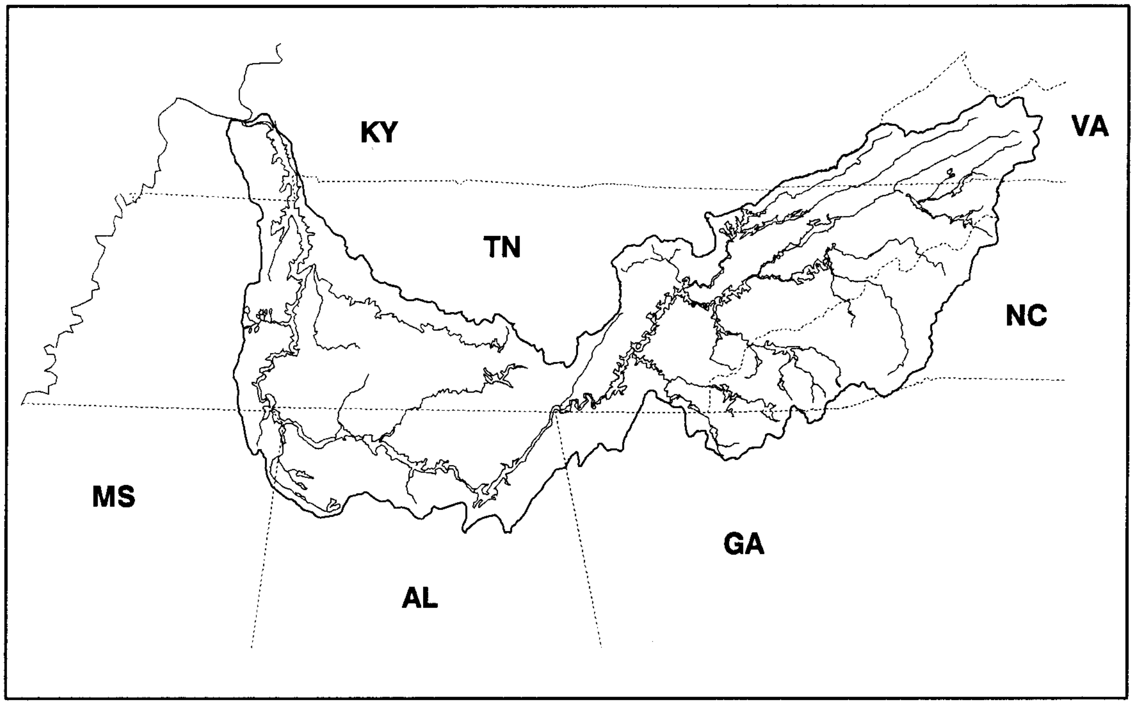
TENNESSEE VALLEY RESERVOIR AND STREAM QUALITY - 1993

SUMMARY OF VITAL SIGNS AND USE SUITABILITY MONITORING

VOLUME I



CLEAN WATER INITIATIVE

TENNESSEE VALLEY AUTHORITY
Resource Group
Water Management

TENNESSEE VALLEY RESERVOIR AND STREAM QUALITY - 1993
SUMMARY OF VITAL SIGNS AND USE SUITABILITY MONITORING

Volume I

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EXECUTIVE SUMMARY

TVA initiated a systematic, Valley-wide water quality and aquatic ecological monitoring program in 1986. The program started with a stream component, and a reservoir monitoring component was added in 1990. The two primary objectives of these monitoring efforts are to evaluate the ecological health (Vital Signs Monitoring) of major streams and reservoirs in the Tennessee Valley and to examine how well these water resources meet the swimmable and fishable goals of the Clean Water Act (Use Suitability Monitoring).

Vital Signs Monitoring

Stream monitoring has been conducted on 12 large tributaries since 1986. Beginning in 1994, six additional tributaries will be monitored; all with watersheds of at least 500 square miles. Reservoir monitoring started with 12 reservoirs (mostly mainstream reservoirs) in 1990 and has expanded progressively to the full complement of 30 reservoirs in 1993. No further expansion of either stream or reservoir monitoring is planned. This report summarizes results of these monitoring efforts in 1993. Volume I is the main body of the report and Volume II is a data summary organized by sample locations within watershed areas.

Until 1991, the ecological health evaluations were based on subjective evaluation of the data. A weight-of-evidence approach was used--a stream or reservoir was deemed healthy if most of the physical, chemical, and biological monitoring components appeared healthy. Beginning with the 1991 results, a more quantitative approach was developed that has been used the last three years. This approach integrates information on important indicators of ecological health. For reservoirs, five indicators are used--dissolved oxygen, chlorophyll, sediment quality, benthic macroinvertebrates, and fishes. Stream evaluations are similar except dissolved oxygen is not rated and nutrient concentrations are substituted for chlorophyll concentrations. For each indicator (or metric), scoring criteria are developed that assign a score ranging from 1 to 5 representing very poor to excellent conditions, respectively. Scores for all indicators at a location are summed. For streams and smaller reservoirs, only one site is monitored. For larger reservoirs, multiple sites are monitored, and the overall reservoir score is achieved by totaling scores for all locations. The resulting total is divided by the maximum possible score. Thus, the possible range of scores is from 20 percent (all metrics very poor) to 100 percent (all metrics excellent). Hence, an overall ecological health rating of good, fair, or poor is obtained for each stream site or reservoir. A health rating border-line between two of these categories is considered poor-fair or fair-good. Each year, the most recent information is

evaluated with the same basic approach, modified to incorporate improvements based on comments from reviewers and additional data.

Stream monitoring results for 1993 indicated seven streams rated good (three of these received perfect scores), three streams rated fair to good, and one stream rated poor. Full evaluation was not possible for one stream because only three of the four indicators were monitored in 1993. The only stream to receive a poor rating was the French Broad River. This overall rating was caused by poor scores for nutrients and fishes, a fair score for benthos, and a good score for sediment quality.

Reservoirs are stratified into two groups for evaluation: run-of-river reservoirs and deep storage reservoirs. Separate scoring criteria were used for the two categories. Overall ratings for the 11 run-of-river reservoirs in 1993 ranged from 58 to 88 percent. Four reservoirs rated good (75 to 88 percent), three rated fair to good (71 to 73 percent), three rated fair (63 to 68 percent), and one rated poor to fair (58 percent). Overall ratings for the 19 storage reservoirs ranged from 52 to 72 percent. Two reservoirs rated fair to good (both 72 percent), 14 rated fair (58 to 67 percent), and three rated poor (52 to 56 percent).

Most streams and reservoirs had ratings comparable to those observed in 1991 and 1992. Tributary reservoirs had generally poorer ratings, primarily because of low dissolved oxygen in the hypolimnion. This is an ecologically undesirable condition that is partly due to the strong thermal stratification that occurs in deep reservoirs with relatively long retention times.

Use Suitability Monitoring

Use Suitability Monitoring provides screening level information on the suitability of selected areas within TVA reservoirs for water contact activities (swimmable) as determined by bacteriological studies and suitability of fish from TVA reservoirs for human consumption (fishable) as determined by fish tissue studies.

Bacteriological Studies--Bacteriological samples are collected at over 260 sites in the Tennessee Valley. These include designated swimming areas, canoe access sites, highly used recreational areas, and selected nonrecreation sites that provide information on pollution sources or inflow stream water quality. Recreation sites are sampled at least once every two years.

In 1993, 71 swimming areas and 14 canoe access points were sampled for bacteriological conditions. All but two swimming areas met the regulatory criterion to be considered safe. Even those two sites met the criterion if samples collected after heavy rains were excluded. Four canoe access points on the Duck River exceeded the criterion, both in dry and wet weather.

Bacteriological sampling at nonrecreational areas was conducted at 35 sites in 1993. Only one reservoir site and two stream sites failed to meet recreation criteria.

These results are consistent with previous surveys. Fecal coliform concentrations were generally lower in 1993 due to lower than normal summer rainfall. Bacteriological water quality in most areas of TVA reservoirs is good. In streams it is much poorer, especially after rainfall.

Fish Tissue Studies--Fish tissue studies examine fillets from important fish species for selected metals, pesticides, and polychlorinated biphenyls (PCBs) on the U.S. Environmental Protection Agency's list of priority pollutants. Resulting data are provided to appropriate state agencies to determine whether further study is needed or fish consumption advisories should be issued. Fish tissue data reported here represent autumn 1992 collections. Results for fish collected in autumn 1993 were not available at the time this report was prepared due to the time delay required for laboratory analysis.

Results of fish tissue screening studies in 1992 did not reveal any new areas in need of intensive investigations. Concentrations of at least one contaminant were high enough to warrant sampling again at the screening level in 1993. Results of intensive studies (i.e., in-depth studies on waterbodies where there are known or suspected problems) did not indicate substantial changes from previous years.

1.0 INTRODUCTION

1.1 Background

The Tennessee Valley Authority (TVA) started a Stream Monitoring Program in 1986 to evaluate the major tributaries of the Tennessee Valley at fixed locations. A parallel program, Reservoir Monitoring, was begun in 1990 when funds were appropriated by Congress for TVA to strengthen its stewardship responsibilities. The combined Stream and Reservoir Monitoring efforts consolidated several newly-developed activities along with several existing activities to form an integrated program. These monitoring efforts, in addition to River Action Team watershed examinations and public information/educational activities, are now part of TVA's comprehensive Clean Water Initiative.

1.2 Objectives

Objectives of these monitoring efforts are to provide information on the "health" or integrity of the aquatic ecosystem in major Tennessee River tributaries and reservoirs and to provide screening level information for describing how well these water resources meet the "fishable" and "swimmable" goals of the Clean Water Act.

The ecological integrity of stream and reservoir ecosystems is examined as part of an activity called Vital Signs monitoring. The basis of Vital Signs monitoring is examination of key physical, chemical, and biological indicators to evaluate the health of each stream or reservoir and to target detailed assessment studies if significant problems are found. In addition, this information establishes a baseline for comparing future water quality conditions as watershed improvements are made.

Another activity, Use Suitability monitoring, examines how well streams and reservoirs meet the fishable and swimmable goals of the Clean Water Act. Examination of levels of toxic contaminants in fillets from important fish species is the basis for the fishable use evaluation. Swimmable or water contact uses are examined by conducting bacteriological sampling at designated swimming beaches and other highly used recreation areas.

Using a quantitative approach to evaluate ecological health of water resources is relatively new, especially for reservoirs. This is only the third year TVA has used this approach, and we continue to make improvements based on experience gained each year. Ecological health evaluations drawn from this newly implemented monitoring program are subject to revision in future

years as more data and experience are acquired on each reservoir. We welcome comments and suggestions for improvements in these ecological health evaluation methodologies. Please send comments/suggestions to the address above or contact appropriate individuals listed under key contacts on page ii.

1.3 Summary Report Description

Volume I of this report summarizes and integrates results from TVA's stream and reservoir monitoring activities in 1993. Chapter 1 provides background and objectives for the monitoring program. Chapter 2 describes the basis for study design and specific methods for sample collection. Chapter 3 describes the philosophical approach and data evaluation methods used for each indicator to determine stream and reservoir ecological health.

Chapter 4 provides an overview of hydrologic and meteorologic conditions for 1993. Conditions in streams and reservoirs are greatly affected by streamflow, rainfall, and temperature, as well as by physical and geologic characteristics of the watershed. Dams, and resulting reservoirs' dynamics, are important factors in the ecological health of regulated river systems. It is important to consider all these variables and their effects in evaluating ecological conditions of the Tennessee River system in any given year.

Chapter 5 discusses the 1993 monitoring results from a Valley-wide perspective. Discussion topics include an overview of ecological conditions, ecological indicators which "drove" the health ratings, changes from previous years, embayment monitoring (initiated in 1993), and swimmable and fishable conditions.

Chapters 6-17 provide a watershed-by-watershed summary and conclusions for each of the 12 watershed drainage areas in the Tennessee Valley. Each chapter provides a physical description of the watershed followed by a description of the physical characteristics, ecological health, and use suitability of each reservoir and stream monitoring site within the watershed. The ecological health evaluation is based on an integration of physical, chemical, and biological information gathered using the different Vital Signs monitoring tools.

Detailed summaries of 1993 results on each reservoir and stream are provided in Volume II of this report. Volume II is for technical audiences who prefer to form their own evaluation of conditions. It also serves as a detailed technical summary of conditions at TVA monitoring sites in 1993.

In addition to this technical summary report, a nontechnical document, *RiverPulse*,is available. *RiverPulse* (TVA, 1994) is broadly distributed to Tennessee Valley residents and users of TVA reservoirs. Annual issues of the technical report have been prepared since 1990, and annual

issues of *Riverpulse* are available for 1991, 1992, and 1993. There also is a series of annual activity reports providing detailed results for each monitoring tool (e.g., water, sediment, benthos, fish, etc.). These detailed reports provide the basis for the summary report. Specific citations for summary and detailed reports are in the list of references. Copies of any of these documents are available from: TVA Water Management Library, 1101 Market Street, HB 2C-C, Chattanooga, TN 37402, Telephone: (615) 751-7338, FAX: (615) 751-7479.

2.0 DATA COLLECTION METHODS

2.1 Vital Signs Monitoring

2.1.1 Introduction

The study design for Vital Signs Monitoring is based on meeting the objectives outlined in Section 1.2. Several assumptions are fundamental to the study design:

1. Ecological health evaluations must be based on information on physical, chemical, and biological components of the ecosystem;

2. Vital Signs monitoring is a long-term effort to document the status of the river/reservoir system and track results of water quality improvement efforts;

3. Monitoring methods must be responsive by providing current information to resource managers;

4. The basic design must be considered dynamic and flexible, rather than rigid and static, and must allow adoption of new environmental monitoring techniques as they develop to meet specific needs; and

5. This is a monitoring program; it does not address specific cause/effect mechanisms. (The step beyond monitoring is assessment in which cause/effect investigations would target specific, identified concerns.)

Three important aspects were considered in establishing the study design: representative sampling locations; important ecological indicators; and frequency of sampling. The program that emerged balances these considerations as follows.

Sampling Locations--For reservoirs, the following three areas were selected for monitoring: the inflow area, generally riverine in nature; the transition zone or mid-reservoir area where water velocity decreases due to increased cross-sectional area, suspended materials begin to settle, and algal productivity increases due to increased water clarity; and the forebay, the lacustrine area near the dam, Figure 2.1. Overbanks, basically the floodplain which was inundated when the dam was built, were included in transition zone and forebay areas. Another important reservoir area, embayments, also was considered. However, monitoring all embayments is beyond the scope of this program. Previous studies have shown that ecosystem interactions within an embayment are mostly controlled by activities and characteristics within the embayment watershed, usually with relatively little influence from the main body of the reservoir. As a result,

only four, large embayments, all with drainage areas greater than 500 square miles and surface areas greater than 4500 acres, are included in the Vital Signs Monitoring Program. These were added in 1993 and are reported on here for the first time.

The stream monitoring sampling locations were located to sample the cumulative water quality for as large a percentage of a tributary watershed as possible, with sampling locations located in the free-flowing reaches of the river near the downstream end of the watershed, but upstream of any impounded water.

Ecological Indicators--Selection of appropriate ecological indicators for monitoring was tailored to the specific objective and type of monitoring location. Physical, chemical, and biological indicators were selected to provide information from various habitats or ecological compartments on the health of that particular habitat or compartment. In reservoirs (Figure 2.1) the open water or pelagic area was represented by physical and chemical characteristics of water (including chlorophyll) in midchannel. The shoreline or littoral area was evaluated by sampling the fish community. The bottom or benthic compartment was evaluated using two indicators: quality of surface sediments in midchannel (determined by chemical analysis of sediments and acute toxicity testing of pore water); and examination of benthic macroinvertebrates from a transect across the full width of the sample area (including overbanks if present).

In streams, all available habitats were included to truly characterize the sample site. This is more easily accomplished in streams than in reservoirs because most habitats are visible. The same basic indicators used for reservoirs were also used in streams.

For both reservoirs and streams, information from each indicator was evaluated separately and results were then combined (without weighing) to arrive at an overall evaluation of reservoir ecological health. (See Chapter 3 for more details on the ecological health evaluation and scoring process.)

Sampling Frequency--Sampling frequencies were selected to take into consideration the expected temporal variation for each indicator. Physical and chemical components vary significantly in the short term, whereas biological components are more representative of long-term conditions. As a result, sampling for physical and chemical indicators is needed more frequently than biological indicators. In reservoirs, physical and chemical indicators were examined monthly from spring to fall and in streams every other month throughout the year. Biological indicators were sampled once each year for reservoir and stream sites. In reservoirs, benthic macroinvertebrate sampling was conducted in early spring (February-April), and fish assemblage sampling was conducted in autumn

(September-November). In streams, benthic and fish community sampling is conducted in late spring-early summer (May-June).

2.1.2 Reservoir Vital Signs Monitoring

The Vital Signs component of reservoir monitoring includes four main activities to examine and evaluate reservoir health:

(1) physical/chemical characteristics of water;

(2) acute toxicity and physical/chemical characteristics of sediment;

(3) benthic macroinvertebrate community sampling; and,

(4) fish assemblage sampling.

(In addition, aquatic macrophyte community information is included to provide a more comprehensive evaluation of each reservoir's ecological health.)

Data collection methods for each of these activities are given below. Sampling locations and specific monitoring activities for each reservoir are listed in Table 2.1 and shown in Figure 2.2.

Physical/Chemical Characteristics of Water--In 1993, physical/chemical water quality variables were measured at a total of 57 sampling locations on 30 reservoirs. Three specific QA/QC measures were incorporated in the reservoir physical/chemical water sampling activities. These included: (1) collection and analysis of triplicate sets of water samples once during the year at all forebay sampling locations to assess sample collection, laboratory analysis, and natural sample variability; (2) preparation and analysis of sample container blanks each collection day to assess the degree of contamination associated with the sample bottles and/or the sample handling processes; and, (3) preparation and analysis of sample filtration blanks with each set of filtered samples to assess the degree of contamination associated with the field sample filtration and handling.

The water quality monitoring activities on the Vital Signs reservoirs followed a "basic" (11 run-of-the-river reservoirs) or a "limited" (19 tributary reservoirs) sampling strategy (Table 2.1).

> ***Basic***--Monitoring on the run-of-the-river reservoirs included monthly water quality surveys (April through September) at forebays and transition zones. Basic monthly water quality sampling included in situ water column measurements of temperature, dissolved oxygen, pH, and conductivity; Secchi depth measurements; surface fecal coliform; photic zone (defined as twice the Secchi depth) composite chlorophyll-a samples; and photic zone composite and near-bottom samples for

nutrients (organic nitrogen, ammonia nitrogen, nitrate+nitrite nitrogen, total phosphorus, and dissolved orthophosphorus), total organic carbon, color, and suspended solids. Physical/chemical water quality sampling was not conducted at most run-of-the-river reservoir inflows because most of these locations are tailwater areas of upstream dams; water quality characteristics there are more representative of processes in the upstream reservoir.

Limited--Tributary storage reservoirs were sampled monthly (April through October) for a smaller list of parameters. The approach was the same as for the run-of-the-river reservoirs, except that no fecal coliform, color, or suspended solids samples were collected, and only photic zone composites for nutrients and organic carbon samples were collected and only in April and August. The April and August nutrient samplings were designed to provide information on nutrient concentrations available at the beginning of the growing season, then near the end of the growing season. Forebays were sampled on all these reservoirs, and mid-reservoir locations were sampled on all but the smaller reservoirs.

Physical/chemical water quality data were stored on EPA's water quality data storage and retrieval (STORET) system. Reservoir health evaluation methods used to assess physical/chemical quality are described below (Section 3.1.2).

Acute Toxicity and Physical/Chemical Characteristics of Sediment--Annual sediment samples and near-bottom water samples were collected during the summer of 1993 from 59 locations, i.e., the forebays and transition zones (or mid-reservoir) of the 11 mainstream reservoirs and 19 tributary reservoirs as shown in Table 2.1. In addition, ten of the 59 locations were randomly selected for replicate QA/QC sampling. Sampling efforts were repeated at each of the ten sites. Replicate samples were handled and processed independently. Results from these ten sets of replicates were used to assess field methods consistency, variations in laboratory toxicity and physical/chemical analyses, and spatial homogeneity of the sediment. Eckman dredge samplers were used to collect the top three centimeters of sediment and Kemmerer or Isco water samplers were used to collect the near-bottom water. Each sediment sample was a composite of at least three subsamples independently collected at each sampling location from the original stream channel bed. At each sampling site, the subsamples were composited, thoroughly mixed to uniform color and consistency, and split into two fractions: one fraction for acute toxicity testing, and one fraction for physical/chemical analyses. Samples were placed on ice immediately after collection, compositing,

and splitting, and were shipped or carried to the appropriate laboratory. One split from each sampling location and the sample of near-bottom water were shipped to the Toxicity Testing Laboratory (TTL) for toxicity testing; the other split at each sampling location was shipped or carried to the Environmental Chemistry Laboratory (ECHE) for chemical and physical analyses.

Acute Toxicity Testing--Within 36 hours of collection, all sediment samples were screened for toxicity using Rotox® (rotifer, Brachionus calyciflorus survival) and daphnid (Ceriodaphnia dubia) acute tests. Organisms were exposed to undiluted interstitial (pore) water from the sediment and near bottom water. Interstitial water was obtained by refrigerated centrifugation of sediment. Control water consisted of Moderately Hard Reconstituted Water, MHRW (TVA, 1992b), (hardness of 80-100 mg/L as $CaCO_3$) enriched with 10 percent Tennessee River water from TTL's experimental channels for the daphnid test and MHRW adjusted to pH=7.5 using HCl for the rotifer test. All samples were aerated to bring dissolved oxygen levels to near saturation (8.4 mg/L at 25°C) before testing. Water chemistry (temperature, DO, pH, conductivity, alkalinity, and hardness) was measured for all samples and controls. After centrifugation of the sediment, pore water samples were collected and preserved and sent to the Environmental Chemistry Laboratory for un-ionized ammonia analysis. Four replicates of five individuals each were used in both tests. Rotifer (24-hr) and daphnid (48-hr) acute toxicity was reported if average survival in the four replicates was significantly reduced (95 percent probability) from the control.

Physical/Chemical Characteristics--Splits of the same sediment samples used in the toxicity testing were analyzed for 13 metals, un-ionized ammonia (in pore water), total and volatile solids, particle size, and 26 selected trace organics (organochlorine pesticides and PCBs, Table 2.3).

Additional details for the collection methods, acute toxicity testing protocols and results, and the physical/chemical analytical results are given in TVA technical report (Moses, Simbeck, and Wade, 1994). How this sediment quality information was used in the reservoir health evaluations is described below in Section 3.1.2, Reservoir Sediment Quality Rating Scheme.

Benthic Macroinvertebrate Community Sampling--Benthic macroinvertebrate community samples were collected in the spring (March and April) of 1993 at 69 locations on the 30 Vital Signs

reservoirs, Table 2.1. At each sample location, a line-of-sight transect was established across the width of the reservoir, and Ponar grab samples were collected at ten equally-spaced locations along this transect. When rocky substrates were encountered, a Peterson dredge was used. Only those samples which were collected from the permanently wetted bottom portion of the reservoir (i.e., those Ponar or Peterson samples collected below the elevation of the minimum winter pool level) were used to evaluate the condition of the benthic community. Samples were washed in the field, transferred to a labeled collection jar, and fixed with 10 percent buffered formalin solution. Specimens were sent to the laboratory where they were sorted, counted, and identified to the lowest practical taxon, typically genus or species, and reported as number per square meter. Six metrics (Table 3.1) were chosen to evaluate the benthic macroinvertebrate community as it relates to the overall ecological health of the reservoir. These metrics and the rating scheme are described in Section 3.1.2, Reservoir Benthic Community Rating Scheme.

To assess the reproducibility of benthic macroinvertebrate sampling results, replicate samples were collected at nine of the 69 sampling locations in 1993, with all types of reservoir locations (i.e., forebay, transition zone, and inflow) included. At each of the replicate sampling locations, the sampling protocol involved collection of a first set of ten samples, leaving the sampling location, and then returning as near as possible to the original transect site (on the same day) and repeating the collection of a second (replicate) set of ten samples. The results from the nine sets of replicate samples were then evaluated for reproducibility. Benthic macroinvertebrate data are available in computer-readable form from TVA upon request.

Fish Assemblage Sampling--In the autumn of 1993, electrofishing and/or gill netting data were collected from 69 locations on the 30 Vital Signs reservoirs to evaluate the fish assemblage, Table 2.1. Fifteen electrofishing runs (300 meters in length) were made at each location (forebay, transition or mid-reservoir, and inflow) with all habitats sampled in approximate proportion to their occurrence at the sampling location. Habitat distinctions were based on major changes in substrate (e.g., bluff, rip-rap, mud, etc.) and/or presence of cover such as brush or boat docks. Twelve experimental gill nets were also set overnight at each location covering all habitat types where conditions permitted. At some inflow locations, flow and/or lack of suitable sites limited the number of nets that could be set. All fish collected from either electrofishing or gill netting were enumerated, with length and weight measurements taken on important sport species. Estimated numbers were used when high densities of fish were encountered during electrofishing. Young-of-the-year (YOY) fish were counted separately from adults. All fish measured were inspected for external diseases, parasites, and anomalies. Twelve metrics (Table 3.3) were chosen to evaluate the fish assemblage as

it relates to the overall ecological health of the reservoir and are described in Section 3.1.2, Reservoir Fish Assemblage Rating Scheme.

If the fish assemblage at a particular sampling location appeared to have changed substantially (up or down) from the previous year, the site was resampled (within one to two weeks) to assure that sampling conditions were not causing anomalous results. Resample results were used for two sampling locations (Cherokee Reservoir forebay and Guntersville Reservoir transition zone) during 1993 fish assemblage evaluations.

All data were recorded on a portable field data logger and downloaded to a personal computer before being added to the TVA mainframe fisheries data base. Fish assemblage data are available in computer-readable form from TVA upon request.

Aquatic Macrophytes--Coverage of aquatic macrophytes was determined from large-scale (1 inch=600 feet or 1 inch=1000 feet) color aerial photography flown during maximum submerged macrophyte coverage (late summer or early fall of 1993). Boat surveys to determine species composition of the dominant macrophyte communities were conducted at selected sites at the approximate time of the aerial overflight. Aquatic macrophyte colonies were delineated on mylar overlays attached to photographic prints, labeled according to species, and areal coverage determined using an electronic planimeter. Reservoirs flown for aerial photography in 1993 included Kentucky, Wilson, Wheeler, Guntersville, Nickajack, Chickamauga, Tellico, South Holston, and lakes in the Beech River project. For reservoirs where aerial photography was unavailable, standard field surveys and historical information were used to estimate community composition and coverage. Submersed aquatic plant populations generally are rare in tributary reservoirs because of the wide fluctuations of water surface elevations associated with their operation for floodwater storage. Known populations have been extremely small, short-lived, and of little significance.

A detailed summary of TVA's Aquatic Plant Management Program for 1993 and planned work for 1994 is available in a technical report (Burns, Bates, and Webb, 1994) that is updated and published annually.

2.1.3 Stream Vital Signs Monitoring

In 1993, Vital Signs stream sampling locations were located on 12 major tributaries to the Tennessee River (Figure 2.3 and Table 2.2). At each stream sampling location, four types of information were collected and examined to assess the ecological health of the stream and to provide information for evaluating the conditions found in the downstream receiving reservoir. These four

components of stream monitoring (which complement the same four components for reservoir monitoring) were:

(1) physical/chemical characteristics of water;
(2) acute toxicity and physical/chemical characteristics of sediment;
(3) benthic macroinvertebrate community sampling; and
(4) fish community sampling.

Physical/Chemical Characteristics of Water--In 1993, physical/chemical water quality characteristics were measured bimonthly (odd numbered months) at 12 stream locations (Table 2.2). QA/QC methods for the stream water quality sampling activities included: (1) collection and analysis of duplicate sets of water samples at five stream locations to assess sample collection, laboratory analysis, and natural sample variability; (2) preparation and analysis of sample container blanks (for metals and nutrient analyses) each collection day to assess the degree of contamination associated with the sample bottles and/or the sample handling processes; and, (3) preparation and analysis of sample filtration blanks (dissolved nutrients and dissolved metals) with each set of filtered samples to assess the degree of contamination associated with the field sample filtration and handling. Physical/chemical water quality characteristics measured in 1993 included:

On-Site Measurements--flow, temperature, dissolved oxygen, pH, conductivity, alkalinity, and fecal coliform bacteria; and

Laboratory Measurements--physical analyses (hardness, color, turbidity, total suspended solids, total dissolved solids, and chemical oxygen demand), nutrient analyses (organic nitrogen, ammonia nitrogen, nitrite+nitrate nitrogen, total phosphorus, dissolved orthophosphorus, and total organic carbon), major cations/anions analyses (calcium, magnesium, sodium, potassium, chloride, and sulfate), and metal analyses (total and dissolved aluminum, dissolved cadmium, total and dissolved copper, total and dissolved iron, dissolved lead, total and dissolved manganese, dissolved nickel, dissolved silver, and total and dissolved zinc).

The physical/chemical water quality data are stored on EPA's water quality data storage and retrieval (STORET) system. Methods used to assess physical/chemical quality of each stream sampling location in regard to the ecological health evaluations are described in Section 3.1.3.

Acute Toxicity and Physical/Chemical Characteristics of Sediment--During the summer of 1993, an annual sediment and bottom water sample was collected at each of the 12 Vital Signs stream sampling locations, Table 2.2. Each sediment sample was a composite of at least five surficial sediment subsamples. At stream sampling locations with shallow and wadable water, subsamples were collected using clean stainless steel spoons. At sampling locations with deeper water, divers collected subsamples using one-liter glass jars. The subsamples were composited and thoroughly mixed to ensure uniform color and texture. At each sampling location the composited sample was then split for acute toxicity and for physical/chemical analyses. The split samples were placed on ice immediately and shipped to the Toxicity Testing Laboratory (TTL) at Browns Ferry Nuclear Plant for toxicity testing and to the Environmental Chemistry Laboratory (ECHE) for chemical and physical analyses.

Acute toxicity testing and physical/chemical analyses of the split samples were performed in exactly the same manner as described in Section 2.1.2, Reservoir Acute Toxicity and Physical/Chemical Characteristics of Sediment. Additional details for the collection methods, acute toxicity testing protocols and results, and the physical/chemical analytical results are given in a TVA technical report (Moses, Simbeck, and Wade, 1994b). How this sediment quality information was used in the stream health evaluations is described in Section 3.1.3, Stream Sediment Quality Rating Scheme.

Benthic Macroinvertebrate Community Sampling--Benthic macroinvertebrates were sampled at the 12 stream sites between mid-May and early July (streamflow conditions permitting) in order to maximize collection before hatching of winged adults. The benthic sampling sites were located as close as possible to the corresponding water quality sampling location (Table 2.2), with exact site selection depending upon the presence of suitable habitat types. Stream habitat in Tennessee Valley rivers and streams can generally be classified as riffle, run, or pool.

Both quantitative (Hess and Surber) and qualitative (D-net and handpicking) samples were collected to define relative abundance and species occurrence at each site. Quantitative sampling was completed in substrate types ranging from rubble to gravel in both riffle and pool habitats. Qualitative sampling was limited to a maximum of two man-hours per site, or was discontinued when redundancy in organisms being collected was observed. In total, seven samples were collected per station. These include: (a) three Hess samples in pools at the head of a riffle in substrate that contained a light covering of silt; (b) three Surber samples collected in shallow riffle habitat and along the borders of emergent vegetation (limited to areas where the water did not exceed the depth of the sampling frame); and (c) a single qualitative sample of bottom fauna organisms using D-nets and

handpicking from all habitats present. Habitats targeted for qualitative sampling were leaf packs, woody debris, emergent aquatic vegetation, and boulders.

All specimens were preserved in 10 percent formalin solution and returned to the laboratory for sorting, enumeration, and identification. Specimens were identified to the lowest practical taxon, typically genus or species. Twelve metrics, based on a classification system developed by Kerans et.al (1992), were used to evaluate the stream benthic ecological health (Table 3.4). Methods used to assess the ecological health of the benthic community at each stream sampling location are described below (Section 3.1.3, Stream Benthic Community Rating Scheme). Benthic macroinvertebrate data are available in computer-compatible form from TVA, upon request.

Fish Community Sampling--Fish community sampling was conducted in summer (May-July) at 11 of the 12 stream sampling locations in 1993, Table 2.2. (The Elk River site was not sampled.) A boat-mounted electrofishing unit was used for deep pool habitats, and a backpack electrofishing unit, dip nets, and seine were used for wadable habitats. At each stream site, at least four general habitats (run, riffle, shallow pool, and deep pool) were sampled until three consecutive units of sampling effort (seine haul or timed shocking run) produced no additional species per habitat. Additional habitats were sampled as determined by the field crew leader. Fish specimens that were difficult to identify were preserved and their identity later confirmed. All fish collected were enumerated. Numbers were estimated if high densities were encountered during electrofishing. Young-of-the-year (YOY) fish were counted separately from adults. All fish measured were inspected for external diseases, parasites, and anomalies.

A modified version of Karr's (1981) index of biotic integrity (IBI) was used to assess the condition of the resident fish community, Table 3.5. This evaluation scheme is described in Section 3.1.3, Stream Fish Community Rating Scheme. Fish community data are available in computer-readable form from TVA upon request.

2.2 Use Suitability Monitoring

Use Suitability monitoring provides screening level information on the suitability of selected reservoir areas and stream reaches in the Tennessee Valley for water contact recreation (swimmable) and suitability of fish for human consumption (fishable). The use suitability evaluation is based on results of: (1) bacteriological sampling at recreation areas, and (2) collection and analysis of fish tissue.

2.2.1 Bacteriological Sampling

In 1989, TVA began periodically sampling recreation sites in the Tennessee Valley for fecal coliform bacteria to determine each site's suitability for water contact recreation. In addition to swimming beaches, many other recreation sites were also included in the program, such as canoe launch areas, picnic areas, boat ramps, and marinas. This bacteriological sampling program now includes approximately 260 sites and is designed to sample all locations on a frequency of about once every other year. Prior to 1993, the sampling frequency was approximately once every five years.

Samples are collected in a manner to conform with state criteria and federal guidelines; at each site at least ten fecal coliform samples are collected within a 30-day sampling period during the summer recreation season. QA/QC procedures include running at least one duplicate sample at each site and preparation and analyses of sample container blanks each collection day to assess degree of contamination associated with sample containers, handling process, and analytical equipment. The suitability of a recreation site for water contact recreation is based on EPA guidelines for fecal coliform bacteria (EPA, 1991).

In 1993, fecal coliform samples were collected in spring and summer at 59 designated swimming beaches and 14 canoe access sites to evaluate use suitability for whole body water contact recreation. In addition, 53 informal recreation sites where incidental water contact may occur (e.g., boat launch ramps, picnic areas, parks, marinas, etc.), were sampled.

Monthly (April through September) bacteriological samples were collected at 20 forebay and transition zone locations and four major tributary embayments on the run-of-the-river reservoirs as part of the basic Vital Signs Reservoir Monitoring (Table 2.1).

All TVA bacteriological sampling data are stored on EPA's water quality data storage and retrieval (STORET) system. A technical report (Fehring, 1994) provides specific details and evaluations of TVA's 1993 bacteriological monitoring results, and is available upon request.

2.2.2 Fish Tissue Sampling

In cooperation with Valley states, since 1987 TVA has collected and analyzed fish from over 80 Tennessee Valley reservoir and stream locations as part of both "screening" and "intensive" evaluations. In screening studies, composited fillets of indicator fish species (primarily channel catfish) are analyzed for a wide range of potential contaminants to identify possible problem areas where intensive investigation may be needed. Intensive studies are conducted on reservoirs or streams where contamination problems are known or suspected, based on the screening study information. For intensive studies, individual fillets from several important fish species are analyzed for specific contaminants to better document the number of species contaminated and level of

contamination in each species. Intensive studies also include a higher density of sampling locations in the reservoir or stream of interest to better define the spatial extent of the contamination. The intent is to provide information that state public health officials can use to determine whether fish consumption advisories should be issued to protect human health.

Screening Studies--Channel catfish were collected from 16 reservoirs in autumn of 1992. Fillets were removed, composited by location, and analyzed for metals, PCBs, and pesticides on EPA's Priority Pollutant List (Table 2.3). During the preparation process, observations of external and internal conditions of each fish were recorded along with length, weight, sex, fillet weight, and liver weight.

Intensive Studies--The following six TVA reservoirs were examined intensively in 1992: Wheeler, Nickajack, Watts Bar, Fort Loudoun, Melton Hill, and Ocoee No. 1 (Parksville Reservoir). In each case, the contaminant of concern was PCBs, except for Wheeler, where DDT is the problem. Chlordane was also of concern in some reservoirs. Fish consumption advisories that recommend either limiting the quantity of fish eaten or avoiding any consumption are in effect for all these reservoirs except Ocoee No. 1.

All fish tissue data are stored on EPA's water quality data storage and retrieval (STORET) system. A technical report (Williams and Dycus, 1993) provides specific details and evaluations of TVA's 1991 and 1992 fish tissue studies and is available on request.

Figure 2.1

Schematic of Key Reservoir Sampling Areas

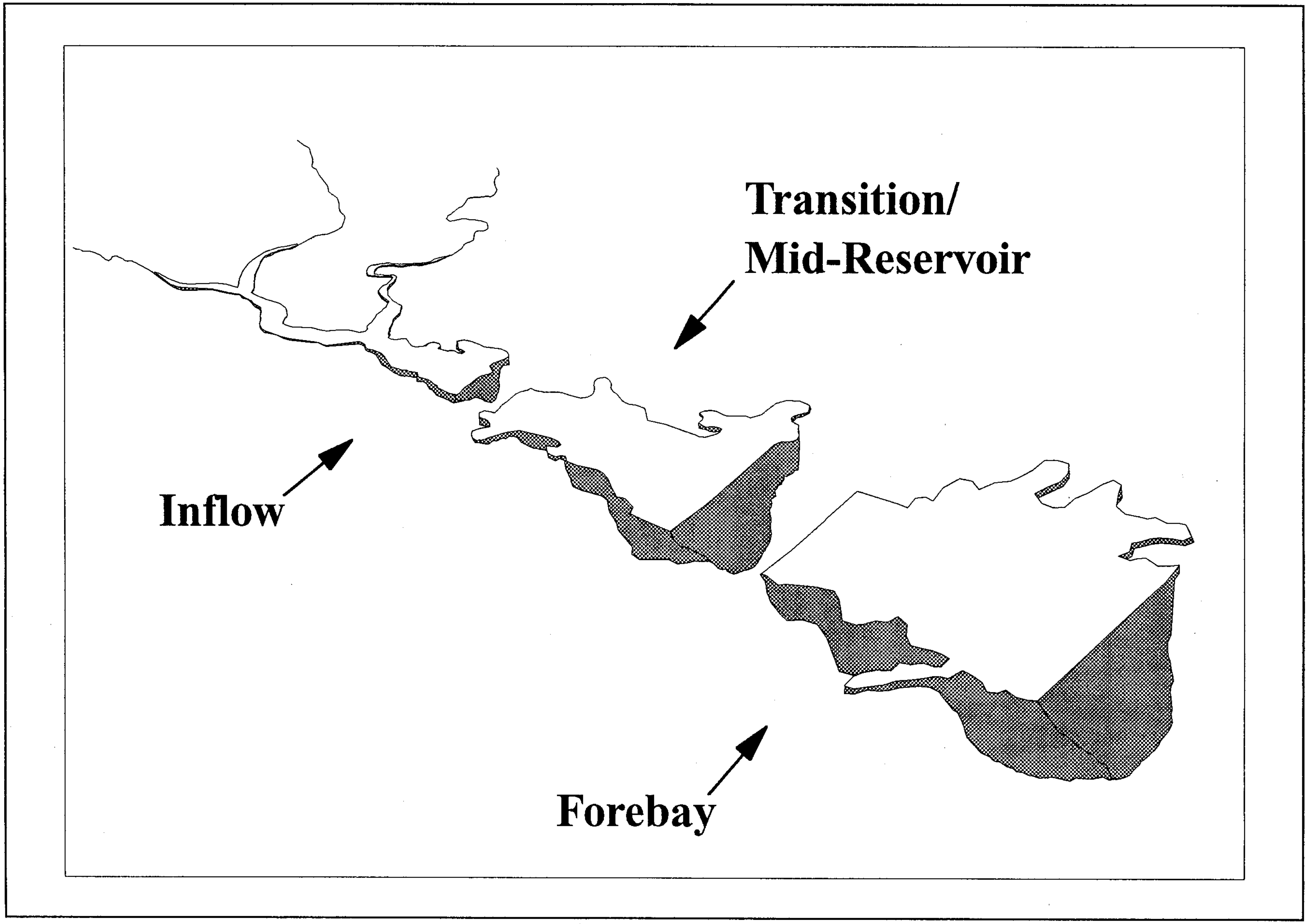
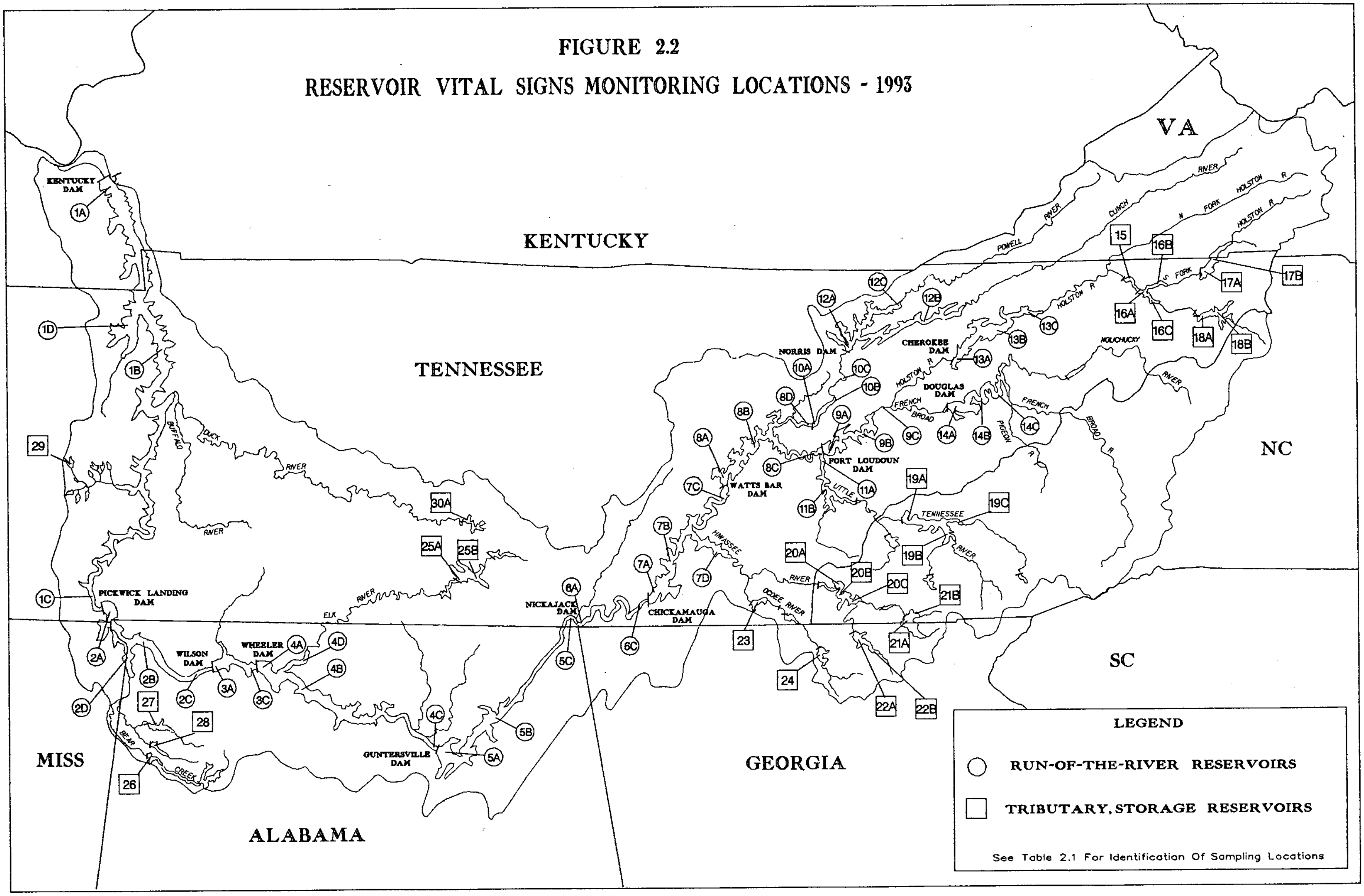


FIGURE 2.2

RESERVOIR VITAL SIGNS MONITORING LOCATIONS - 1993



PRODUCED BY TVA MAPPING SERVICES

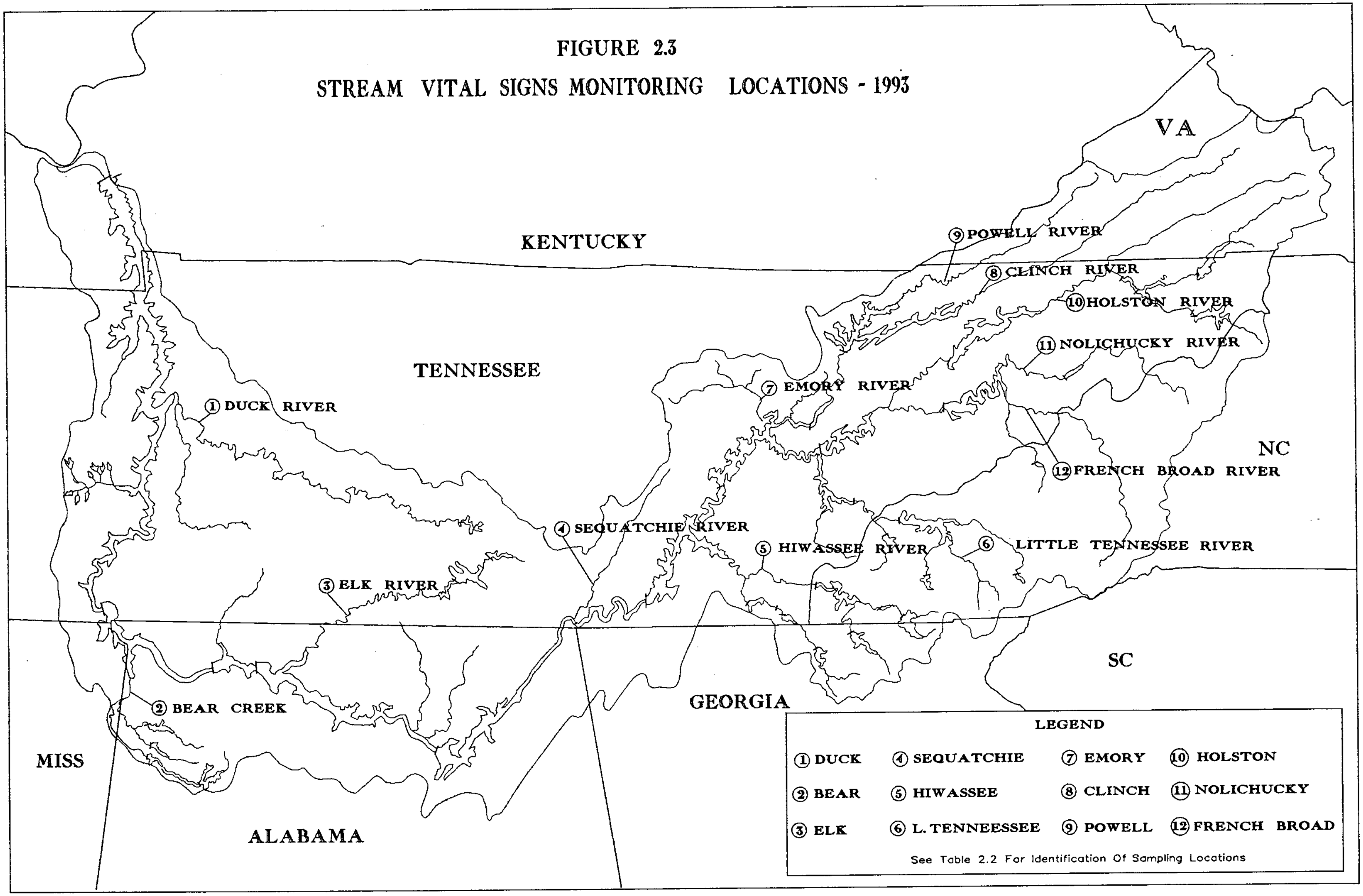


FIGURE 2.3
STREAM VITAL SIGNS MONITORING LOCATIONS - 1993

PRODUCED BY TVA MAPPING SERVICES

Table 2.1
1993 Vital Signs Monitoring

Run-of-the-River Reservoirs
--Basic Monitoring Strategy--

Reservoir	Sampling Locations[a]	STORET ID #	Description[b]	Reservoir Vital Signs Monitoring Tools: Water Quality[c]	Sediment Quality[d]: Toxicity	Sediment Quality[d]: Phy/Chem	Benthic Invertebrates[e]	Fish Community[f] Diversity/RFAI
Kentucky	TRM 23.0	202832	1A-FB	M	A	A	A	A
	TRM 85.0	477403	1B-TZ	M	A	A	A	A
	TRM 200-206	--	1C-I	-	-	-	A	A
	Big Sandy 7.4	477210	1D-E	M	A	A	A	A
Pickwick	TRM 207.3	476799	2A-FB	M	A	A	A	A
	TRM 230.0	016923	2B-TZ	M	A	A	A	A
	TRM 253-259	--	2C-I	-	-	-	A	A
	Bear Cr 8.4	017849	2D-E	M	A	A	A	A
Wilson	TRM 260.8	016912	3A-FB	M	A	A	A	A
	TRM 273-274	--	3C-I	-	-	-	A	A
Wheeler	TRM 277.0	016900	4A-FB	M	A	A	A	A
	TRM 295.9	017009	4B-TZ	M	A	A	A	A
	TRM 347-348	--	4C-I	-	-	-	A	A
	Elk River 6.0	017850	4D-E	M	A	A	A	A
Guntersville	TRM 350.0	017261	5A-FB	M	A	A	A	A
	TRM 375.2	017522	5B-TZ	M	A	A	A	A
	TRM 420-424	--	5C-I	-	-	-	A	A
Nickajack	TRM 425.5	476344	6A-FB	M	A	A	A	A
	TRM 469-470	--	6C-I	-	-	-	A	A
Chickamuaga	TRM 472.3	475358	7A-FB	M	A	A	A	A
	TRM 490.5	475265	7B-TZ	M	A	A	A	A
	TRM 518-529	--	7C-I	-	-	-	A	A
	Hiwassee 8.5	477512	7D-E	M	A	A	A	A

Table 2.1 (continued)
1993 Vital Signs Monitoring

Run-of-the-River Reservoirs
--Basic Monitoring Strategy (continued)--

Reservoir	Sampling Locations[a]	STORET ID #	Description[b]	Reservoir Vital Signs Monitoring Tools: Water Quality[c]	Sediment Quality[d]: Toxicity	Sediment Quality[d]: Phy/Chem	Benthic Invertebrates[e]	Fish Community[f] Diversity/RFAI
Watts Bar	TRM 531.0	475317	8A-FB	M	A	A	A	A
	TRM 560.8	476041	8B-TZ	M	A	A	A	A
	TRM 600-601	--	8C-I	-	-	-	A	A
	CRM 19-22	--	8D-I	-	-	-	A	A
Fort Loudoun	TRM 605.5	477404	9A-FB	M	A	A	A	A
	TRM 624.6	475603	9B-TZ	M	A	A	A	A
	TRM 652	--	9C-I	-	-	-	A	A
Melton Hill	CRM 24.0	477064	10A-FB	M	A	A	A	A
	CRM 45.0	476194	10B-TZ	M	A	A	A	A
	CRM 59-66	--	10C-I	-	-	-	A	A
Tellico	LTRM 1.0	476260	11A-FB	M	A	A	A	A
	LTRM 15.0	476456	11B-TZ	M	A	A	A	A
	LTRM 21.0	476295	-	-	A	A	-	-
			Totals	24	25	25	35	35

Table 2.1 (continued)
1993 Vital Signs Monitoring

Tributary Storage Reservoirs
--Limited Monitoring Strategy--

Reservoir	Sampling Locations[a]	STORET ID #	Description[b]	Reservoir Vital Signs Monitoring Tools: Water Quality[c]	Sediment Quality[d]: Toxicity	Sediment Quality[d]: Phy/Chem	Benthic Invertebrates[e]	Fish Community[f] Diversity/RFAI
Norris	CRM 80.0	476009	12A-FB	M	A	A	A	A
	CRM 125.0	477186	12B-MR	M	A	A	A	A
	PRM 30.0	477187	12C-MR	M	A	A	A	A
Cherokee	HRM 53.0	475025	13A-FB	M	A	A	A	A
	HRM 76.0	475028	13B-MR	M	A	A	-	A
	HRM 91	--	13C-I	-	-	-	A	A
Douglas	FBRM 33.0	475081	14A-FB	M	A	A	A	A
	FBRM 51.0	477510	14B-MR	M	A	A	-	A
	FBRM 61	--	14C-I	-	-	-	A	-
Ft.Pat Henry	SFHR 8.7	477509	15-FB	M	A	A	A	A
Boone	SFHR 19.0	475858	16A-FB	M	A	A	A	A
	SFHR 27.0	476221	16B-MR	M	A	A	A	A
	WRM 6.5	477511	16C-MR	M	A	A	A	A
South Holston	SFHR 51.0	475859	17A-FB	M	A	A	A	A
	SFHR 62.5	475573	17B-MR/I	M	A	A	A	A
Watauga	WRM 37.4	475576	18A-FB	M	A	A	A	A
	WRM 45.5	477513	18B-MR	M	A	A	A	A
Fontana	LTRM 62.0	370004	19A-FB	M	A	A	A	A
	LTRM 81.5	370177	19B-MR	M	A	A	A	A
	TkRM 3.0	370162	19C-MR	M	A	A	A	A

Table 2.1 (continued)
1993 Vital Signs Monitoring

Tributary Storage Reservoirs
--Limited Monitoring Strategy (continued)--

				Reservoir Vital Signs Monitoring Tools				
					Sediment Quality[d]			Fish Community[f]
Reservoir	Sampling Locations[a]	STORET ID #	Description[b]	Water Quality[c]	Toxicity	Phy/Chem	Benthic Invertebrates[e]	Diversity/RFAI
Hiwassee	HiRM 77.0	370001	20A-FB	M	A	A	A	A
	HiRM 85.0	370154	20B-MR	M	A	A	A	A
	HiRM 90	--	20C-I	-	-	-	A	A
Chatuge	HiRM 122.0	370003	21A-FB	M	A	A	A	A
	Shooting Cr 1.5	370178	21B-FB	M	A	A	A	A
Nottely	NRM 23.5	120883	22A-FB	M	A	A	A	A
	NRM 31.0	120806	22B-MR	M	A	A	A	A
Ocoee No.1	ORM 12.5	475684	23-FB	M	A	A	A	A
	ORM 16.5	--	-	-	A	-	-	-
Blue Ridge	ToRM 54.1	130032	24-FB	M	A	A	A	A
Tims Ford	ERM 135.0	477072	25A-FB	M	A	A	A	A
	ERM 150.0	475768	25B-MR	M	A	A	A	A
Bear Creek	BCM 75.0	017041	26-FB	M	A	A	A	A
Cedar Creek	CCM 25.2	017233	27-FB	M	A	A	A	A
L.Bear Creek	LBCM 12.5	017474	28-FB	M	A	A	A	A
Beech	BRM 36.0	475876	29-FB	M	A	A	A	-
Normandy	DRM 249.5	477453	30-FB	M	A	A	A	A
			Totals	33	34	33	34	34

Footnotes

a. BCM - Bear Creek Mile	BRM - Beech River Mile	CCM Cedar Creek Mile
CRM - Clinch River Mile	DRM - Duck River Mile	ERM - Elk River Mile
FBRM - French Broad River	HiRM - Hiwassee River Mile	HRM - Holston River Mile
LBCM - Little Bear Creek Mile	LTRM - Little Tennessee River Mile	NRM - Nottely River Mile
ORM - Ocoee River Mile	PRM - Powell River Mile	SFHR - So Fork Holston River Mile
TRM - Tennessee River Mile	ToRM - Toccoa River Mile	TkRM - Tuckaseegee River Mile
WRM - Watauga River Mile	PRM - Powell River Mile	

b. Numbers are keyed to Figure 2.2. FB - forebay; TZ - transition zone; MR - mid-reservoir; I - Inflow; and E - embayment. MR/I - Sampling location was referred to as an inflow location in the fish community evaluation (sampling done in autumn at lower reservoir water level elevations); and, as a mid-reservoir location in the evaluation of the water quality data (sampling done in summer at higher water level elevations).

c. --Basic Monitoring Strategy--

M - monthly water quality surveys (April through September). The surveys include: in situ water column measurements of temperature, dissolved oxygen, pH, and conductivity; Secchi depth measurements; surface fecal coliform and photic zone chlorophyll-a samples; and surface and near-bottom water samples for nutrients (organic nitrogen, ammonia nitrogen, nitrate+nitrite nitrogen, phosphorus, and dissolved ortho phosphorus), total organic carbon, color, and suspended solids.

--Limited Monitoring Strategy--

M - monthly water quality surveys (April through October). The surveys include: in situ water column measurements of temperature, dissolved oxygen, pH, and conductivity; Secchi depth measurements; and, photic zone chlorophyll-a samples. Twice a year (April and August) surface water samples are collected for nutrients (organic nitrogen, ammonia nitrogen, nitrate+nitrite nitrogen, phosphorus, and dissolved ortho phosphorus), and total organic carbon. Once a year (August) bottom water samples are collected for ammonia nitrogen. No samples are collected for fecal coliform, color, and suspended solids.

d. A - annual summer samples of sediment pore water and bottom water are examined for acute toxicity (rotifers and Ceriodaphnia). At the same time, the sediment is collected and analyzed for metals, total and volatile solids, particle size, and twenty-six trace organics (organochlorine pesticides and PCBs).

e. A - annual benthic invertebrate samples are collected, enumerated and identified to lowest practical taxon (genus or species) in the spring of year.

f. A - annual electroshocking and gill-netting techniques are used to evaluate the near-shore fish community, during autumn.

Table 2.2
1993 Vital Signs Monitoring

STREAM VITAL SIGNS MONITORING LOCATIONS, 1993

Tributary Stream	River Mile	STORET ID #	Description
Duck River	26.0	475793	USGS stream gage above Hurricane Mills, TN
Bear Creek	27.3	017019	TVA stream gage near Bishop, AL
Elk River	36.5	477330	USGS stream gage at Veto Road bridge near Prospect, TN
Sequatchie River	6.3	477177	Valley Road bridge near Jasper, TN
Hiwassee River	36.9	477369	East Patty Road bridge near Benton, TN
Little Tennessee River	94.7	370158	USGS stream gage near Needmore, NC
Emory River	18.3	475838	USGS stream gage at Oakdale, TN
Clinch River	159.8	475846	USGS stream gage near Tazewell, TN
Powell River	65.4	475098	TVA stream gage near Arthur, TN
Holston River	118.7	475945	TVA stream gage near Surgoinsville, TN
Nolichucky River	10.3	477150	TVA stream gage at David Thomas bridge near Lowland, TN
French Broad River	77.5	475086	US Hwy 411 bridge at Oldtown, TN

Table 2.3
1993 Vital Signs Monitoring

PHYSICAL/CHEMICAL MEASUREMENTS - SEDIMENT		
Description, units	**Detection Limits (dry weight)**	**Sediment Quality Guidelines[a]**
Metals and Ammonia		
Aluminum, mg/g	1 mg/g	--
Arsenic, mg/kg	1 mg/kg	8 mg/kg[b]
Cadmium, mg/kg	0.5 mg/kg	6 mg/kg[b]
Calcium, mg/g	0.5 mg/g	--
Chromium, mg/kg	10 mg/kg	75 mg/kg[b]
Copper, mg/kg	2 mg/kg	50 mg/kg[b]
Iron, mg/g	1 mg/g	--
Lead, mg/kg	5 mg/kg	60 mg/kg[b]
Magnesium, mg/g	0.5 mg/g	--
Manganese, mg/g	0.1 mg/g	--
Mercury, mg/kg	0.1 mg/kg	1 mg/kg[b]
Nickel, mg/kg	5 mg/kg	50 mg/kg[b]
Zinc, mg/kg	10 mg/kg	300 mg/kg
Un-ionized Ammonia (in pore water), μg NH_3/l	10 $\mu g/l$	200 $\mu g/l$
Solids		
Total solids, %	0.1%	--
Total volatile solids, %	0.1%	--
Particle size, <0.062 mm diameter, %	0.1%	--
Particle size, <0.125 mm diameter, %	0.1%	--
Particle size, <0.50 mm diameter, %	0.1%	--
Particle size, <2.0 mm diameter, %	0.1%	--
Organochlorine Pesticides and PCB's		
Aldrin, $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
α-Benzene Hexachloride (BHC), $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
β-Benzene Hexachloride (BHC), $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
γ-Benzene Hexachloride (Lindane), $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
δ-Benzene Hexachloride (BHC), $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
Chlordane, $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
Dieldrin, $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
ρ,ρ DDT, $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
ρ,ρ DDD, $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$
ρ,ρ DDE, $\mu g/kg$	10 $\mu g/kg$	10 $\mu g/kg$

Table 2.3 (continued)
1993 Vital Signs Monitoring

PHYSICAL/CHEMICAL MEASUREMENTS - SEDIMENT		
Description, units	**Detection Limits (dry weight)**	**Sediment Quality Guidelines[a]**
Organochlorine Pesticides and PCB's (continued)		
α-Endosulfan, μg/kg	10 μg/kg	10 μg/kg
ß-Endosulfan, μg/kg	10 μg/kg	10 μg/kg
Endosulfan Sulfate, μg/kg	10 μg/kg	10 μg/kg
Endrin, μg/kg	10 μg/kg	10 μg/kg
Endrin Aldehyde, μg/kg	10 μg/kg	10 μg/kg
Heptachlor, μg/kg	10 μg/kg	10 μg/kg
Heptachlor Epoxide, μg/kg	10 μg/kg	10 μg/kg
Methoxychlor, μg/kg	10 μg/kg	10 μg/kg
PCB-1221, μg/kg	100 μg/kg	100 μg/kg
PCB-1232, μg/kg	100 μg/kg	100 μg/kg
PCB-1242, μg/kg	100 μg/kg	100 μg/kg
PCB-1248, μg/kg	100 μg/kg	100 μg/kg
PCB-1254, μg/kg	100 μg/kg	100 μg/kg
PCB-1260, μg/kg	100 μg/kg	100 μg/kg
PCB-1016, μg/kg	100 μg/kg	100 μg/kg
PCBs, Total, μg/kg	100 μg/kg	100 μg/kg
Toxaphene, μg/kg	500 μg/kg	500 μg/kg

[a] Unless otherwise noted, guidelines are suggested TVA Sediment Quality Guidelines.
[b] EPA Region V Guidelines for polluted freshwater sediment (EPA, 1977).

3.0 ECOLOGICAL HEALTH AND USE SUITABILITY DETERMINATION METHODS

3.1 Vital Signs Monitoring

3.1.1 Introduction

The objective of Vital Signs monitoring is to determine the health or integrity of the aquatic ecosystem within each reservoir or at each stream sampling location. There are no official or universally accepted guidelines or criteria upon which to base such an evaluation. Consequently, an evaluation methodology was developed to assess the overall ecological health or condition of each of the 30 TVA Vital Signs reservoirs and 12 Vital Signs stream monitoring locations. The ecological health evaluation system combines both biological and physical/chemical information to examine reservoir and stream health. Five aquatic ecosystem indicators are used for reservoirs: dissolved oxygen, chlorophyll-a, sediment quality, benthic macroinvertebrates, and fish community; and four aquatic ecosystem indicators are used for streams: nutrient concentration, sediment quality, benthic macroinvertebrates, and fish community.

A critical step in developing an ecological health evaluation is deciding for each indicator what represents good conditions and what indicates poor conditions. This is more easily done for evaluation of streams because there usually are essentially unaltered reference sites that can be examined to define "good" conditions for each indicator, for example the various indices of biotic integrity for fish and benthic stream communities. Because reservoirs are man-made alterations of natural streams, there are no "reference reservoirs." An alternative approach to "reference conditions" is required.

3.1.2 Reservoir Ecological Health

Scoring criteria for the reservoir dissolved oxygen and chlorophyll-a indicators were based on what could be considered a conceptual model. This simply means that the criteria were developed subjectively, based on several years experience in evaluating biological systems in reservoirs. This experience has shown that below a threshold level of chlorophyll, primary production is not sufficient to support an active, biologically healthy food chain. In addition, chlorophyll concentrations above a higher threshold levels result in undesirable eutrophic conditions. Minimum and maximum chlorophyll concentrations were selected based on this experience and professional judgment. The conceptual model for dissolved oxygen criteria for a reservoir is quite complicated due to the combined effects of flow regulation and the potential for oxygen depletion in the hypolimnion. The scoring criteria described below attempt a multidimensional approach that includes considering dissolved oxygen levels both in the water column and near the bottom of the reservoir.

For the benthic macroinvertebrate and fish community indicators, scoring criteria are developed based on statistical examination of two or more years of data from TVA reservoirs. For these indicators, all previously collected TVA reservoir data for a selected community characteristic (e.g., number of taxa, total abundance, etc.) were ranked and divided into good, fair, and poor groupings. (Specific procedures used to determine scoring criteria for each grouping are given in Section 3.1.2, Benthic Community Rating Scheme and Fish Assemblage Rating Scheme.) Data for the current year of monitoring (e.g., 1993) are then compared to these criteria and scored accordingly. This approach is valid if the data base is sufficiently large and if it can be safely assumed that the data base covers the full spectrum of good to poor conditions.

The sediment quality indicator scoring criteria uses a combination of two characteristics: sediment toxicity to test organisms; and sediment chemical analyses for ammonia, heavy metals, pesticides, and PCBs (using published guidelines for many of these analytes).

Dissolved Oxygen (DO) Rating Scheme--Oxygen is vital for life. In situations where funding is limited and only one indicator of reservoir health could be measured, DO would likely be the indicator of choice. Hutchinson (1975) states that probably more can be learned about the nature of a lake from a series of oxygen measurements than from any other kind of chemical data. The presence, absence, and levels of DO in a lake or reservoir both control and are controlled by many physical, chemical, and biological processes (e.g., photosynthesis, respiration, oxidation-reduction reactions, bacterial decomposition, temperature). DO measurements coupled with observations of water clarity (Secchi depth), temperature, nutrients, and some basic hydrologic and morphometric information provide meaningful insight into the ecological health of a reservoir.

Ideally, a reservoir has near-saturation concentrations of DO throughout the water column available to fish, insects, and zooplankton for respiration. This is usually the case during winter and spring, when most reservoirs are well mixed. However, in summer (characterized by more available sunlight, warmer water temperatures, and lower flows) both thermal stratification and increased biological activity may combine to produce a greater biochemical demand for oxygen than is available, particularly in the deeper portions of the reservoir. As a result, summer levels of DO often are low in the metalimnion and hypolimnion. Hypolimnetic and metalimnetic oxygen depletion are common, but undesirable, occurrences in many reservoirs, especially storage impoundments. Not only do lower concentrations of DO in the water column affect the assimilative capacity of a reservoir, but if they are low enough and/or sustained long enough, they adversely affect the health and diversity of the fish and benthic communities. Sustained near-bottom anoxia also promotes the biochemical release of ammonia, sulfide, and dissolved metals into the interstitial pore and

near-bottom waters. If this phenomenon persists long enough, these chemicals can cause chronic or acute toxicity to bottom-dwelling animals.

A dissolved oxygen concentration of 2 mg/L was selected as a level below which undesirable ecological conditions exist. Values below this level primarily cause adverse impacts on benthic macroinvertebrate organisms and loss of quality habitat for fish. Historic information for reservoirs in the Tennessee Valley has shown that the burrowing mayfly (Hexagenia sp.) disappears from the benthic community at DO concentrations of 2 mg/L and below (Masters and McDonough, 1993). Most fish species avoid areas with DO concentrations below 2.0 mg/L (loss of habitat); fish growth and reproduction is reduced at these levels, and many highly desirable species such as sauger and walleye simply cannot survive at such low levels of DO.

The ecological health evaluation considers oxygen concentrations in both the water column (WC_{DO}) and near the bottom of the reservoir (B_{DO}). The DO rating at each sampling location (ranging from 1 "poor" to 5 "good") is based on monthly summer water column and bottom water DO concentrations. (Summer is defined as a six-month period when maximum thermal stratification and maximum hypolimnetic anoxia is expected to occur: April through September for the run-of-the-river reservoirs and May through October for the tributary reservoirs.) The final DO rating is the average of the water column DO rating and the bottom DO rating:

$$\text{DO Rating} = 0.5\ (WC_{DO}\ \text{rating} + B_{DO}\ \text{rating}),\ \text{where:}$$

***WC_{DO}* (Water Column DO) Rating**--a six-month average of the percent of the reservoir cross-sectional area (at the location where the sampling was conducted--see Figure 3.1) that has a dissolved oxygen (DO) concentration less than 2.0 mg/L.

Average Cross-Sectional Area (DO less than 2 mg/L)	WC_{DO} Rating for Sampling Location
<5%	5 (good);
≥5% but ≤10%	3 (fair);
>10%	1 (poor).

Because most state DO water quality criteria for fish and aquatic life specify a minimum of 5.0 mg/L DO at the 1.5 meter (5 foot) depth, the WC_{DO} rating was lowered if the measured DO at the 1.5 meter depth at a sampling location was below 5.0 mg/L at any time. These adjustments were as follows:

Minimum DO at 1.5 meter depth	Sampling Location WC_{DO} Rating Change
<5.0 mg/L	Decreased one unit (e.g., 5 to 4);
<4.0 mg/L	Decreased two units (e.g., 5 to 3);
<3.0 mg/L	Decreased three units (e.g., 5 to 2);
etc.	etc.

B_{DO} (Bottom DO) Rating--a six month average of the percent of the reservoir cross-sectional bottom length (at the location where sampling was conducted, Figure 3.1) that has a DO concentration less than 2.0 mg/L, as follows:

Average Cross-Sectional Length (DO less than 2 mg/L)	B_{DO} Rating for Sampling Location
0%	5 (good);
0 to 10%	4
10 to 20%	3 (fair);
20 to 30%	2
>30%	1 (poor).

The average percent cross-sectional bottom length was computed based on the total cross-sectional bottom length at average minimum winter pool elevation. In addition, if anoxic bottom conditions (i.e., 0 mg/L) were observed at a location, the B_{DO} rating was lowered one unit, with a minimum rating of 1.

Chlorophyll Rating Scheme--Algae are the base of the aquatic food chain. Consequently, measuring algal biomass or primary productivity is important in evaluating ecological health. Without algae converting sunlight energy, carbon dioxide, and nutrients into oxygen and new plant material, a lake or reservoir could not support other aquatic life. Chlorophyll-a is a simple, long-standing, and well-accepted measurement for estimating algal biomass, algal productivity, and trophic condition of a lake or reservoir (Carlson, 1977). Too little primary productivity in reservoirs (mean summer chlorophyll-a concentrations less than 3 μg/L) indicates an inability to sustain a well-fed, growing, balanced, and healthy aquatic community. This eventually results in low standing stocks of fish. Too much primary productivity (mean summer concentrations greater than 15 μg/L) often is evidenced by occasional dense algal blooms, poor water clarity, and the predominance of noxious blue-green algae, and indicates poor ecological health. The large amounts of algal plant material produced under these conditions also deplete oxygen concentrations as the algae die and decompose. This can cause or aggravate problems of low DO in bottom waters.

Chlorophyll ratings at each sampling location are based on the average summer concentration of monthly, photic zone chlorophyll-a samples (corrected) collected from April through September (or October), as shown below. If triplicate samples are collected at a sampling location, the median value of the triplicate is used in calculating the summer average and the maximum.

Average Chlorophyll-a Concentration*	Sampling Location Chlorophyll Rating
Less than 3 μg/L	3 (fair);**
3 to 10 μg/L	5 (good);
10.1 to 15 μg/L	3 (fair);
Greater than 15 μg/L	1 (poor).

* If any single chlorophyll-a sample exceeds 30 μg/L, the value is not included in calculating the average, but the rating is decreased one unit, (i.e., 5 to 4, or 4 to 3, etc.) for each sample that exceeded 30 μg/L.

** If nutrients are present (e.g., nitrate+nitrite greater than 0.05 mg/L and total phosphorus greater than 0.01 mg/L) but chlorophyll-a concentrations are generally low (e.g., $\leq$ 2 μg/L), another/other limiting or inhibiting factors such as toxicity is likely. When these conditions exist, chlorophyll is rated 2 (poor).

Sediment Quality Rating Scheme--Contaminated bottom sediments can have direct adverse impacts on bottom fauna and can often be long-term sources of toxic substances to the aquatic environment. They may impact wildlife and humans through the consumption of contaminated food or water or through direct contact. These impacts may occur even though the water above the sediments meets water quality criteria. There are many sediment assessment methods, but there is no single method that measures all contaminated sediment impacts at all times and to all biological organisms (EPA, 1992). TVA's approach combines two sediment assessment methods--one biological, the other chemical--to evaluate sediment quality. TVA's scoring criterion is based on ratings for the toxicity of sediment pore water (S_{TOX}) to test organisms, and the chemical analysis of sediment (S_{CHM}) for heavy metals, PCBs, organochlorine pesticides, and un-ionized ammonia (Table 2.3). The final sediment quality score or rating is the average of these two ratings:

Sediment Quality Rating = 0.5 (S_{TOX} rating + S_{CHM} rating), where:

S_{TOX} (Sediment Toxicity) Rating--Sediment toxicity is evaluated using both Rotox® (rotifer Brachionus calyciflorus survival) and daphnid (Ceriodaphnia dubia) acute tests. The acute toxicity evaluations entail the exposure of these organisms (zooplankton) to interstitial pore water from sediment. The survival rates of the organisms are based on the average survival in four replicates of five individuals

each, compared to a control. If average survival is significantly reduced (95 percent probability) from the control, the sample is considered to be toxic. Sampling locations are rated as follows:

Sampling Location S_{TOX} Rating	Percent Survival of Ceriodaphnia and/or Branchionus
5 (good)	Survival not significantly different than control and greater than or equal to 80 percent for both species, (i.e., no significant toxicity);
3 (fair)	Survival not significantly different from control, but less than 80 percent survival for either species; or
1 (poor)	Survival of either organism significantly less than control, (i.e., significant toxicity).

S_{CHM} (Sediment Chemistry) Rating--Splits of the same sediment used in the sediment toxicity testing are analyzed for heavy metals, organochlorine pesticides and PCBs, and un-ionized ammonia. Sediment chemistry ratings are based on: (a) concentrations of heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, and Zn) that exceed freshwater sediment guidelines (EPA, 1977); (b) detectable amounts of PCBs or pesticides; and (c) concentrations of un-ionized ammonia in pore water above 200 μg NH_3/L. Each sampling location is rated as follows:

Sampling Location S_{CHM} Rating	Sediment Chemistry*
5 (good)	No analytes exceed guidelines;
3 (fair)	One or two analytes exceed guidelines;
1 (poor)	Three or more exceed guidelines.

* Analytes (i.e., heavy metals, pesticides, PCBs and ammonia) and guidelines are listed in Table 2.3.

Benthic Community Rating Scheme--Six community characteristics (or metrics), with scoring criteria specific to either run-of-the-river or storage reservoirs, are used to evaluate the ecological health of the benthic macroinvertebrate community (Table 3.1). These characteristics are:

1. **Taxa Richness**--The number of different taxa present. An increase in total taxa or taxa richness is used to indicate better conditions than low taxa richness.

2. **Longed-Lived species**--The number of taxa (Corbicula, Hexagenia, mussels, and snails) present. These organisms are long-lived and their presence indicate conditions which allow long-term survival.

3. **EPT**--The number of different taxa within these orders (Ephemeroptera-mayflies, Plecoptera-stoneflies, and Tricoptera-caddisflies). Higher numbers of this metric indicate good water quality conditions in streams. A similar use is incorporated here despite expected lower numbers in reservoirs than in streams.

4. **Proportion as Chironomidae**--The percent of the total organisms in the sample that are chironomids. A higher proportion indicates poor conditions.

5. **Proportion as Tubificidae**--The percent of the total organisms present that are tubificids. A higher proportion indicates poor quality.

6. **Proportion as Dominant Taxa**--The percent of total organisms present that are members of the dominant taxon. This metric is used as an evenness indicator. A large proportion comprised by one or two taxa indicates poor conditions.

Specific scoring criteria were developed for each of the six metrics for both run-of-the-river reservoirs and tributary reservoirs. And given the substantial habitat differences among forebays, transition zones/mid-reservoirs, and inflows, specific scoring criteria were also developed for each of these areas (Table 3.1). Data handling also differed among the metrics. Metric 1, taxa richness, is the average total number of taxa per sample at each site. Metrics 2 and 3 are handled similarly. For Metric 4 the proportion of chironomids in each sample is calculated, then these proportions are averaged for a location. An alternative that was considered was to sum the number of chironomids in all samples and divide by the sum of the total individuals for all samples. The approach selected gives equal weight to all samples regardless of sample size or sampling gear (Ponar or Peterson dredge). This eliminates the bias introduced in the alternate approach when one sample at a site has an exceptionally large or small density. Metric 5 is calculated in the same way. Metric 6, proportion as dominant taxa, is calculated as proportion for each sample, similar to computations for Metrics 4 and 5. The proportion is calculated for the dominant taxon in each sample even if the dominant taxon differed among the samples at a site. This allows more discretion to identify imbalances at a site than developing an average for a single dominant taxon for all samples at the site.

A quantitative approach is used to evaluate the benthic macroinvertebrate community information. The range of values for each of the six metrics found in the available data base (in this case, all the 1991, 1992, and 1993 Vital Signs benthic monitoring data) serves as the basis for

evaluation criteria. For each metric at each of the three reservoir sampling zones (forebay, transition zone/mid-reservoir, and inflow) and two reservoir types (run-of-the-river and tributary) the data base values are divided into three groups using Ward's minimum variance analysis (SAS, 1989). This procedure places observations into three homogenous groups of approximate equal size. The groups are sorted and categorized as poor, fair, or good. Scoring criteria represent values between the highest and the lowest value in each group (Table 3.1). Results for each metric for the current year are then compared with these criteria and assigned quantitative values of 1 (poor), 3 (fair), or 5 (good) if they fall within the bottom-, middle-, or top-group, respectively. This results in a minimum score of 6 if all metrics at a site are poor, and a maximum score of 30 if all metrics are good. Detailed scoring criteria for each metric are provided in Table 3.1.

Metrics are summed for each reservoir sampling site to yield a final benthic score and are evaluated as follows:

Sum of Benthic Community Metric Scores	Sampling Location Benthic Rating
6-10	1 (poor)
11-15	2
16-20	3 (fair)
21-25	4
26-30	5 (good)

Fish Assemblage Rating Scheme--In 1993, a Reservoir Fish Assemblage Index (RFAI) (Hickman et.al, 1994) was used to rate fish assemblages as they relate to the overall ecological health of the reservoir. The RFAI is based on 12 metrics with scoring criteria specific to either run-of-the-river or storage reservoirs. Scoring criteria also are specific for the type of sample location within reservoirs--forebay, transition zone/mid-reservoir, or inflow; and for the type of sampling gear used (i.e., electrofishing for littoral fish communities and gill netting for pelagic fish communities). The metrics address the following 12 reservoir fish assemblage characteristics. Table 3.2 lists the trophic, reproductive, and tolerance designations of fish species collected as part of Vital Signs Reservoir Monitoring activities.

Species Richness and Composition

1. **Total number of species**--Greater numbers of species are considered representative of healthier aquatic ecosystems. As conditions degrade, numbers of species at a site decline.

2. **Number of piscivore species**--Higher diversity of piscivores is indicative of better quality environment.

3. **Number of sunfish species**--Lepomid sunfish (excludes black basses, crappies, and rock bass) are basically insectivores, and high diversity of this group is indicative of reduced siltation and high sediment quality in littoral areas.

4. **Number of sucker species**--Suckers are also insectivores but inhabit the pelagic and more riverine sections of reservoirs. This metric closely parallels the lithophilic spawning species metric (Metric 10) and may be deleted from future RFAI calculations.

5. **Number of intolerant species**--This group is made up of species that are particularly intolerant of habitat degradation. Higher densities of intolerant individuals represent better environmental quality.

6. **Percentage of tolerant individuals** (excluding Young-of-Year)--This metric signifies poorer quality with increasing proportions of individuals tolerant of degraded conditions.

7. **Percent dominance by one species**--Ecological quality is considered reduced if one species dominates the resident fish community.

Trophic Composition

8. **Percentage of individuals as omnivores**--Omnivores are less sensitive to environmental stresses due to their ability to vary their diets. As trophic links are disrupted due to degraded conditions, specialist species such as insectivores decline while opportunistic omnivorous species increase in relative abundance.

9. **Percentage of individuals as insectivores**--Due to the special dietary requirements of this group of species and the limitations of their food source in degraded environments, proportion of insectivores increases with environmental quality.

Reproductive Composition

10. **Number of lithophilic spawning species**--Lithophilic broadcast spawners are selected due to their sensitivity to siltation. Numbers of lithophilic spawning species increase in reservoirs providing suitable conditions reflective of good environmental quality.

Abundance and Fish Health

11. **Total catch per unit effort** (number of individuals)--This metric is based upon the assumption that high quality fish assemblages support large numbers of individuals.

12. **Percent individuals with anomalies**--Incidence of diseases, lesions, tumors, external parasites, deformities, blindness, and natural hybridization are noted for all fish measured, with higher incidence indicating poor environmental conditions.

Each metric is assigned a score of 5, 3, or 1 -- representing "good," "fair," or "poor," conditions, respectively. Due to the distinct habitat differences among reservoirs and sampling locations--and the differences in fish assemblages they support--different scoring criteria are used for each of the 12 metrics for: (a) each reservoir type (i.e., run-of-the-river and tributary storage reservoirs); (b) each sampling location (forebay, transition/mid-reservoir, and inflow); and (c) each type of sampling gear used to collect the fish data (electrofishing and gill netting). Scoring criteria by reservoir type, by sampling location, and by sampling gear type are listed for each of the 12 fish community metrics in Table 3.3. There is not yet enough information for inflow sampling locations on tributary reservoirs to establish criteria for the fish community metrics at these particular sites.

The average of the sum of the electrofishing scores and the sum of the gill netting scores results in the Reservoir Fish Assemblage Index (RFAI) for each sampling location. The range of "attainable" RFAI values could be from 12 (if all metrics scored 1) to 60 (if all metrics scored 5). This range of RFAI values, from 12 to 60, is divided into five equal groupings to evaluate the overall health of the fish assemblage at each sampling location, as follows:

RFAI Score	Sampling Location Rating
12-21	1 (poor)
21-31	2
32-41	3 (fair)
42-51	4
52-60	5 (good)

A discussion of the development of the RFAI and results of the fish evaluations for the 1991-1993 Vital Signs Monitoring data are available in TVA technical reports (Scott, et. al, 1992; Brown, et. al, 1993; and Hickman et. al, 1994).

Overall Reservoir Health Determination--The overall ecological evaluation methodology combines the five previously discussed aquatic ecosystem indicators (DO, chlorophyll, sediment quality, benthic macroinvertebrates, and fish assemblage) into a single numeric value. This facilitates spatial comparisons among reservoirs and temporal comparisons for a reservoir through time.

The first step in determining an overall reservoir health score is to sum the ratings for all indicators (ranging from 1-poor to 5-excellent) at a sample site. The number of indicators monitored at each site varies. Generally, all five indicators are included; however, this is not always the case. For example, chlorophyll and sediment quality are not monitored at the inflows on run-of-the-river reservoirs because in situ plankton production of chlorophyll does not occur significantly in that part of a reservoir and because sediments do not accumulate there. The number of sites per reservoir also varies from one (the forebay) in small tributary reservoirs to four (forebay, transition zone, inflow, and embayment) in selected run-of-the-river reservoirs. As a result, the number of ratings vary from five to 18 for the 30 reservoirs monitored in 1993. Specific information on what indicators were sampled in each reservoir is in Table 2.1.

To arrive at an overall health evaluation for a reservoir, the sum of the ratings from all sites are totaled, divided by the maximum potential ratings for that reservoir, and expressed as a percentage. For example, a small reservoir with only one sample site, the minimum health evaluation would be 20 percent (all five indicators rated poor-1 for a total score of 5 divided by the maximum possible total of 25) and the maximum would be 100 percent (all five indicators rated good-5). This same range of 20 to 100 percent applies to all reservoirs regardless of the number of sample sites, and the same calculation process is used.

The next step is to divide the 20-100 percent scoring range into categories representing good, fair, and poor ecological health conditions. This has been achieved as follows:

1. Results are plotted and examined for apparent groupings.

2. Groupings are compared to known, a priori conditions (focusing on reservoirs with known poor conditions), and good-fair and fair-poor boundaries were established subjectively.

3. The groupings are compared to a trisection of the overall scoring range. A scoring range is adjusted up or down a few percentage points to ensure a reservoir with known conditions falls within the appropriate category. This is done only in circumstances where a nominal adjustment is necessary.

Based on these considerations, during the first two years of development (1991-1992), scoring ranges were as follows:

	Poor	Fair	Good
Run-of-the-river reservoirs	≤52%	>52-72%	>72%
Tributary, storage reservoirs	≤56%	>56-72%	>72%

The difference in the poor scoring range between the two types of reservoirs is due to the fact that two storage reservoirs with known poor conditions rated slightly higher than the boundary for the lower (poor) grouping on the run-of-the-river reservoirs. Hence, the high end of the lower scoring range for storage reservoirs was shifted upward from 52 to 56 percent to accommodate these reservoirs with known poor conditions.

Based on the experience gained in developing this evaluation process, review of the evaluation scheme by other state and federal professionals, and results of another year of monitoring, slight modifications were made in the original evaluation process and the numerical scoring criteria for each of the five ecological health indicators. In 1993, run-of-the-river reservoirs with overall scores greater than 72 percent were evaluated as "good"; those between 52 percent and 72 percent were rated "fair"; and those whose overall scores were less than 52 percent were rated "poor." Similarly, in 1993, tributary storage reservoirs were evaluated as "good" if their overall reservoir percentage was greater than or equal to 72 percent; "fair" if its overall reservoir percentage was between 57 percent and 72 percent; and "poor" if its overall reservoir percentage was less than 57 percent. The 1993 scoring ranges were:

	Poor	Fair	Good
Run-of-the-river reservoirs	<52%	52-72%	>72%
Tributary, storage reservoirs	<57%	57-72%	≥72%

Two examples that illustrate the overall reservoir health evaluation methodology are presented in Tables 3.6 and 3.7. Wilson Reservoir (Table 3.6) has five aquatic health indicators at one location and three indicators at another location. Cherokee Reservoir (Table 3.7) has five aquatic health indicators at one location and four indicators at another location.

3.1.3 Stream Ecological Health

An evaluation methodology similar to the Reservoir Ecological Health Evaluation (Section 3.1.2) is used to assess the overall ecological health at each of the 12 stream monitoring locations. Particular emphasis is given to the relationship between the conditions found at the stream sampling site and the potential for impacts on conditions in the downstream reservoir. The following

overview summarizes TVA's stream ecological health evaluation methodology. The evaluations are based on four aquatic health indicators: (1) total phosphorus (as a measure of nutrient enrichment and potential for excessive algal productivity); (2) sediment quality; (3) benthic community; and (4) fish community.

At each stream sampling location the four aquatic health indicators are rated as "good," "fair," or "poor." Equal weights are given to each indicator, and each rating is assigned a numeric value of 1, 3, or 5 corresponding to "poor," "fair," or "good." The four scores are summed to produce an overall stream health evaluation at the sampling location ranging from 4 to 20. A stream sampling location with an overall rating of 9 or less ($\leq$45 percent) was rated "poor"; 10 to 15 (50 percent to 75 percent) "fair"; and 16 to 20 (80 percent to 100 percent) "good."

Nutrient Concentration Rating Scheme--Phosphorus is an essential nutrient required by aquatic plants for photosynthesis and growth. In freshwater ecosystems phosphorus is most often the nutrient least available to plants relative to their needs, and thus can limit algal productivity. When present in excess of critical concentrations, in combination with sufficient nitrogen phosphates, it can stimulate algae and other aquatic plant growth, sometimes to an undesirable level that interferes with water uses. To prevent the development of biological nuisances and to control accelerated phosphorus loading for the protection of downstream receiving waterways, EPA recommends a guideline for maximum total phosphorus concentration of 0.10 mg/L for streams or flowing waters and 0.05 mg/L at the point where any stream enters a lake or reservoir (EPA, 1986). These guidelines are used as the basis to evaluate total phosphorus concentrations in Tennessee Valley streams (average of 6 samples per year):

Average Total Phosphorus Concentration*	Sampling Location Nutrient Enrichment Rating
Less than 0.05 mg/L	5 (good);
0.05 to 0.10 mg/L	3 (fair);
Greater than 0.10 mg/L	1 (poor).

* In addition, waters that receive high nitrogen concentrations in the presence of sufficient phosphorus often stimulate the growth of algae and other aquatic plants to an undesirable extent. High average (relative to the majority of Valley streams) nitrate+nitrite nitrogen concentrations greater than 0.65 mg/L resulted in lowering a rating from "good" to "fair" or from "fair" to "poor," as appropriate.

Sediment Quality Rating Scheme--The stream sediment quality evaluation methodology is the same as for reservoir sediment quality. The scoring criterion is based on ratings for the acute

toxicity of sediment pore water (S_{TOX}) to both Rotox® (rotifer, Brachionus calyciflorus survival) and daphnid (Ceriodaphnia dubia), and the chemical analysis of sediment (S_{CHM}) for heavy metals, PCBs, organochlorine pesticides, and un-ionized ammonia. The final sediment quality score or rating is the average of these two ratings. (Details are given in Section 2.1.2, Reservoir Sediment Quality Rating Scheme.)

Sediment Quality Rating = 0.5 (S_{TOX} rating + S_{CHM} rating).

Benthic Community Rating Scheme--A modified version of the benthic index of biotic integrity (BIBI) (Kerans et. al, 1992) is used to rate the condition of the benthic community. Twelve benthic community attributes such as total taxa richness and richness of specific taxa, relative abundance of functional and trophic groups and certain tolerant organisms, and total abundance are used. Each of the 12 metrics is scored based on best expected conditions at reference sites supporting healthy benthic communities and good water quality. At each site three Surber (riffle), three Hess (pool), and one qualitative sample were taken. EPT, intolerant snail and mussel species metrics were computed pooling all qualitative and quantitative samples. Total abundance was computed pooling all quantitative samples. The remaining metrics were computed separately for each quantitative sample at a site.

Taxa Richness and Community Composition

1. Taxa richness
2. Occurrence of intolerant snail and mussel species*
3. Number of mayfly (Ephemeroptera) taxa
4. Number of stonefly (Plecoptera) taxa
5. Number of caddisfly (Trichoptera) taxa
6. Total number of EPT taxa*
7. Percentage as oligochaetes
8. Percentage in the two most dominant taxa

Trophic and Functional-Feeding Group

9. Percent as omnivores and scavengers
10. Percent as collector-filterers
11. Percent as predators

Abundance

12. Total abundance of individuals (combined quantitative samples, lower score given for extremely low values or extremely high values)

* Metric applied to qualitative and quantitative samples combined. All other metrics applied to individual quantitative samples and resultant scores averaged.

Values obtained for each of these metrics are scored (1-poor, 3-fair, or 5-good) against best expected value based on data from reference sites supporting healthy fish communities and having good water quality (Table 3.4). Metric scores are then summed to produce an index ranging from 12 to 60. The resultant benthic community index for each stream location is classified as "poor" (<30), "fair" (34-44), or "good" (>45). If the index score falls between 30-33, professional judgment is used to categorize the benthic community as either poor or fair.

Fish Community--A modified version of Karr's (1981) index of biotic integrity (IBI) is used to assess the condition of the resident fish community at 11 of the 12 stream monitoring locations. (Fish community sampling was not conducted on the Elk River in 1993.) An index and rating are produced for each site by applying the following 12 metrics.

Species richness and composition

1. Number of native species
2. Number of darter species
3. Number of native sunfish species (excluding Micropterus sp.)
4. Number of sucker species
5. Number of intolerant species
6. Percentage of individuals as tolerant species

Trophic structure

7. Percentage of individuals as omnivores
8. Percentage of individuals as specialized insectivorous minnows and darters
9. Percentage of individuals as piscivores

Fish abundance and condition

10. Catch rate (average number per unit of sampling effort, seine hauls and shocking runs)
11. Percentage of individuals as hybrids
12. Percentage of individuals with poor condition, injury, deformity, disease, or other anomaly

Actual values obtained for each of these metrics are scored (1-poor, 3-fair, or 5-good) against values expected under pristine conditions (i.e., best expected value, Table 3.5). The 12 metric scores are then summed to produce an index ranging from 12 to 60, and the fish community at the stream sampling location is rated as "poor" (index <36), "fair" (index 40-44), or "good" (index >46). Professional judgment is involved when a fish community index falls between ratings. For example, an index of 38 falls between "poor" and "fair" and would be either "poor" or "fair"

depending on the judgment of the biologist taking the sample. Judgment usually is influenced by which of the 12 metrics rates poorest, condition of the coexisting macroinvertebrate community, or previous IBI ratings obtained for the site.

3.2 Use Suitability

3.2.1 Bacteriological Quality Evaluation

Each of the seven Valley states follows the EPA guideline of using a geometric mean fecal coliform concentration of 200 colonies per 100 milliliters (200/100 mL) of water to determine use suitability for whole body water contact recreation (EPA, 1991). Six of the states use an additional fecal coliform criterion to determine if a site is unsuitable for water contact recreation; either a percentage of samples exceeds 400/100 mL, or a maximum concentration of 1000/100 mL for any one sample.

TVA reports on the bacteriological condition of stream and reservoirs throughout the Valley in its publication *RiverPulse* using the following three categories:

Posted by the State:

+ The state has issued a public advisory against water contact and has posted signs near the body of water with the advisory.

+ Each area presently posted exceeds the geometric mean criterion due to a known human source of contamination.

Exceeds Criterion:

+ The geometric mean of a minimum of ten fecal coliform bacteria samples collected by TVA over a period of not more than 30 days from May through September exceeds 200/100 mL.

+ Each site identified is believed to exceed criterion due to animal waste.

Meets Criterion:

+ The geometric mean of a minimum of ten fecal coliform bacteria samples collected by TVA over a period of not more than 30 days from May through September is less than 200/100 mL.

TVA recommends no water contact recreation for at least two days following rain events at locations which only partially support water contact because of the bacteria which are washed into the

water. In addition, TVA recommends no water contact recreation in the immediate vicinity of wastewater discharges regardless of what fecal bacteria data show, because of the possibility of mechanical breakdowns and sewage bypasses or overflows.

3.2.2 Fish Tissue Consumption Advisories

TVA and state agencies coordinate with one another in conducting fish tissue studies in the Tennessee Valley. There is a shared interest in the status of TVA reservoirs as important and valuable resources. As the government organizations responsible for regulatory and public health decisions related to lakes and streams, state agencies are interested in knowing both the ecological health of Valley reservoirs and whether the fish are safe to eat.

Prior to initiating sample collections each autumn, TVA and involved Valley state agencies meet to discuss the previous year's results and decide appropriate direction for further study. The group reaches agreement on species to collect, locations to sample, and the agencies responsible for conducting each part of the work. TVA provides its results to the appropriate states, then the states take action to protect public health. This usually involves deciding whether to issue an advisory against consuming selected species or age classes of fish. TVA's role in this process is to provide accurate results, to provide consultation to the state(s) as appropriate, and support the state's decisions.

Figure 3.1

Cross-section of Tellico Reservoir Forebay Showing Areas where Summer DO Concentrations averaged less than or equal to 2 mg/l.

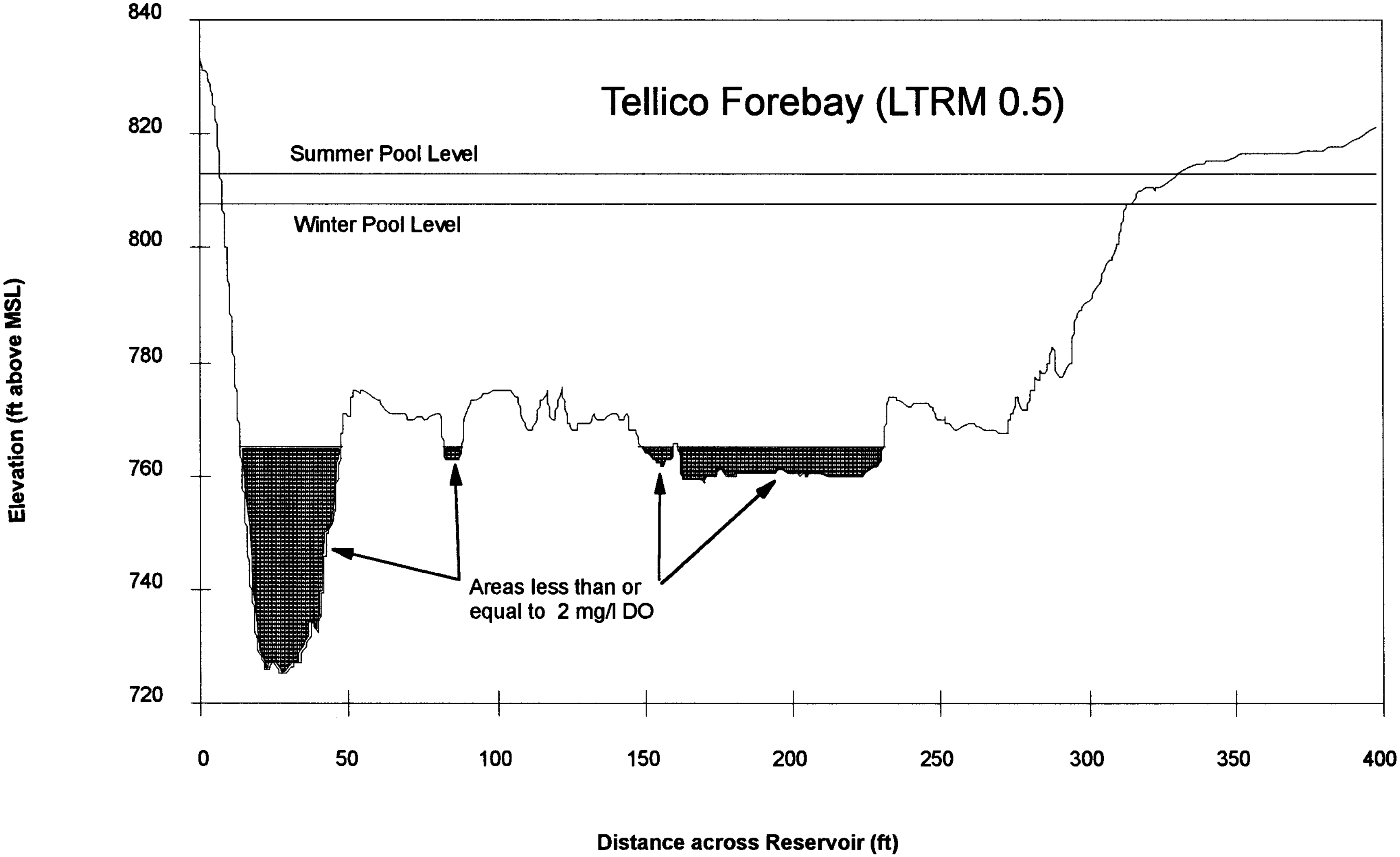


Table 3.1
1993 Vital Signs Monitoring

Reservoir Benthic Macroinvertebrate Community metrics and scoring criteria developed for Tennessee Valley Reservoirs, with a score of 5 representing highest quality, and a score of 1 the poorest.

Run-of-the-River Reservoirs

Benthic Community Metrics	Forebay			Transition			Inflow		
	5	3	1	5	3	1	5	3	1
Taxa Richness	>6.1	4.6-6.1	<4.6	>7.6	6.5-7.6	<6.5	>8.0	5.2-8.0	<5.2
Long Lived Species	>1.2	0.35-1.2	<0.35	>2.4	1.3-2.4	<1.3	>1.9	1.3-1.9	<1.3
EPT (mayfly, stonefly, caddisfly)	>0.95	0.5-0.95	<0.5	>0.95	0.6-0.95	<0.6	>1.4	0.6-1.4	<0.6
% Chironomidae	<30	30-45	>45	<25	25-40	>40	<10	10-30	>30
% Tubificidae	<25	25-50	>50	<20	20-40	>40	<11	11-25	>25
% Dominant Taxa	<75	75-90	>90	<65	65-70	>70	<70	70-80	>80

Tributary Reservoirs

Benthic Community Metrics	Forebay						Mid-Res/Inflow		
	5	3	1				5	3	1
Taxa Richness	>4.3	2.3-4.3	<2.3	--	--	--	>6.2	3.4-6.2	<3.4
Long Lived Species	>1.0	0.15-1.0	<0.15	--	--	--	>0.45	0.15-0.45	<0.15
EPT (mayfly, stonefly, caddisfly)	>0.35	0.15-0.35	<0.15	--	--	--	>0.3	0.09-0.3	<0.09
% Chironomidae	<30	30-50	>50	--	--	--	<25	25-70	>70
% Tubificidae	<30	30-60	>60	--	--	--	<45	45-75	>75
% Dominant Taxa	<78	78-91	>91	--	--	--	<70	70-80	>80

Table 3.2
1993 Vital Signs Monitoring

Core fish species list with trophic tolerance, and reproductive designations (*) for use in Reservoir Fish Assemblage Index (RFAI) for TVA reservoirs, 1993.

Species	Trophic Guild	Tolerance	Lithophilic Spawner
Chestnut lamprey	PS		L
Spotted gar	PI		
Longnose gar	PI	TOL	
Shortnose gar	PI	TOL	
Bowfin	PI		
American eel	PI		
Skipjack herring	PI	INT	
Gizzard shad	OM	TOL	
Threadfin shad	PL		
Mooneye	IN		L
Chain pickerel	PI		
Central stoneroller	HB		
Common carp	OM	TOL	
Goldfish	OM	TOL	
Silver chub	IN	INT	
Golden shiner	OM	TOL	
Emerald shiner	IN		
Ghost shiner	IN		
Spotfin shiner	IN		
Mimic shiner	IN	INT	
Steelcolor shiner	IN		
Pugnose minnow	IN		
Bluntnose minnow	OM		
Fathead minnow	OM		
Bullhead minnow	IN		
River carpsucker	OM		
Quillback	OM		
Northern hog sucker	IN	INT	L
Smallmouth buffalo	OM		
Bigmouth buffalo	PL		
Black buffalo	OM		
Spotted sucker	IN	INT	L
Silver redhorse	IN		L
Shorthead redhorse	IN		L
River redhorse	IN	INT	L
Black redhorse	IN	INT	L
Golden redhorse	IN		L

Table 3.2 (continued)
1993 Vital Signs Monitoring

Core fish species list with trophic tolerance, and reproductive designations (*) for use in Reservoir Fish Assemblage Index (RFAI) for TVA reservoirs, 1993.

Species	Trophic Guild	Tolerance	Lithophilic Spawner
Blue catfish	OM		
Black bullhead	OM	TOL	
Yellow bullhead	OM	TOL	
Brown bullhead	OM	TOL	
Channel catfish	OM		
Flathead catfish	PI		
Blackstripe topminnow	IN		
Blackspotted topminnow	IN		
Mosquitofish	IN	TOL	
Brook Silverside	IN		
White bass	PI		L
Yellow bass	PI		L
Rock bass	PI	INT	
Redbreast sunfish	IN	TOL	
Green sunfish	IN	TOL	
Warmouth	IN		
Orangespotted sunfish	IN		
Bluegill	IN		
Longear sunfish	IN	INT	
Redear sunfish	IN		
Spotted sunfish	IN		
Smallmouth bass	PI		
Spotted bass	PI		
Largemouth bass	PI		
White crappie	PI		
Black crappie	PI		
Yellow perch	IN		
Logperch	IN		L
Sauger	PI		L
Walleye	PI		L
Freshwater drum	IN		

*Designations:
Trophic: herbivore (HB), parasitic (PS), planktivore (PL), omnivore (OM), insectivore (IN), piscivore (PI)
Tolerance: tolerant (TOL), intolerant (INT)
Lithophilic spawning species (L)

Table 3.3
1993 Vital Signs Monitoring

Reservoir Fish Assemblage Index metrics and scoring criteria developed for TVA ***Run-of-the-River*** reservoirs. Scoring reflects fish community quality, with a score of 5 representing highest quality, and a score of 1 the poorest.

Metric	Gear*	Inflow			Transition			Forebay		
		5	3	1	5	3	1	5	3	1
Species Richness										
1. Total species	E	>27	21-27	<21	>25	19-25	<19	>25	21-25	<21
	G	--	--	--	>21	18-21	<18	>19	17-19	<17
2. Piscivore species	E	>9	5-9	<5	>8	6-8	<6	>8	7-8	<7
	G	--	--	--	>9	7-9	<7	>9	8-9	<8
3. Sunfish species	E	>4	3-4	<3	>5	4-5	<4	>5	4-5	<4
	G	--	--	--	>2	2	<2	>2	2	<2
4. Sucker species	E	>5	4-5	<4	>3	2-3	<2	>2	2	<2
	G	--	--	--	>3	2-3	<2	>3	2-3	<2
5. Intolerant species	E	>4	3-4	<3	>2	2	<2	>2	2	<2
	G	--	--	--	>2	2	<2	>2	2	<2
6. Percent tolerant individuals	E	<40	40-60	>60	<30	30-60	>60	<30	30-60	>60
	G	--	--	--	<20	20-35	>35	<25	25-40	>40
7. Percent dominance by one species	E	<30	30-50	>50	<40	40-60	>60	<40	40-60	>60
	G	--	--	--	<30	30-40	>40	<30	30-40	>40
Trophic Composition										
8. Percent individuals as omnivores	E	<30	30-60	>60	<30	30-60	>60	<30	30-60	>60
	G	--	--	--	<35	35-55	>55	<35	35-50	>50
9. Percent individuals as insectivores	E	>50	30-50	<30	>70	40-70	<40	>60	30-60	<30
	G	--	--	--	>15	5-15	<5	>10	5-10	<5
Reproductive Composition										
10. Lithophilic spawning species	E	>7	5-7	<5	>4	3-4	<3	>5	4-5	<4
	G	--	--	--	>5	5	<5	>5	5	<5
Abundance and Health										
11. Total catch per unit effort	E	>120	70-120	<70	>130	70-130	<70	>130	80-130	<80
	G	--	--	--	>30	15-30	<15	>40	20-40	<20
12. Percent individuals with anomalies	E	<1	1-3	>3	<1	1-3	>3	<1	1-3	>3
	G	--	--	--	<1	1-3	>3	<1	1-3	>3

* E=electrofishing; G=gill netting

Table 3.3 (continued)
1993 Vital Signs Monitoring

Reservoir Fish Assemblage Index metrics and scoring criteria developed for TVA ***Tributary*** reservoirs. Scoring reflects fish community quality, with a score of 5 representing highest quality, and a score of 1 the poorest.

Metric	Gear*	Inflow			Mid-Reservoir			Forebay		
		5	3	1	5	3	1	5	3	1
Species Richness										
1. Total species	E	--	--	--	>17	15-17	<15	>25	21-25	<21
	G	--	--	--	>16	13-16	<13	>14	11-14	<11
2. Piscivore species	E	--	--	--	>6	5-6	<5	>5	4-5	<4
	G	--	--	--	>7	7	<7	>6	5-6	<5
3. Sunfish species	E	--	--	--	>3	3	<3	>4	3-4	<3
	G	--	--	--	>1	1	<1	>1	1	<1
4. Sucker species	E	--	--	--	>3	2-3	<2	>2	2	<2
	G	--	--	--	>3	2-3	<2	>3	2-3	<2
5. Intolerant species	E	--	--	--	>2	2	<2	>3	2-3	<3
	G	--	--	--	>1	1	<1	>1	1	<1
6. Percent tolerant individuals	E	--	--	--	<20	20-40	>40	<20	20-40	>40
	G	--	--	--	<20	20-40	>40	<20	20-40	>40
7. Percent dominance by one species	E	--	--	--	<40	40-60	>60	<40	40-60	>60
	G	--	--	--	<30	30-50	>50	<30	30-50	>50
Trophic Composition										
8. Percent individuals as omnivores	E	--	--	--	<15	15-30	>30	<20	20-40	>40
	G	--	--	--	<30	30-50	>50	<30	30-50	>50
9. Percent individuals as insectivores	E	--	--	--	>70	50-70	<50	>70	40-70	<40
	G	--	--	--	>10	5-10	<5	>15	5-15	<5
Reproductive Composition										
10. Lithophilic spawning species	E	--	--	--	>5	4-5	<4	>4	3-4	<3
	G	--	--	--	>4	3-4	<3	>3	2-3	<2
Abundance and Health										
11. Total catch per unit effort	E	--	--	--	>100	60-100	<60	>120	60-120	<60
	G	--	--	--	>25	15-25	<15	>20	10-20	<10
12. Percent individuals with anomalies	E	--	--	--	<1	1-3	>3	<1	1-3	>3
	G	--	--	--	<1	1-3	>3	<1	1-3	>3

* E=electrofishing; G=gill netting

Table 3.4
1993 Vital Signs Monitoring

Benthic Macroinvertebrate Community Index of Biotic Integrity (IBI) metrics and scoring criteria developed for Tennessee Valley Streams, with a score of 5 representing highest quality, and a score of 1 the poorest.

Stream Benthic Index of Biotic Integrity Metrics				
Metric	**Sampling Gear**	**Score**		
		1	**3**	**5**
Taxa Richness and Community Composition				
1. Taxa Richness	Surber or Hess	<9	9-17	≥18
2. Occurrence of mollusk species*	Combined	0	--	≥1
3. Number of mayfly (Ephemeroptera) taxa	Surber or Hess	<3	3-5	≥6
4. Number of stonefly (Plecoptera) taxa	Surber or Hess	<2	--	≥2
5. Number of caddisfly (Trichoptera) taxa	Surber or Hess	<2	2-3	≥4
6. Number of EPT taxa*	Combined	<14	14-24	≥25
7. Proportion of oligochaetes	Surber or Hess	≥0.05	0.01-0.049	<0.01
8. Proportion of the two most abundant taxa	Surber or Hess	≥0.75	0.5-0.749	<0.5
Trophic and Functional-Feeding Group				
9. Proportion as omnivores and scavangers	Surber or Hess	≥0.9	0.6-0.89	<0.6
10. Proportion as collectors/filterers	Hess	≥0.5	0.2-0.49	<0.2
	Surber	≥0.6	0.3-0.59	<0.3
11. Proportion as predators	Surber or Hess	≤0.04	--	>0.04
Abundance				
12. Total abundance in quantitative samples (Lower scores given for extremely low and high values)	Combined	≤400 >5000	401-500 4001-5000	501-4000
* Metric applied to qualitative and quantitative samples combined. All other metrics applied to individual quantitative samples and resultant scores averaged.				

Table 3.5
1993 Vital Signs Monitoring

Fish Community Index of Biotic Integrity (IBI) metrics and scoring criteria developed for Tennessee Valley Streams, with a score of 5 representing highest quality, and a score of 1 the poorest.

Stream Fish Community Index of Biotic Integrity Metrics

Metric	Duck River 22.5			Bear Creek 25.2			Sequatchie River 7.1			Hiwassee River 37.0		
	1	3	5	1	3	5	1	3	5	1	3	5
Species Richness and Composition												
1. Number of native species	<27	27-53	>53	<23	23-44	>44	<23	23-45	>45	<21	21-41	>41
2. Number of darter species	<5	5-9	>9	<4	4-7	>7	<5	5-8	>8	<5	5-8	>8
3. Sunfish species, less Micropterus	<3	3-5	>5	<3	3-5	>5	<3	3-5	>5	<2	2-3	>3
4. Number of sucker species	<4	4-7	>7	<4	4-7	>7	<4	4-7	>7	<4	4-7	>7
5. Number of intolerant species	<4	4-6	>6	<2	2-3	>3	<3	3-4	>4	<2	2	>2
6. Percent tolerant individuals	>20	10-20	<10	>20	10-20	<10	>20	10-20	<10	>20	10-20	<10
Trophic Composition												
7. Percent omnivores	>30	15-30	<15	>30	15-30	<15	>30	15-30	<15	>30	15-30	<15
8. Percent specialized insectivores	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50
9. Percent piscivores	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Abundance and Health												
10. Catch rate*	<8	8-16	>16	<8	8-16	>16	<8	8-16	>16	<8	8-16	>16
11. Percentage hybrids	>1	0-1	0	>1	0-1	0	>1	0-1	0	>1	0-1	0
12. Percent individuals with anomalies	>5	2-5	>2	>5	2-5	>2	>5	2-5	>2	>5	2-5	>2

* Average number per seine haul or five minutes of boat electroshocking

Table 3.5 (continued)
1993 Vital Signs Monitoring

Fish Community Index of Biotic Integrity (IBI) metrics and scoring criteria developed for Tennessee Valley Streams, with a score of 5 representing highest quality, and a score of 1 the poorest.

Stream Fish Community Index of Biotic Integrity Metrics

Metric	Little Tenn River 94.3			Emory River 21.7			Powell River 65.4			Clinch River 172.3		
	1	3	5	1	3	5	1	3	5	1	3	5
Species Richness and Composition												
1. Number of native species	<11	11-20	>20	<15	15-29	>29	<21	21-39	>39	<22	22-42	>42
2. Number of darter species	<3	3-4	>4	<5	5-8	>8	<5	5-8	>8	<5	5-8	>8
3. Sunfish species, less Micropterus	0	1	>1	<2	2	>2	<2	2-3	>3	<2	2-3	>3
4. Number of sucker species	<2	2-3	>3	<2	2	>2	<3	3-4	>4	<3	3-5	>5
5. Number of intolerant species	<2	2	>2	<2	2	>2	<3	3-4	>4	<3	3-5	>5
6. Percent tolerant individuals	>20	10-20	<10	>20	10-20	<10	>20	10-20	<10	>20	10-20	<10
Trophic Composition												
7. Percent omnivores	>30	15-30	<15	>30	15-30	<15	>30	15-30	<15	>30	15-30	<15
8. Percent specialized insectivores	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50
9. Percent piscivores	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Abundance and Health												
10. Catch rate*	<7	7-13	>13	<7	7-13	>13	<8	8-16	>16	<8	8-16	>16
11. Percentage hybrids	>1	0-1	0	>1	0-1	0	>1	0-1	0	>1	0-1	0
12. Percent individuals with anomalies	>5	2-5	>2	>5	2-5	>2	>5	2-5	>2	>5	2-5	>2

* Average number per seine haul or five minutes of boat electroshocking

Table 3.5 (continued)
1993 Vital Signs Monitoring

Fish Community Index of Biotic Integrity (IBI) metrics and scoring criteria developed for Tennessee Valley Streams, with a score of 5 representing highest quality, and a score of 1 the poorest.

Stream Fish Community Index of Biotic Integrity Metrics

Metric	Holston River 118.0			Nolichucky River 8.5			French Broad R 78.0		
	1	3	5	1	3	5	1	3	5
Species Richness and Composition									
1. Number of native species	<20	20-38	>38	<19	19-36	>36	<21	21-40	>40
2. Number of darter species	<4	4-7	>7	<5	5-8	>8	<4	4-7	>7
3. Sunfish species, less Micropterus	<2	2-3	>3	<2	2-3	>3	<2	2-3	>3
4. Number of sucker species	<3	3-5	>5	<4	4-6	>6	<4	4-6	>6
5. Number of intolerant species	<3	3-4	>4	<2	2-3	>3	<2	2-3	>3
6. Percent tolerant individuals	>20	10-20	<10	>20	10-20	<10	>20	10-20	<10
Trophic Composition									
7. Percent omnivores	>30	15-30	<15	>30	15-30	<15	>30	15-30	<15
8. Percent specialized insectivores	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50
9. Percent piscivores	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Abundance and Health									
10. Catch rate*	<8	8-16	>16	<8	8-16	>16	<7	7-13	>13
11. Percentage hybrids	>1	0-1	0	>1	0-1	0	>1	0-1	0
12. Percent individuals with anomalies	>5	2-5	>2	>5	2-5	>2	>5	2-5	>2

* Average number per seine haul or five minutes of boat electroshocking

Table 3.6
1993 Vital Signs Monitoring

Computational Method For Evaluation of Reservoir Health

Wilson Reservoir - 1993 (Run-of-the-river reservoir)

Aquatic Health Indicators	Observations			Ratings		
	Forebay	Transition Zone	Inflow	Forebay	Transition Zone	Inflow
Dissolved Oxygen:		No Samples	Tailrace DOs	1	No Rating	4
Less Than 2 mg/L (Summer Avg.)				(poor)		(fair)
% of X-Sectional Area	11.0 (1)	-	-			
% of X-Sectional Bottom Length	44.2 (1)*	-	-	*DO was 0 mg/L on the bottom		
Less Than 5 mg/l at 1.5m						
Yes/No	No	-	Yes*	*Minimum DO was 4.3 mg/L		
Chlorophyll-a, µg/L:		No Samples	No Samples	3	No Rating	No Rating
Summertime Average	10.2	-	-	(fair)		
Maximum Concentration	25.0	-	-			
Sediment Quality:		No Samples	No Samples	4.5	No Rating	No Rating
Toxicity	T1 T2			(good)		
Ceriodaphnia Survival	100% 95%	-	-			
Rotifer Survival	65% 85%	-	-			
Chemistry						
Metals/NH3/pesticides	None (5)	-	-			
Benthic Community:		No Samples		3	No Rating	5
Dominance	5		5	(fair)		(good)
Tubificidae	5		5			
Chironomidae	1		5			
EPT	1		5			
Long-lived	3		5			
Taxa richness	5		5			
Total	20	-	30			
Fish Community:		No Samples		4	No Rating	4
Electrofishing Score	46		-	(fair)		(fair)
Gill Netting Score	38		42			
Overall	42	-	42			
		Sampling Location Sum		15.5 of 25	--	13 of 15
		Reservoir Sum		28.5 of 40 [71%]		
		OVERALL RESERVOIR EVALUATION		"fair" (yellow)		

Overall Reservoir Evaluation Key:
Less than 52% - poor (red)
52% to 72% - fair (yellow)
Greater than 72% - good (green)

Table 3.7
1993 Vital Signs Monitoring

Computational Method For Evaluation of Reservoir Health

Cherokee Reservoir - 1993 (Tributary storage reservoir)

Aquatic Health Indicators	Observations			Ratings		
	Forebay	Transition Zone	Inflow	Forebay	Transition Zone	Inflow
Dissolved Oxygen: Less Than 2 mg/L (Summer Avg.) % of X-Sectional Area % of X-Sectional Bottom Length Less Than 5 mg/l at 1.5m Yes/No	 21.5 (1) 43.0 (1)* No	 26.0 (1) 52.0 (1)* No	No Samples - -	1 (poor) *DO was 0 mg/L on the bottom	1 (poor)	No Rating
Chlorophyll-a, µg/L: Summertime Average Maximum Concentration	 7.6 17.0	 9.4 14.0	No Samples - -	5 (good)	5 (good)	No Rating
Sediment Quality: Toxicity Ceriodaphnia Survival Rotifer Survival Chemistry Metals/NH3/pesticides	 100% (5) 90% NH3 (3)	 95% (1) 75% Cu, NH3 (3)	No Samples - - -	4 (fair)	2 (poor)	No Rating
Benthic Community: Dominance Tubificidae Chironomidae EPT Long-lived Taxa richness Total	 3 3 1 3 1 5 16	No Samples -	 5 5 3 5 5 5 28	3 (fair)	No Rating	5 (good)
Fish Community: Electrofishing Score Gill Netting Score Overall	 32 40 36	 30 38 34	 34 36 35	3 (fair)	3 (fair)	3 (fair)
	Sampling Location Sum			16 of 25	11 of 20	8 of 10
	Reservoir Sum			35 of 55 [64%]		
	OVERALL RESERVOIR EVALUATION			"fair" (yellow)		

Overall Reservoir Evaluation Key:
Less than 57% - poor (red)
>57% and <72% - fair (yellow)
Greater than 72% - good (green)

4.0 HYDROLOGIC OVERVIEW OF 1993

Many water quality characteristics (e.g., temperature, dissolved oxygen, conductivity, water clarity, suspended solids, etc.) exhibit changes due to seasonal variations in atmospheric temperature and rainfall. During those times of the year when runoff is minimal (normally August-October), streamflow is largely derived from the base flow of groundwater. Because of greater contact between the water and the soil/rock and the longer groundwater residence times, groundwater contains more dissolved minerals (i.e., higher concentrations of hardness and alkalinity, higher pHs and conductivities, etc.) than does surface water. During those times of the year when runoff is higher (normally January-March), streamflow is principally derived from rapid overland runoff that allows little time for mineral dissolution.

Consequently, during those times of the year with higher rainfall and subsequent higher flows, base flow accounts for a smaller proportion of the total streamflow, resulting in lower concentrations of most dissolved constituents. In addition, periods of intense rainfall and high overland flows wash off or "flush" a watershed and transport soil particles to streams, often carrying large loads of nonpoint source pollutants (nutrients, suspended solids, fecal bacteria, etc.) to streams and rivers.

In addition to flood control, electric power generation, and navigation, an important benefit of the TVA's system of dams and reservoirs is its ability to maintain adequate streamflow during extended periods of low rainfall and low runoff by the controlled release of water from tributary storage impoundments. However, this alteration of natural streamflow (diminishing high flows during floods and augmenting low flows during droughts) by storing and then slowly releasing water from tributary storage impoundments creates conditions of strong thermal stratification and low dissolved oxygen in the bottom waters of these tributary storage impoundments. (Additional details about reservoir stratification and water quality impacts are discussed in Chapter 5.)

From a water quality perspective, the lower streamflows occurring during the warmer summer months, combined with naturally occurring higher water temperatures and lower dissolved oxygen concentrations, result not only in lakes becoming thermally stratified but also having less water and less oxygen available to dilute and assimilate the wastes discharged to them. In addition, the warmer water temperatures increase aquatic biological processes (respiration, bacteriological decomposition, etc.). This results in oxygen being used at a faster rate, which can further lower oxygen concentrations. In combination, these factors (low streamflows and diminished assimilative

capacity, warmer temperatures and higher biological oxygen consumption rates, and the inhibition of mixing and reaeration caused by thermal stratification) result in low dissolved oxygen concentrations and adversely impact the health of aquatic life. The summer of 1993 was a case in point. July 1993 was the hottest month on record (since 1890s) in the Tennessee Valley. Valley-wide temperatures averaged almost 83°F (28.3°C), about 5°F (2.8°C) above normal for July. For example, in Chattanooga, all 31 days in July had temperatures above 90°F (32.2°C), with temperatures up to 104°F (40.0°C) and 15 days with temperatures 98°F (36.7°C) or higher. This record-breaking heat (and low streamflows) resulted in high water temperatures in the Tennessee River. In fact, all nine mainstem Tennessee River reservoirs had surface water temperatures that exceeded 86°F (30.0°C), some with highs up to 90°F (32.2°C).

In addition, Tennessee Valley rainfall and runoff were well below normal in the summer of 1993. In July, Valley-wide rainfall averaged only 1.76 inches (45 mm), a deficit of 3 inches (76 mm) below the long-term July mean of 4.77 inches (121 mm) as a result rainfall runoff was only 0.66 inches (17 mm), compared to the long-term July mean of 1.03 inches (26 mm). Further, runoff was significantly lower in the western half of the Tennessee Valley than in the eastern half. In July, runoff above Chattanooga was 90 percent of the long-term mean, while runoff was only 64 percent of the long-term mean above Kentucky Dam. For the period of January through July, runoff above Chattanooga was 80 percent of the long-term mean, while runoff was 72 percent of the long-term mean above Kentucky Dam. Consequently, flows in the Tennessee River in 1993 increasingly fell below the long-term average as the river flowed downstream from Fort Loudoun Dam to Kentucky Dam.

The high temperatures and low flows of July 1993 adversely impacted dissolved oxygen concentrations in the Tennessee River, particularly in the downstream reservoirs. In mid-July, hypolimnetic anoxia (DOs equal to 0 mg/L) was found in the forebays of Kentucky, Pickwick, Wilson, Wheeler, and Chickamauga Reservoirs. All time low concentrations of DO were recorded in the releases from Chickamauga Dam on July 16 (2.2 mg/L) and Nickajack Dam on July 19 (1.8 mg/L) when flows from both dams were only 9000 cfs. During the first two weeks of July (July 1 to 15), daily flows averaged only about 17,250-17,500 cfs at Chickamauga and Nickajack Dams, or about 55 percent of the normal flow for this period of time. Once the effects of the high temperatures and low flows on DOs in the Tennessee River were recognized, flows were immediately increased (by drawing water from tributary storage reservoirs) and DO concentrations improved. For example, at Chickamauga Dam, from July 16-31, average daily flows were increased to an average of about

24,500 cfs (about 80 percent of the normal flow for July) and DOs in the releases increased to an average of about 4.3 mg/L, ranging from 3.2 to 6.3 mg/L. Compounding this whole situation were the record-setting rains and flooding occurring in the mid-West along the Mississippi and Missouri Rivers during the "flood of the century." During this period, TVA minimized discharge from the Tennessee River through Kentucky Dam so as to not increase flood crests on the lower Ohio and Mississippi Rivers and worsen the already catastrophic flooding in those areas.

Obviously, examining atmospheric temperature, rainfall, and runoff patterns during 1993 aids in interpretation of the Vital Signs monitoring data and the ecological health assessments of the streams and reservoirs. Interestingly, interpretation of the biological components of stream monitoring results for 1993 is not influenced by these extreme hydrologic conditions. The low rainfall and low streamflows during the spring and early summer allowed benthic sample collection before the more stressed conditions developed in mid-to-late summer.

4.1 Atmospheric Temperature

Average annual temperature in the TVA region is approximately 60 degrees Fahrenheit, °F (15.6 degrees Celsius, °C), with January usually being the coldest month and July the hottest. According to U.S. Department of Commerce (USDOC) climatic data, atmospheric temperatures in the TVA region averaged only about 0.3°F (0.2°C) warmer than normal in 1993; however, 1993 was a year of extremes (USDOC, 1993). January and July were unusually warm with 5.0°F (2.8°C) and 4.7°F (2.6°C) above normal, respectively; while, March and April were below normal with departures greater than -2.0°F (-1.1°C) (Figure 4.1a).

In review, 1993 began with an unusually warm January but cooled to below normal in February. As has often occurred in the last 15 years, another cold spring with late freezes was experienced. A record-breaking late season blizzard struck the Valley in mid-March and hit hardest in the eastern half. Summer was hotter than normal, with Tennessee, Alabama, Georgia, North Carolina, and Virginia all having the hottest July on record since the 1890s. The persistent heat and high humidity created great stress on livestock and people. The daily records for Chattanooga Airport provide an indication of the unusual conditions. All 31 days had maximums above 90°F (32.2°C), with the observed maximums ranging from 92°F (33.3°C) to 104°F (40°C) and 15 days of 98°F (36.7°C) or higher. The last four months had near or below normal temperatures, and the annual average temperature was only slightly above normal.

4.2 Rainfall

The Tennessee River basin averages about 51-52 inches (1295-1320 millimeters [mm]) of precipitation annually. However, there are large variations in the spatial distribution of precipitation. The range is from a high of about 93 inches (2360 mm) in the mountains of southwestern North Carolina near Highlands, North Carolina, to a low of about 37 inches (940 mm) in the shielded valleys of these same mountains near Asheville, North Carolina. Elsewhere in the Valley, precipitation usually ranges within five to ten inches (127 mm to 254 mm) of the basin average. March is usually the wettest month and October the driest.

Rainfall across the Tennessee Valley in 1993 averaged only 39.8 inches (1011 mm), almost 12 inches (about 300 mm) or 23 percent less than the long-term 100-year average. The diminished rainfall in 1993 followed another dry year, 1992, when annual rainfall was about 8 inches (204 mm) or about 15 percent below the long-term average. The period January-May 1992 ranked as one of the ten driest on record in the Tennessee Valley. During 1993, only the month of December had rainfall greater than normal (6.1 inches [155 mm] compared to normal December rainfall of 4.8 inches [122 mm]); the greatest rainfall deficit occurred in July (1.8 inches [45 mm] compared to the normal July rainfall of 4.8 inches [122mm]). In addition to the extremes of December and July, March and September precipitation was close to average while February, April, June and October were more than an inch (254 mm) below average (Figure 4.1b). During March 1993, the Tennessee Valley received the equivalent of 5.4 inches (137 mm) of rain, much of this during the "Winter Snow Storm of the Century" when many areas received record amounts (greater than 20 inches [about 500 mm]) of snowfall.

The unusually persistent hot weather and below average rainfall in the summer was related to an unusual upper air pattern, which kept the storm track well west and north of the region and allowed very few cold fronts to reach the Tennessee Valley. This nearly stationary position of a strong upper air trough over the Rocky Mountains was associated with the record flooding in the middle of the country and kept the Southeast hot and dry. This general pattern was most persistent in the summer, but frequently alternated with a pattern having an upper trough over or to the east of the Valley in the other seasons. This latter trough kept most storms associated with it to the south of the TVA region. These two upper air patterns dominated the weather during 1993, so significant rainfall events tended to occur only when there was a transition period between one and the other.

4.3 Streamflow

Streamflow varies seasonally with rainfall, although during the spring and summer evaporation and transpiration also significantly reduce the amount of runoff. Watersheds that receive 50 to 60 inches (1270 to 1524 mm) of precipitation annually average about 20 to 30 inches (508 to 762 mm) of runoff. In a normal year, the discharge of the Tennessee River (approximately 66,000 cfs [1868 $meters^3$/second]) corresponds to about 22 inches (about 560 mm) of runoff distributed over the 40,900 square mile (105,930 square kilometer) drainage basin. A larger amount of runoff occurs during the wet winter and spring months (January-April) when precipitation events are frequent, temperatures are low, and there are no leaves on deciduous vegetation. Consequently, soil absorption, evaporation, and plant transpiration losses are low at that time of year, and both runoff and streamflow are higher than during the summer and autumn months. Average rainfall in the eastern and western portions of the Tennessee Valley (above and below Chattanooga) is about equal. However, topographic differences (viz. the largely steep and mountainous terrain in the eastern portion of the Valley, compared with the mostly flat and rolling terrain in the western portion of the Valley) and generally shallower soils result in higher amounts of runoff above Chattanooga.

In 1993, runoff for the Tennessee River basin was well below normal, particularly from February through July and particularly in the western half of the Valley. Runoff above Chattanooga was only slightly below normal in 1993, 21.4 inches, or 92 percent of the long-term mean of 23.4 inches. However, runoff above Kentucky Dam was only 17.6 inches, a deficit of almost 5 inches and only 78 percent of the long-term mean of 22.5 inches (Figure 4.1c.). Table 4.1 shows that the 1993 releases from tributary reservoirs in the western part of the Valley (e.g., Normandy, Tims Ford, etc.) were below their long-term means, while the releases from tributary reservoirs in the eastern part of the Valley (e.g., South Holston, Watauga, etc.) were close to normal. Consequently, flows in the Tennessee River in 1993 increasingly fell below the long-term average as the river flowed downstream from Fort Loudoun Dam to Kentucky Dam.

Figure 4.2 presents the relative contributions of streamflow based on long term averages from major tributaries and local inflows to each of the mainstem Tennessee River reservoirs. The flow through each mainstem reservoir is dominated by the inflow from the immediately adjacent upstream reservoir. However, several large tributaries (e.g., Hiwassee River, Elk River, Duck River) do provide substantial inputs to a few mainstem reservoirs, and consequently can have a significant impact on water quality, depending on the volume and chemical quality of the inflows.

FIGURE 4.1 Temperature, Precipitation, and Runoff – Tennessee River Basin, 1993

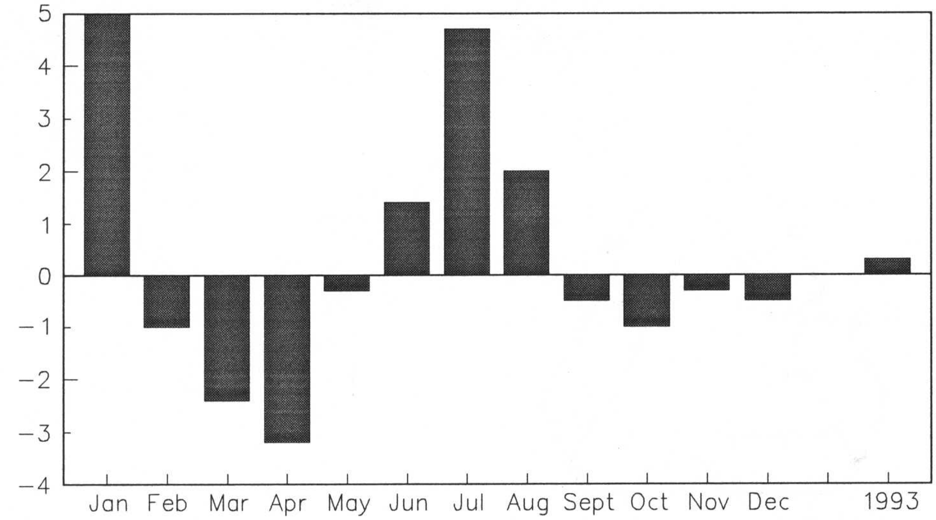


FIGURE 4.1a. Temperature Departures From Long–Term Mean (deg F) in the TVA Region

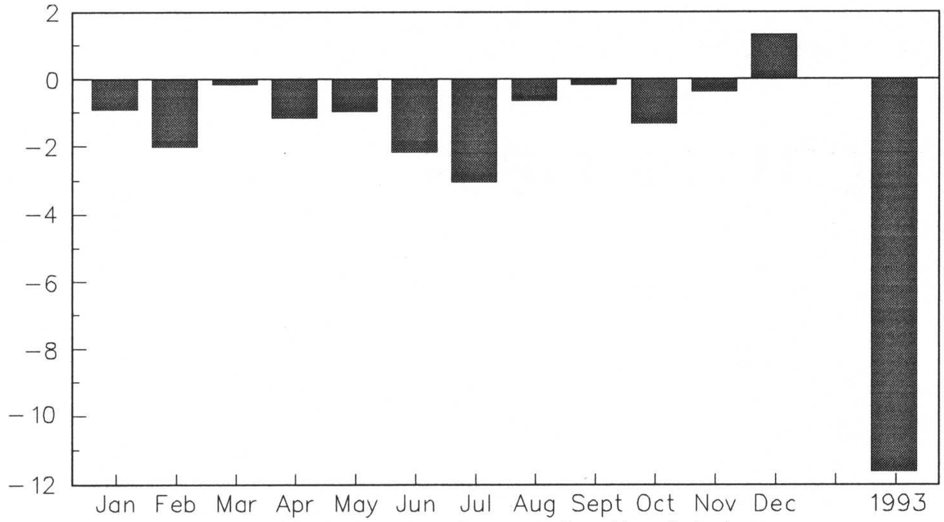


FIGURE 4.1b. Precipitation Departures From Long–Term Mean (Inches)
For The Tennessee River Basin

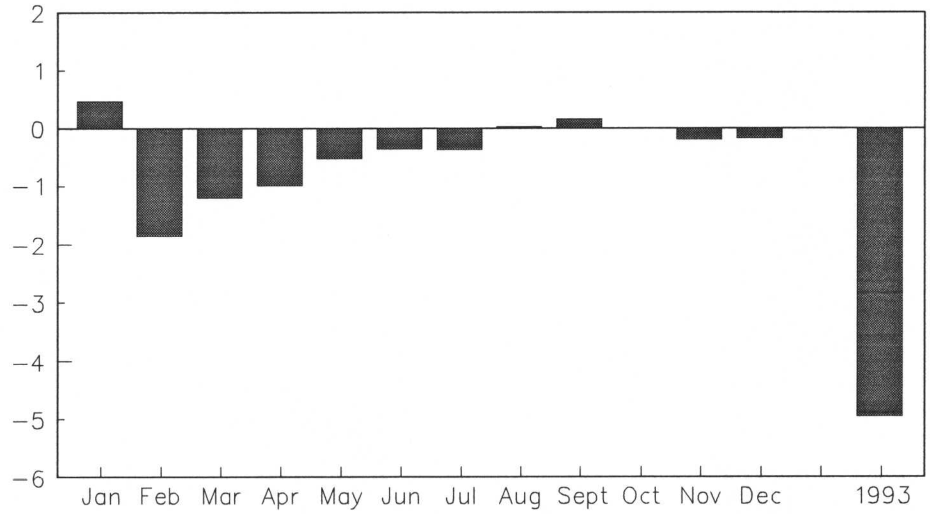


FIGURE 4.1c. Runoff Departures From Long–Term Mean (Inches)
For Tennessee River Basin, Above Kentucky Dam

Figure 4.2 Average Annual Tennessee River Flows Showing Contributions of Major Tributaries and Local Inflows.

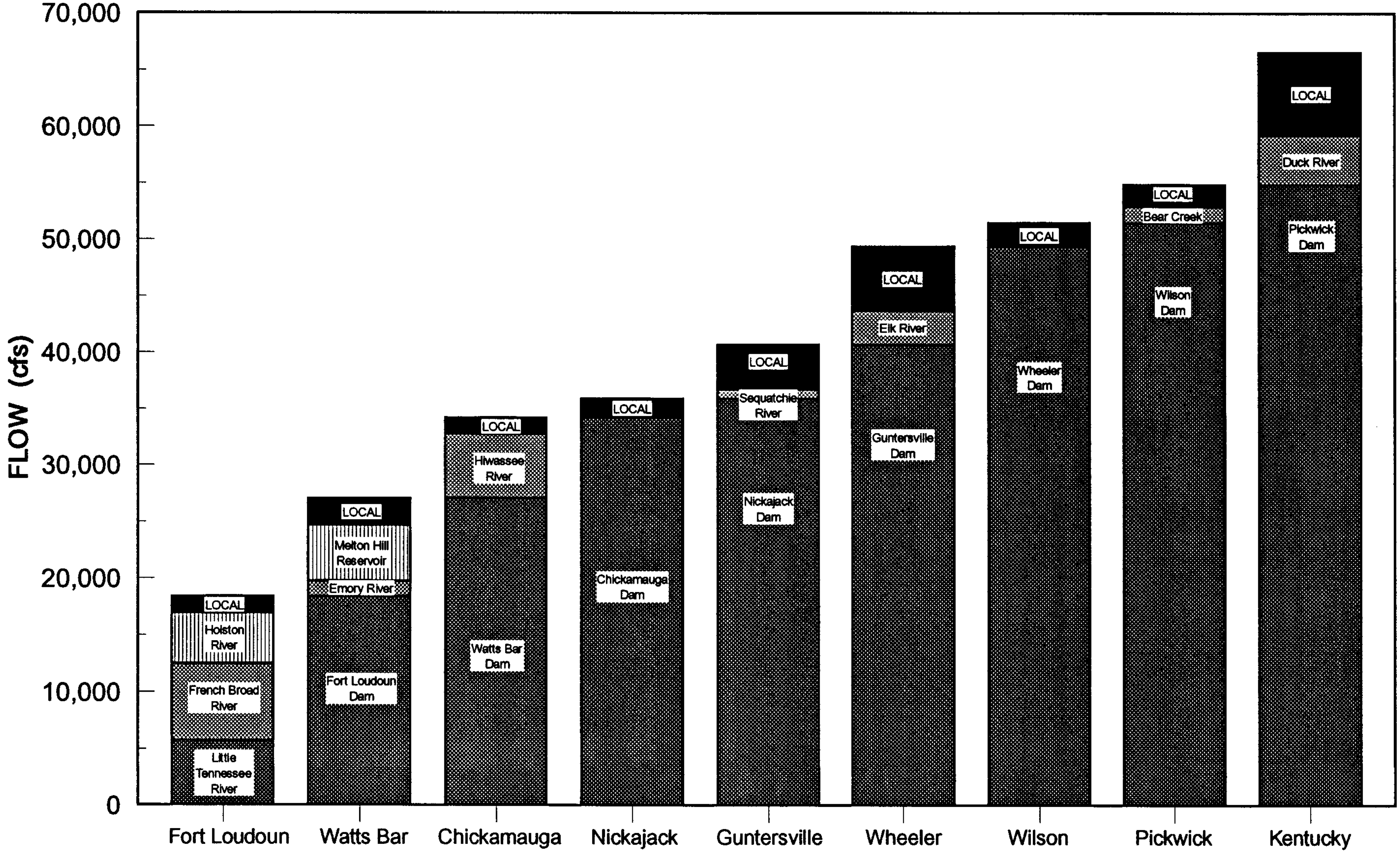


Table 4.1

CHARACTERISTICS OF VITAL SIGNS RESERVOIRS

Reservoir Name	Drainage Area (sq. miles)	Reservoir Length[a] (miles)	Surface Area[a] (acres) 1000's	Depth at Dam[a] (ft)	Volume[a] (ac-ft) 1000's	Average Annual Drawdown[b] (ft)	Average Reservoir Flow-POR (cfs)	Average Hydraulic Residence Time-1993[a] (days)	CY 1993 Reservoir Flow (cfs)
				Run-of-the-River Reservoirs					
Kentucky	40,200	184.3	160.3	88	2,839	5	66,600	27.5	52,097
Pickwick	32,820	52.7	43.1	84	924	6	54,900	9.6	48,566
Wilson	30,750	15.5	15.5	108	634	3	51,500	6.8	47,236
Wheeler	29,590	74.1	67.1	66	1,050	6	49,400	11.4	46,264
Guntersville	24,450	75.7	67.9	65	1,018	2	40,700	12.9	39,691
Nickajack	21,870	46.3	10.4	60	241	0	35,900	3.6	34,092
Chickamauga	20,790	58.9	35.4	83	628	7	34,200	9.6	32,887
Watts Bar	17,300	72.0/24.0[c]	39.0	105	1,010	6	27,100	19.5	26,145
Fort Loudoun	9,550	50.0	14.6	94	363	6	18,400	9.7	18,897
Melton Hill	3,343	44.0	5.7	69	120	0	4,920	12.7	4,764
Tellico	2,627	33.2	16.5	80	415	6	6,300[d]	34.0	6,159[d]
				Tributary, Storage Reservoirs					
Norris	2,912	73.0/53.0[c]	34.2	202	2,040	32	4,190	249.4	4,124
Cherokee	3,428	54.0	30.3	163	1,481	28	4,460	162.2	4,604
Douglas	4,541	43.1	30.4	127	1,408	48	6,780	109.4	6,490
Ft Patrick Henry	1,903	10.4	0.9	81	27	0	2,650	5.6	2,423
Boone	1,840	17.4/15.3[c]	4.3	129	189	25	2,550	38.5	2,477
South Holston	703	23.7	7.6	239	658	33	976	341.3	972
Watauga	468	16.3	6.4	274	569	26	714	403.5	711
Fontana	1,571	29.0	10.6	460	1,420	64	3,840	173.5	4,126
Hiwassee	968	22.2	6.1	255	422	45	2,020	98.8	2,154
Chatuge	189	13.0	7.0	124	234	10	459	291.3	405
Nottely	214	20.2	4.2	167	170	24	416	228.0	376
Ocoee #1 (Parksville)	595	7.5	1.9	115	85	7	1,420	33.1	1,296
Blue Ridge	232	11.0	3.3	156	193	36	614	156.2	623
Tims Ford	529	34.2	10.6	143	530	12	940	328.7	813
Bear Creek	232	16.0	0.7	74	10	11[e]	380	14.4	337
Cedar Creek	179	9.0	4.2	79	94	14[e]	282	185.7	255
Little Bear Creek	61	7.1	1.6	82	45	12[e]	101	253.9	90
Beech	16	5.3	0.9	32	11	1[e]	14	616.2	9
Normandy	195	17.0	3.2	83	110	11	320	201.7	275

[a] Measurements based on normal maximum pool.
[b] Tennessee River and Reservoir System Operation and Planning Review, Final EIS, TVA/RDG/EQS-91/1, 1990.
[c] Major/minor arms of reservoir.
[d] Estimated flow based on releases from Chilhowee Dam (POR avg. = 4770cfs), and adjusted based on the additional drainage area between Chilhowee Dam (1977 sq miles) and Tellico Dam (2627 sq miles).
[e] Estimated based on difference between normal maximum summer pool and average minimum winter pool elevations.

5.0 DISCUSSION

The quality of water in a river system is a result of the quality of water flowing into it from many sources (e.g., tributary streams, discharges from metropolitan areas, overland runoff) and the internal physical, chemical, and biological processes which occur within the river. The water quality of major tributaries to a river is governed by geologic characteristics, rainfall, and human activities within the watershed.

The Tennessee River originates with the confluence of the French Broad and Holston Rivers at Knoxville, Tennessee. It receives water from a variety of tributaries reflecting the geochemical characteristics of the watersheds they drain. For example, the French Broad and Holston Rivers are nutrient-rich and moderately hard, with greater hardness in the Holston; the Little Tennessee and Hiwassee Rivers are soft and nutrient-poor; the Clinch River is hard with moderate nutrients; while the other two large tributaries, the Elk and Duck Rivers, are relatively hard and nutrient-rich.

Each tributary exerts its influence based on a wide variety of factors, but primarily the volume of inflow and concentrations of various chemical constituents. Nutrient levels are particularly important because of their direct influences on algal primary production and indirect influences on dissolved oxygen.

Just as the characteristics of the Tennessee River are a composite of its major tributaries, each major tributary has characteristics of its tributaries. Given the widely varying geochemical attributes and many different types of land use within a watershed, characteristics of streams and reservoirs vary greatly among major tributary watersheds. These characteristics are further influenced by the location, design, and operation of dams on streams in the watershed.

This report summarizes results and conclusions from 1993 monitoring activities in the Tennessee Valley. This chapter (Chapter 5) examines these results from a Valley-wide perspective. Chapters 6-17 present a watershed-by-watershed perspective for each of 12 delineated drainages that together comprise the Tennessee Valley. Volume II of this report is a detailed summary of the 1993 monitoring results in each of these 12 watershed areas.

5.1 Vital Signs Monitoring

5.1.1 Reservoirs

Reservoirs were divided into two categories for comparative purposes: run-of-the-river reservoirs (the nine mainstream reservoirs plus the two navigable tributary reservoirs) and the 19 tributary storage reservoirs. The primary differences between these two categories are retention time and changes in pool level due to winter drawdown; both have a great effect on the aquatic ecosystem. For comparative purposes, all reservoirs were categorized as good, fair, or poor based on their respective ecological health evaluations.

Run-Of-The-River Reservoirs--The ecological health of all 11 run-of-the-river reservoirs rated fair or better in 1993. The score for Fort Loudoun Reservoir (58 percent) was the lowest of the run-of-the-river reservoirs. This score fell just within the fair range; but low enough to be considered poor-fair. Three reservoirs rated fair - Tellico (63 percent), Watts Bar (68 percent) and Melton Hill (68 percent); four rated good - Nickajack (88 percent), Chickamauga (83 percent), Guntersville (78 percent), and Kentucky (75 percent); and the remaining three reservoirs fell close to the break point used to separate good and fair reservoirs ($\geq$72 percent) - Pickwick (73 percent), Wheeler (72 percent), and Wilson (71 percent).

Figure 5.1 shows an interesting geographical trend to these results. Reservoirs with the lowest scores were at the upstream end of the Tennessee River, followed by reservoirs with the highest scores, and then reservoirs with intermediate scores in the downstream portion of the Tennessee River. There are many factors which in combination result in the observed ecological conditions, and care must be taken not to oversimplify complex ecosystem dynamics. However, one obvious consideration would be the nutrient rich waters from the French Broad and Holston Rivers, coupled with high human population densities in east Tennessee. Together, these create a high potential for undesirable ecological conditions to exist in the upper Tennessee River. Inputs of fairly pristine waters from the Little Tennessee River, further supplemented by inflows from Hiwassee River with low nutrients further downstream, act to dilute the water in the Tennessee River and help diminish the potential for eutrophic conditions in Chickamauga, Nickajack, and Guntersville Reservoirs. In the lower half of the Tennessee River, water naturally rich in nutrients flows from the Elk River to Wheeler Reservoir and from the Duck River to Kentucky Reservoir, stimulating algal growth and potentially shifting ecological conditions toward a more productive state.

The four reservoirs with the lowest ecological health scores (Fort Loudoun, Tellico, Melton Hill, and Watts Bar) had multiple indicators that rated poor or very poor. These were generally dissolved oxygen, sediment, benthos, and/or fish assemblage. For the three reservoirs which scored good (Chickamauga, Nickajack, and Guntersville), all ecological health indicators rated fair or better, except for dissolved oxygen at the inflows to Nickajack and Guntersville Reservoirs. Scores for the next four reservoirs which scored fair to good (Wheeler, Wilson, Pickwick, and Kentucky) varied greatly depending upon the number and location of sample sites within the reservoir. Indicator ratings at sample sites on the Tennessee River portion of each reservoir (i.e., the main body of the reservoir) were fair or better, except for dissolved oxygen at the Wheeler and Wilson forebays. Sample sites in major embayments generally had several indicators with poor or very poor ratings.

Embayments were not monitored prior to 1993. Four of the largest embayments in the Tennessee Valley were included in 1993 monitoring activities--Big Sandy River embayment on Kentucky Reservoir, Bear Creek embayment on Pickwick Reservoir, Elk River embayment on Wheeler Reservoir, and Hiwassee River embayment on Chickamauga Reservoir. All four embayments have surface areas of about 5000 acres (about 2000 hectares) or greater and local drainage areas greater than 500 square miles (1295 km^2). Water quality characteristics within an embayment and the resulting ecological health conditions are largely controlled by factors within the embayment's immediate watershed and the rate of water exchange between the embayment and the main body of the reservoir. The Hiwassee and Elk River embayments have substantial flow through them. The Big Sandy and Bear Creek embayments have much smaller inflows and less water exchange with the main body of the reservoir.

Results from the Hiwassee River and Elk River embayment sites substantiate the above discussion of the potential for inflows from these rivers to affect conditions in the Tennessee River. All five ecological indicators rated good or excellent in the Hiwassee embayment. Three ecological health indicators were poor or very poor, one fair and one good in the Elk River embayment.

Inclusion of monitoring results from embayments had a substantial effect on reservoir health ratings for three of the reservoirs compared to previous years. For example, Kentucky Reservoir rated good (75 percent) in 1993, lower than the 1992 rating, when Kentucky had the best rating (88 percent) of all reservoirs examined. The primary factor responsible for this decrease was addition of the sample site in Big Sandy River embayment. If results from the Big Sandy River embayment were excluded from the overall reservoir score, the revised rating (83 percent) would be

similar to that observed for 1992. Pickwick Reservoir had an ecological health rating of 73 percent for 1993. However, if the Bear Creek embayment information were deleted, the reservoir score would be 80 percent. A similar situation is true for Wheeler. The overall health rating for Wheeler would change from 72 percent to 82 percent if results from the Elk River embayment were excluded. Interestingly, the overall ecological health score for Chickamauga Reservoir would change little if results from the site in Hiwassee River embayment were excluded (i.e., 83 percent with and 81 percent without).

Another factor which lowered ecological health scores in the run-of-the-river reservoirs in 1993 was relatively low dissolved oxygen during summer 1993. Extreme summer weather in 1993 caused record high water temperatures and low DO in much of the Tennessee River. Special dam operations and water releases to reduce impacts from these conditions were started as soon as the low DO conditions were detected. Special monitoring showed these releases improved DO concentrations. However, DO concentrations were lower than in previous years causing lower scores for the overall health rating. (See Chapter 4, Hydrologic Overview of 1993, for additional detail.)

The ecological health score for one other reservoir (Tellico) changed substantially from previous years. The rating was 63 percent (fair) for 1993 compared to 48 percent in 1992 and 44 percent in 1991 (both poor). The primary causes of the higher score were better ratings for DO at the forebay (mostly the result of an improved, more accurate method of calculating the score for this indicator) and addition of information from the transition zone collection site which was relocated in 1993. The change in DO scoring resulted in forebay DO being rated fair in 1993; it had previously been rated poor. Two indicators, chlorophyll and DO, received excellent ratings at the new transition zone site; and the other three indicators rated poor. The higher ecological health score for 1993 is considered to be more representative of the true environmental conditions in Tellico Reservoir than scores in previous years.

Tributary Reservoirs--Monitoring on tributary reservoirs was not fully implemented until 1993. The number of tributary reservoirs included in Vital Signs monitoring expanded from three in 1990 to 19 in 1993. Also, the number of ecological health indicators expanded in 1993 when sediment quality and benthic macroinvertebrates were sampled for the first time on tributary reservoirs. Sample design for tributary reservoirs specifies less intensive monitoring for water chemistry constituents (most notably nutrients) than on the run-of-the-river reservoirs because of the more static nature of water within tributary reservoirs. Monitoring efforts for other ecological

indicators (chlorophyll, sediment, benthos, and fish) were the same on both run-of-the-river and tributary reservoirs for the first time in 1993.

The ecological health evaluations for the tributary reservoirs are more tentative than for the run-of-the-river reservoirs. The data base generally is quite small, and our understanding of how to weigh and integrate results from various ecological health indicators is still in development.

A problem associated with evaluating the ecological health of tributary reservoirs is the individuality of each reservoir. There is substantial variation in physical characteristics (depth, shoreline development, area, length), reservoir operations (retention time, drawdown, depth of outflow, etc.), watershed geochemistry, and land use. This individuality makes it difficult to establish reference or expected conditions, against which to rate the observed ecological characteristics as good, fair, or poor ecological health. (See Section 3.1 for additional discussion.)

Two attributes, long retention times and deep drawdowns, of tributary reservoirs particularly are significant. Long retention times create high potential for thermal and chemical stratification. As solar warming occurs in upper strata during spring and summer, bottom strata remain cold, and thermal stratification develops. If oxygen demand is sufficient, which is the typically the case, anoxia occurs in the bottom waters. Under these conditions, iron and manganese become more soluble, and their concentrations increase. If anoxia continues long enough, high levels of ammonia and sulfide also can develop. These conditions cause stresses to aquatic life and result in low ecological health ratings.

Deep drawdowns of the pool during winter, sometimes below the elevation of the summer thermocline, also have a pronounced effect on aquatic systems of tributary reservoirs. For example: (1) stable shoreline habitats cannot develop or persist; (2) benthic substrates in upper riverine reaches of the reservoir can be covered with sand and silt when the reservoir is full but be washed to gravel or bedrock when the area returns to a riverine environment at winter, low pool elevations; and (3) spring spawning sites can be left dry or covered with many feet of water depending upon dam operations during spring filling. Again, these have undesirable ecological effects.

Considering these factors, the ecological health of tributary reservoirs is not expected to be as good as run-of-the-river reservoirs. Results for 1993 support this expectation. No tributary reservoir rated good for ecological health, and only two rated fair-to-good. Both Fort Patrick Henry Reservoir and Blue Ridge Reservoir scored 72 percent, just at the break point used to indicate good or fair ecological health conditions. Interestingly, Fort Patrick Henry, even though a tributary reservoir, has retention time and drawdown characteristics like a run-of-the-river reservoir. Blue

Ridge Reservoir has quite low primary productivity, which, coupled with essentially a full depth withdrawal from the dam, helps prevent dissolved oxygen problems.

Only one tributary reservoir rated poor. Parksville (Ocoee No. 1) Reservoir scored 52 percent with poor scores for four of the five indicators. Dissolved oxygen had an excellent rating. This is contrary to expectations for a tributary reservoir, but this reservoir represents an unusual case. A very low oxygen demand exists in the hypolimnion due to very low primary productivity rates. The reservoir is recovering from years of pollution problems related to copper mining and industrial activities at Copperhill. A more thorough discussion of Parksville Reservoir is provided in Section 12.5. Two reservoirs (Normandy and Cedar) scored 56 percent, right at the break point between poor and fair. Dissolved oxygen was the primary problem in both cases. Of the remaining 14 reservoirs, eight rated near the middle of the fair range and six rated in the fair range just above poor (Figure 5.2).

Figure 5.2 indicates there were no geographical patterns associated with overall reservoir scores. No particular watershed had mostly high scoring or low scoring reservoirs. Also, physical characteristics such as size or depth seemed to have little influence on reservoir score.

The ecological health indicator which was most often associated with low ecological health scores was DO. As discussed above, this was expected. Poor or very poor DO scores occurred at one or more sample sites in 13 of the 19 tributary reservoirs sampled. All six tributary reservoirs in the middle and western part of the Tennessee Valley were in this group, along with seven of the 13 tributary reservoirs in the eastern, mountainous area of the Valley. The six reservoirs in the middle and western end of the Valley (Tims Ford, Normandy, Bear Creek, Little Bear Creek, Cedar Creek, and Beech Creek) exhibit strong thermal stratification, generally have high chlorophyll concentrations, and have substantial agriculture activities in their watersheds. The seven in the eastern end of the Valley vary greatly in a number of characteristics. Of these, four (Norris, Douglas, Cherokee, and Nottely Reservoirs) had all or mostly very poor DO ratings, followed by South Holston with one very poor rating and Boone and Fontana with only one poor rating and no very poor ratings.

Of the six reservoirs with fair, good, or excellent DO scores, two were in the Holston watershed (Fort Patrick Henry and Watauga), and four were in the Hiwassee watershed (Hiwassee, Chatuge, Blue Ridge, and Parksville). All except Fort Patrick Henry had relatively low nutrient and chlorophyll concentrations (most with seasonal chlorophyll averages below 3.0 μg/L). Although Fort Patrick Henry had high chlorophyll values, lack of stratification and short retention time helped maintain good DO concentrations.

In most cases, reservoirs with poor DO concentrations would be expected to have poor benthic macroinvertebrate communities. This was true for seven of the 13 reservoirs with DO problems. Interestingly, the remaining six reservoirs with poor DO had fair, good, or even excellent benthos scores. Norris and Cherokee Reservoirs in east Tennessee and Little Bear Creek, Cedar Creek, and Beech Creek Reservoirs in the western end of the Valley had very poor DO scores, yet fair benthic macroinvertebrate communities. Bear Creek, also in the western end of the Valley, had a very poor DO score yet an excellent benthos score. These results and their potential implications are difficult to interpret with only one year of benthic macroinvertebrate data available. Additional monitoring results should help clarify these results. An initial interpretation is that the benthic community is able to recover quickly between autumn reoxygenation of bottom sediments and sample collection the following spring. Another possibility is that some of the samples collected along the transect were above the oxygen-stressed stratum. Results from individual samples suggest both factors may have contributed to the observed ratings.

Just as reservoirs with poor DO ratings typically would be expected to have poor benthos, reservoirs with good DO levels would be expected to have a good benthos community, unless some other factor was negatively influencing the benthos. This was the case on Watauga, Hiwassee, and Parksville Reservoirs. All had fair to excellent DO scores yet all had poor or very poor benthic macroinvertebrate communities. Poor scores for Parksville Reservoir were not surprising, given the problems that reservoir has experienced over the years from upstream mining activities. Results for the other two reservoirs were unexpected. Acute toxicity to at least one test animal was observed in all three reservoirs. More detailed assessment efforts would be required to determine whether there is a real relationship between the apparent toxicity and poor benthic communities. Results from additional monitoring in 1994 will be examined closely to determine whether more detailed assessments should be planned.

5.1.2 Streams

Twelve of the major Tennessee River tributaries were included in Vital Signs Stream Monitoring in 1993 (Table 2.2). Six additional streams will be monitored beginning in 1994.

Results for 1993 showed a wide range of ecological conditions among the 12 streams. Three, Clinch, Powell, and Little Tennessee Rivers, had the highest possible scores for all four ecological health indicators (nutrients, sediment, benthic macroinvertebrates, and fish community).

The lowest score (50 percent) was for the French Broad River where nutrients and fish rated poor, benthos rated fair, and sediments rated good.

Scores for the remaining eight streams were evenly distributed within this range. The Emory and Hiwassee Rivers had good overall scores (90 and 88 percent, respectively) with fair ratings for benthos, the only indicator rating less than the maximum score at each stream. The Nolichucky and Sequatchie Rivers also rated good with scores of 80 percent each. At both streams, two indicators rated good and two fair. Three streams rated fair (Duck River-70 percent, Bear Creek-70 percent, and Holston River-68 percent). High nutrient concentrations on the Duck and Holston Rivers caused a poor rating for nutrients; the other three indicators rated fair or good. The lower score for Bear Creek was due to most indicators rating fair, rather than due to any indicator rating poor. Ratings for the remaining stream, Elk River, must be used conservatively because only three indicators were monitored in 1993. The fish community was not sampled in 1993. The overall score for the other indicators was 60 percent; nutrients rated poor, benthos fair, and sediment good. The fish community will be sampled in 1994.

The ecological health indicator that rated poor most often was nutrients. Four streams (Duck, Elk, Holston, and French Broad Rivers) received poor ratings for nutrients. Bear Creek and the Nolichucky River received a fair rating for nutrients and the remaining six streams rated good. All of these results were expected based on individual watershed characteristics.

5.2 Use Suitability Monitoring

5.2.1 Bacteriological Studies

Fifty-nine designated swimming beaches, 12 informal swimming areas, and 14 canoe launching or landing sites were sampled in 1993. All of the designated swimming beaches and informal swimming areas and eight of the canoe access sites met the regulatory criterion of having geometric mean concentrations of fecal coliform bacteria less than 200/100 mL if rainfall samples were excluded. Two swimming beaches, one each on Tims Ford and Watts Bar Reservoirs, and the canoe site sampled on the Elk River, slightly exceeded the criterion when rainfall samples were included. The four access sites on the Duck River exceeded the geometric mean criterion for both rainfall and nonrainfall samples.

Thirty-five nonrecreation sites were also sampled to provide generic bacteriological water quality data on Wilson, Guntersville, Nickajack, Fort Loudoun, Norris, Douglas, Cherokee, Fort Patrick Henry, Boone, South Holston, and Watauga Reservoirs; four sites were sampled on the

Duck, Clinch, and South Holston Rivers; and three sites on Spring, Beidleman, and Thomas Creeks. All but one reservoir site (Nickajack) and two stream sites (Beidleman and Thomas Creeks) met recreation criteria.

A comparison of the results of this survey with surveys in 1974, 1986, and 1989 through 1992 shows bacteria concentrations in 1974 and 1993 were similar, and lower than during the other years. The differences are probably caused by different weather conditions and sampling methods rather than reflecting long-term changes in bacteriological water quality.

Fecal coliform samples were taken in conjunction with Vital Signs monitoring activities on the 11 run-of-the-river reservoirs from April through September 1993. Fifteen of the 155 samples analyzed had concentrations greater than the normal detection limit of 10/100 mL, seven exceeded 100/100 mL. No location had more than one sample exceed 100/100 mL.

The results of studies summarized above are consistent with previous surveys. Fecal coliform concentrations were generally lower in 1993 due to lower than normal summer rainfall. Bacteriological water quality in most areas of TVA reservoirs is good. In streams it is much poorer, especially after rainfall.

5.2.2 Fish Tissue Studies

Availability of results for fish tissue studies is usually delayed because of the intricate laboratory procedures required to analyze fish tissue samples. This process usually takes several months; so results for samples collected in autumn usually are not available until the next spring. Results in this report are for fish collected during summer and autumn 1992. Additional fish were collected in summer and autumn 1993 but results were not available in time to be included in this report.

Screening Studies--Results of screening studies in 1992 did not indicate any new reservoirs or streams in need of intensive investigations. Two streams and six reservoirs had at least one analyte slightly elevated indicating a need to resample in autumn 1993 at the screening level. Streams included the Emory River (PCB concentration in channel catfish 1.1 μg/g) and the Holston River (mercury concentration in largemouth bass 0.57 μg/g). Reservoirs included Pickwick (DDTr 2.5 μg/g), Bear Creek (mercury 0.45 μg/g), Little Bear Creek (mercury 0.56 μg/g), Norris (PCBs 0.9 μg/g), Fontana (PCBs 1.1 μg/g and mercury 0.53 μg/g), and Cherokee (PCBs 0.8 μg/g). Although most reservoirs had multiple sites sampled, an elevated concentration of an analyte at any site would cause that reservoir to be included in this list.

All sites listed above were resampled in autumn 1993 for the same fish species. In addition, because several tributary reservoirs had somewhat elevated mercury concentrations, efforts in autumn 1993 were directed at better evaluating this condition by analyzing both channel catfish, the species typically used as the indicator, and largemouth bass, a top predator which would be expected to have higher mercury concentrations than catfish.

Intensive Studies--Six TVA reservoirs (Wheeler, Nickajack, Watts Bar, Fort Loudoun, Melton Hill, and Parksville) were examined intensively in 1992. Intensive studies are conducted on reservoirs where a contaminant problem is known or suspected. PCBs was the contaminant of interest on all these reservoirs, except Wheeler, where DDTr (total DDT) is the problem. Chlordane was also of interest in some of these reservoirs. Fish consumption advisories which recommend either limiting the quantity of fish eaten or avoiding any consumption are in effect for all six reservoirs except Parksville. These advisories issued by the Tennessee Department of Environment and Conservation and by the Alabama Department of Public Health are based in part on the results of these studies.

Results from autumn 1992 collections indicated somewhat lower concentrations of DDTr in fish from Wheeler Reservoir and PCBs in fish from Nickajack Reservoir. Lower concentrations in one year should not be interpreted as a significant decrease in contaminant concentration. Previous results have shown substantial year-to-year variability. The long-term study on Watts Bar Reservoir identified substantially lower PCB concentrations in 1989 and 1990 than in previous years. Subsequent results for 1991 and 1992 returned to the higher concentrations of previous years. For this reason, comparable studies were repeated on these reservoirs in autumn 1993.

Results of 1992 fish tissue samples from Watts Bar, Fort Loudoun, and Melton Hill Reservoirs generally fell within the range observed in previous years. Likewise, limited results for Tellico Reservoir fell within historical ranges.

Screening studies on Parksville (Ocoee No. 1) Reservoir over the past several years have found PCB concentrations near the level used by the state of Tennessee to issue a "Limit Consumption" advisory. As a result, TVA and the state designed and conducted a more detailed sampling of fish from there in autumn 1992. Results of the 1992 effort confirmed previous results of relatively high PCB concentrations in channel catfish - the average of ten fish was 1.5 $\mu g/g$ at the forebay and 1.0 $\mu g/g$ at an upper reservoir location. Largemouth bass were also examined and found to have lower concentrations than catfish--averages at the two sites were 0.6 and 0.7 $\mu g/g$,

respectively. Bluegill sunfish and rainbow trout composites from these areas had low concentrations. There had been no action taken on these results at the time this report was prepared.

Figure 5.1 Overall Ecological Health of Run-of-the-River Reservoirs in the Tennessee Valley in 1993. (Ecological Health Indicators are shown as a proportion of their contribution to the overall score for each reservoir.)

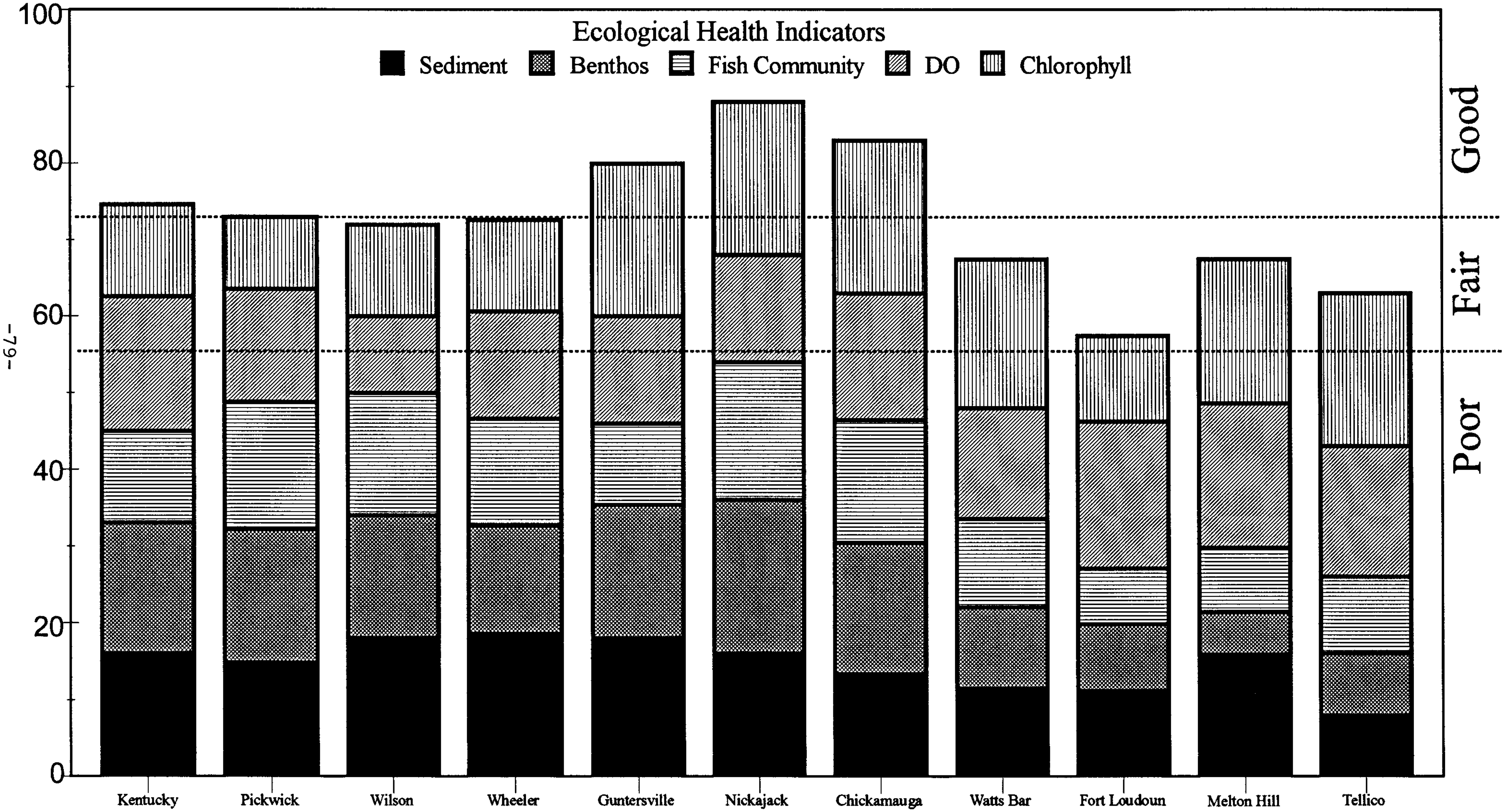
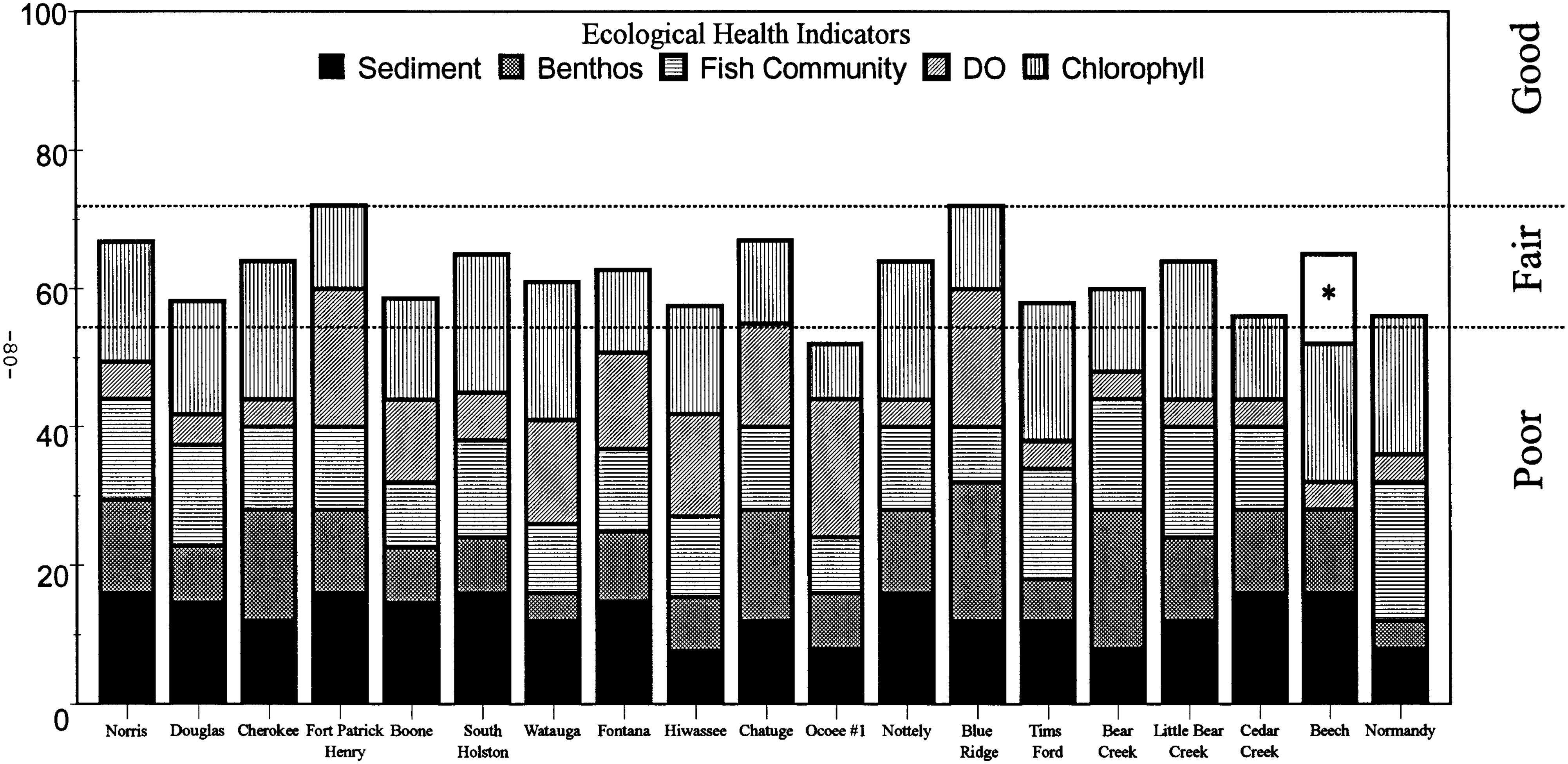


Figure 5.2 Overall Ecological Health of Tributary Reservoirs in the Tennessee Valley in 1993.

(Ecological Health Indicators are shown as a proportion of their contribution to the overall score for each reservoir.)



* Beech Reservoir score is based on four rather than five indicators; indicator and overall scores are shown on the same scale as other reservoirs to facilitate comparisons.

6.0 KENTUCKY RESERVOIR WATERSHED

The Kentucky Reservoir watershed area includes all streams flowing into the Tennessee River downstream of Pickwick Landing Dam at Tennessee River mile (TRM) 206.7 to the confluence of the Tennessee River with the Ohio River. The one exception is the Duck River which is considered a separate watershed. The Kentucky Reservoir watershed area is relatively large (4590 square miles) and has an average annual discharge of about 66,600 cfs. Of that, about 82 percent (54,000 cfs) comes into Kentucky Reservoir from Pickwick Landing Dam. The Duck River supplies about 6 percent (4075 cfs), with the remaining 11 percent coming from local inflows.

Kentucky Reservoir is the dominant feature of this watershed. There are four monitoring sites on Kentucky Reservoir--forebay, transition zone, inflow, and Big Sandy River embayment (Figure 6.1 and Table 2.1). Information from 1993 monitoring activities on Kentucky Reservoir is provided in Section 6.1.

The watershed also includes the seven small reservoirs on the Beech River. The largest, Beech Reservoir, is the only one included in Vital Signs monitoring. Given its small size, the forebay is the only site monitored (Figure 6.1). Monitoring information for Beech Reservoir for 1993 is in Section 6.2.

There were no stream monitoring sites in this watershed in 1993. Beginning in 1994, a site will be established on the Clarks River for monitoring biological conditions.

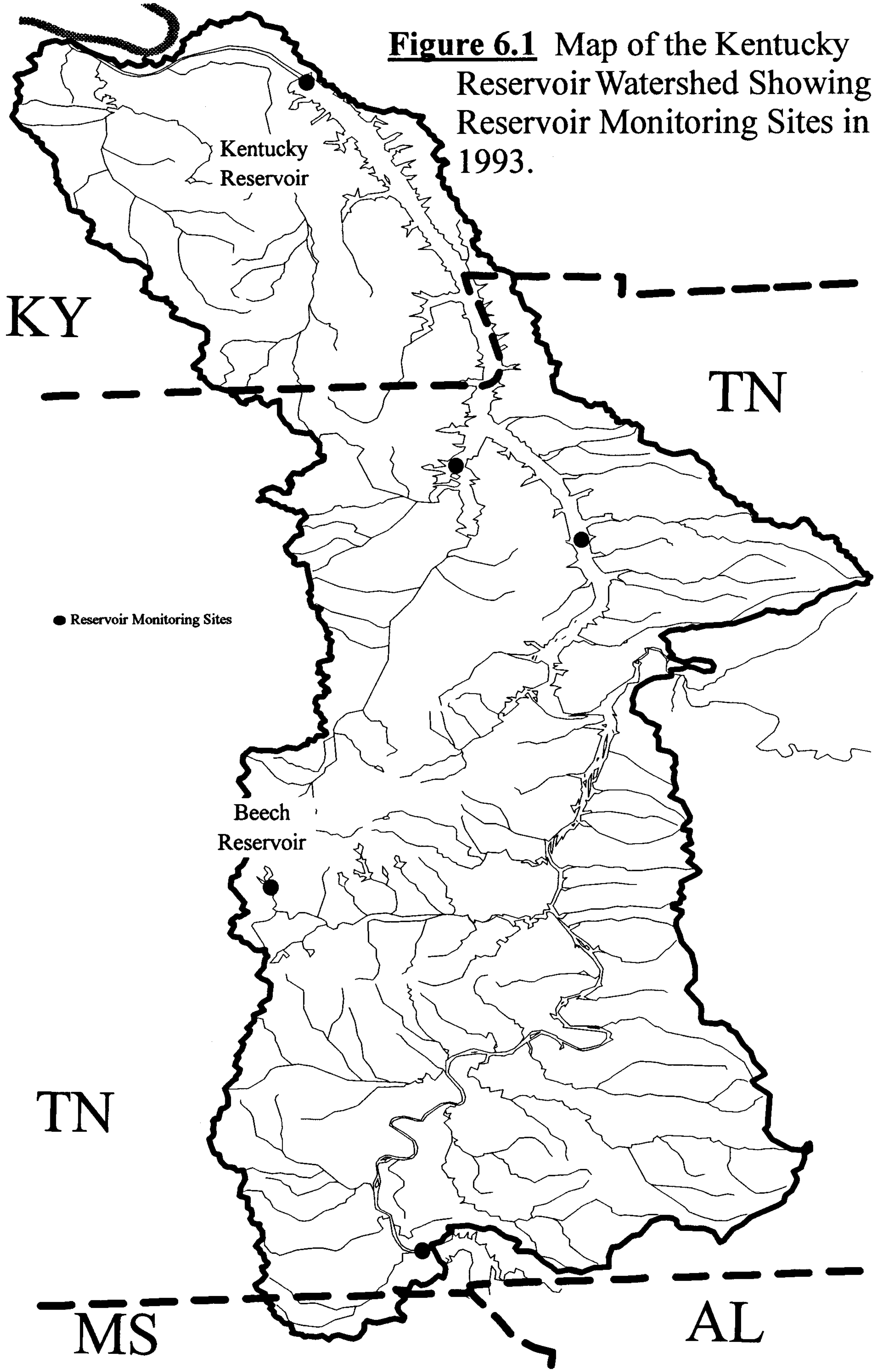


Figure 6.1 Map of the Kentucky Reservoir Watershed Showing Reservoir Monitoring Sites in 1993.

6.1 Kentucky Reservoir

Physical Description

Kentucky Reservoir is the largest reservoir on the Tennessee River. The dam is located at Tennessee River Mile (TRM) 22.4, and the reservoir extends 184 miles upstream to Pickwick Dam at TRM 206.7. At full pool the surface area is 160,300 acres, and the shoreline is 2280 miles. Average annual discharge is about 66,600 cfs, which provides an average hydraulic retention time of about 22 days. Additional information about Kentucky Reservoir is provided in Table 4.1.

The Duck River, a major tributary to the Tennessee River (and Kentucky Reservoir), provides about 6 percent of the total flow through Kentucky Reservoir. The confluence of the Duck River with the Tennessee River is at TRM 110.7.

The transition zone sample location was moved prior to the 1992 sample season from TRM 112.0 to TRM 85.0. Results for 1990 and 1991 at TRM 112.0 indicated that location was more representative of a riverine environment than a transition environment. The 1992 and 1993 results indicate the new transition zone site is correctly located.

Vital Signs monitoring was expanded in 1993 to include a sample site in four of the largest embayments in the Tennessee Valley. One, the Big Sandy River embayment on Kentucky Reservoir, is the largest embayment in the Tennessee Valley. It covers 15,238 surface acres and has over 93 miles of shoreline. Because its watershed is only 629 square miles, there is very little water exchange.

Ecological Health

The ecological health of Kentucky Reservoir rated good (75 percent) in 1993. This is lower than the ecological health index for 1992, when Kentucky had the best rating (88 percent) of all reservoirs examined. It is also lower than the overall rating in 1991. Primary factors responsible for this decrease were lower dissolved oxygen (DO) concentrations due to the hot, dry summer of 1993, and the addition of a sample site in Big Sandy River embayment. If results for the sample site in Big Sandy embayment were excluded from calculating the overall reservoir score, the revised rating (83 percent) would be similar to that observed for 1992.

The transition zone was the best of the four sites examined in 1993. All ecological health indicators (DO, chlorophyll-a, sediment quality, benthos, and fish) rated good or excellent at that site. The site in the Big Sandy embayment approached the other extreme. Three indicators rated poor or

very poor: chlorophyll because of high concentrations, sediment quality because of high ammonia and toxicity to test organisms, and fish assemblage because of low fish abundance and species richness. No indicators at the other two sites (forebay and inflow) rated poor or very poor.

Aquatic plants covered about 3465 acres in 1993 compared to about 2600 acres in 1992 and 2800 in 1991. Most plants were found around islands and shallow embayments downstream of the Duck River.

Reservoir Use Suitability

Use Suitability monitoring activities did not identify any impairments on Kentucky Reservoir in 1993. Twenty-four recreation sites have been sampled for fecal coliform bacteria one or more times on Kentucky Reservoir since 1989. None has exceeded the geometric mean criteria for recreation. In 1992 three sites exceeded one of EPA's recommended guidelines--more than 10 percent of the samples had fecal coliform concentrations greater than 400/100 mL. In 1993 these three sites were resampled, and all met the EPA guideline. Fecal coliform bacteria concentrations have been very low at the Vital Signs locations sampled since 1990.

Examination of channel catfish fillets in autumn 1992 from six locations between Kentucky and Pickwick Dams found only low levels of heavy metals and pesticides at all locations. The only analyte high enough to be of interest was lead at 0.6 μg/g at one location in 1992. Similar concentrations have been found sporadically in previous years, but there has been no pattern in space or time.

6.2 Beech Reservoir

Physical Description

Beech Reservoir, the largest of seven small flood control projects on the Beech River system in western Tennessee, is formed by Beech Dam at Beech River mile 35.0. Beech Reservoir is only 5.3 miles long and averages only about 12 feet deep. It has no hydropower generating facilities, but is the primary source of water for the city of Lexington. The reservoir is an urban lake with considerable residential lakefront development. Consequently, it receives a large amount of recreational use relative to its small size (about 900 acres). Discharge from Beech Dam averages only about 14 cfs per day, resulting in a long hydraulic residence times of 300 to 400 days.

Reservoir Health

During 1991 and 1992 only water quality monitoring was conducted in Beech Reservoir. The 1991 and 1992 data indicated poor ecological health in Beech Reservoir, as evidenced by very low concentrations of dissolved oxygen and high chlorophyll-a concentrations.

In 1993 four of the five ecological health indicators (algae, dissolved oxygen, sediment quality, and benthos) were sampled on Beech Reservoir. Overall, the ecological health rated fair (65 percent). Chlorophyll rated excellent (at the upper end of the mesotrophic range), below observed concentrations during 1991 and 1992. As expected, DO rated very poor. Sediment quality rated good and benthic macroinvertebrates rated fair. The fish assemblage will be added to the sampling regime in 1994.

Reservoir Use Suitability

No bacteriological studies were conducted in 1993. Fecal coliform concentrations were low at the swimming beach in 1990. There are no fish consumption advisories on Beech Reservoir. Fish tissue samples have not been collected by TVA from this reservoir.

7.0 DUCK RIVER WATERSHED

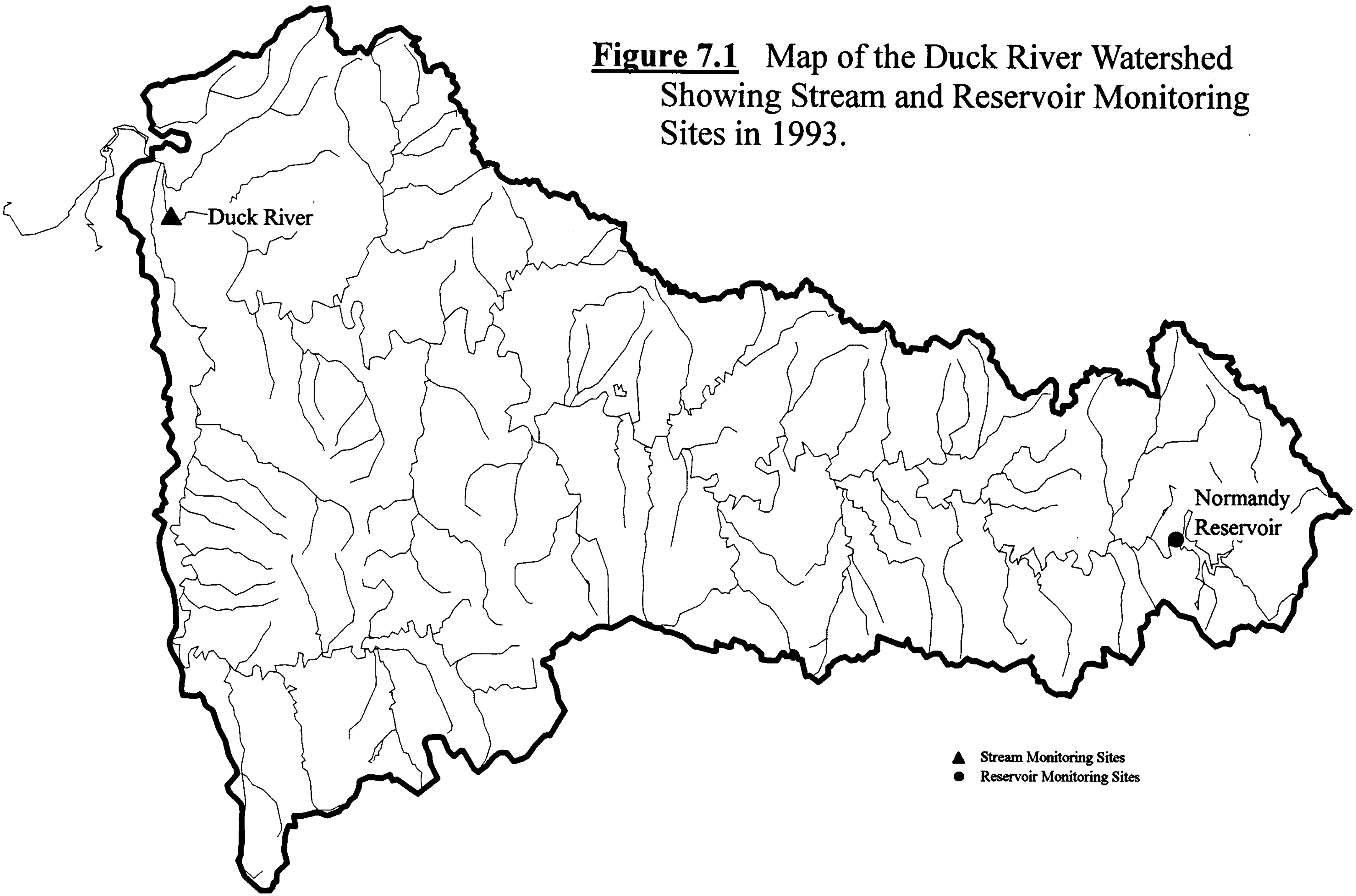
The Duck River Watershed includes all streams flowing into the Duck River. It has an area of 3500 square miles and an average annual discharge of 4075 cfs to Kentucky Reservoir on the Tennessee River. The Duck River basin is underlain almost entirely by limestone, or phosphatic limestone; consequently, waters in the streams draining this basin are fairly hard and contain large concentrations of minerals. Large deposits of phosphate ores permit phosphate mining and refining operations in the basin. Phosphate concentrations in surface and groundwater are significantly higher than in most of the Tennessee Valley. The soils are thin with limestone outcrops at the surface in many places, and sinkholes are common throughout the watershed.

Normandy Reservoir is the only reservoir in this watershed. This is a relatively small reservoir and only the forebay is included in the Vital Signs monitoring program (Figure 7.1).

There is one stream monitoring site on the Duck River at mile 26.0 (Figure 7.1).

Information from monitoring activities on Normandy Reservoir and the Duck River are in Sections 7.1 and 7.2, respectively.

Figure 7.1 Map of the Duck River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.



7.1 Normandy Reservoir

Physical Description

Normandy Reservoir is formed by Normandy Dam at Duck River mile (DRM) 248.6. Normandy Reservoir, constructed primarily for flood control and water supply, has a drainage area of 195 square miles and no electric power generation capacity. One of TVA's smaller reservoirs, Normandy at full pool elevation has about 3200 surface acres, 73 miles of shoreline, and about 17 miles of impounded backwater. The reservoir has an average depth of about 35 feet and an average annual drawdown of about 11 feet. The average annual discharge from Normandy Dam is about 320 cfs, providing an average annual retention time of about 175 days.

Ecological Health

The ecological health of Normandy Reservoir rated poor-fair (56 percent) in 1993. Vital Signs monitoring previously had not been conducted on this reservoir, although several special studies had been completed. As expected, DO conditions were among the poorest observed on any Vital Signs reservoir in 1993. DO rated very poor because anoxia existed, 77 percent of the cross-sectional bottom length had DO concentrations <2.0 mg/L, and 48 percent of the cross-sectional area had DO levels <2.0 mg/L. Sediment quality rated poor due to high levels of ammonia and toxicity to test animals. Benthic macroinvertebrates also rated very poor, likely due to such poor bottom conditions.

Based on past studies, there was concern about very high levels of primary productivity in Normandy Reservoir. Sampling in 1993 did not find this to be the case. Chlorophyll rated good at the forebay sample location because the annual average chlorophyll concentration was within the mesotrophic range, and no single sample had a very high chlorophyll concentration.

The other indicator, fish assemblage, rated excellent. Normandy Reservoir had one of the best fish assemblages examined on tributary reservoirs in 1993. Most of the 12 metrics received the highest possible score.

Reservoir Use Suitability

Fecal coliform samples were collected at two swimming beaches and three boat ramps in 1992. While concentrations were low at the boat ramps, several samples were high at each of the beaches, although the geometric means were well within recreation criteria. The two beaches were sampled again in 1993. Fecal coliform concentrations were much higher, but the geometric means

were still within criteria. Local geese populations are the probable source of the high bacteria concentrations.

There are no fish consumption advisories on Normandy Reservoir. A composite sample of channel catfish collected from the forebay in autumn 1992 was screened for pesticides, PCBs, and selected metals. All analytes were either not detected or found in only low concentrations.

7.2 Duck River Stream Monitoring Site

Physical Description

The Duck River flows westward from its headwaters in northwestern Coffee County, Tennessee, for more than 280 miles through the Nashville basin and Highland Rim physiographic provinces in middle Tennessee to meet the Tennessee River. The basin is approximately 125 miles long and 30 miles wide and drains 3500 square miles.

The stream monitoring location is at the USGS stream gage above Hurricane Mills, Tennessee. The Duck River basin above Hurricane Mills is 2557 square miles or 73 percent of the entire Duck River basin. Principal tributaries in the monitored area include the Piney River (223 square miles), Big Swan Creek (155 square miles), Lick Creek (101 square miles), and Big Bigby Creek (129 square miles) which drain the Highland Rim province; and Rutherford Creek (116 square miles), Fountain Creek (103 square miles), Big Rock Creek (121 square miles), and Garrison Fork (130 square miles) which drain the Nashville Basin. Normandy Dam forms the only major impoundment located on the upstream reach of the Duck River stream monitoring site.

A principal tributary that flows into the Duck River below the stream monitoring location is the Buffalo River that drains 764 square miles (22 percent of the Duck River basin). The Buffalo River basin lies entirely within the Highland Rim province and the streams generally contain low concentrations of dissolved minerals.

Ecological Health

The stream monitoring site on the Duck River showed generally fair ecological health in 1993, similar to 1992. This was driven by high phosphorus concentrations and fair conditions for the fish community. Sediment quality and the benthic macroinvertebrate community both rated good, an improvement over 1992 observations. Undesirable conditions at this site included extensive bank erosion and unstable bottom substrate conditions. Although the Duck contributes only about 6.5 percent of the total flow of Kentucky Reservoir under average flow conditions, it can contribute significant amounts of nutrients and sediment to the reservoir.

Use Suitability

A reach of the Duck River from 3.5 to 7.1 miles downstream of Normandy Dam was found to greatly exceed bacteriological criteria for water contact recreation in 1993, probably due to dairies.

All metal and organic analytes in fish tissue samples were not detected or found in low concentration.

8.0 PICKWICK RESERVOIR - WILSON RESERVOIR WATERSHED

Pickwick Reservoir and Wilson Reservoir on the Tennessee River are the most notable features of this drainage area. Only a small part of the flow leaving this watershed actually originates within the watershed itself. The average annual discharge from Pickwick Dam is 54,900 cfs. Of that, 49,500 cfs (90 percent) is the discharge from Wheeler Dam into Wilson Reservoir. About 2100 cfs enters Wilson Reservoir through local tributaries and about 3400 cfs originates in tributaries to Pickwick Reservoir. The streams within this watershed drain an area of about 3230 square miles. The largest tributaries are Bear Creek, a tributary to Pickwick Reservoir with a drainage area of about 945 square miles, and Shoal Creek, a tributary to Wilson Reservoir, with a drainage area of about 445 square miles.

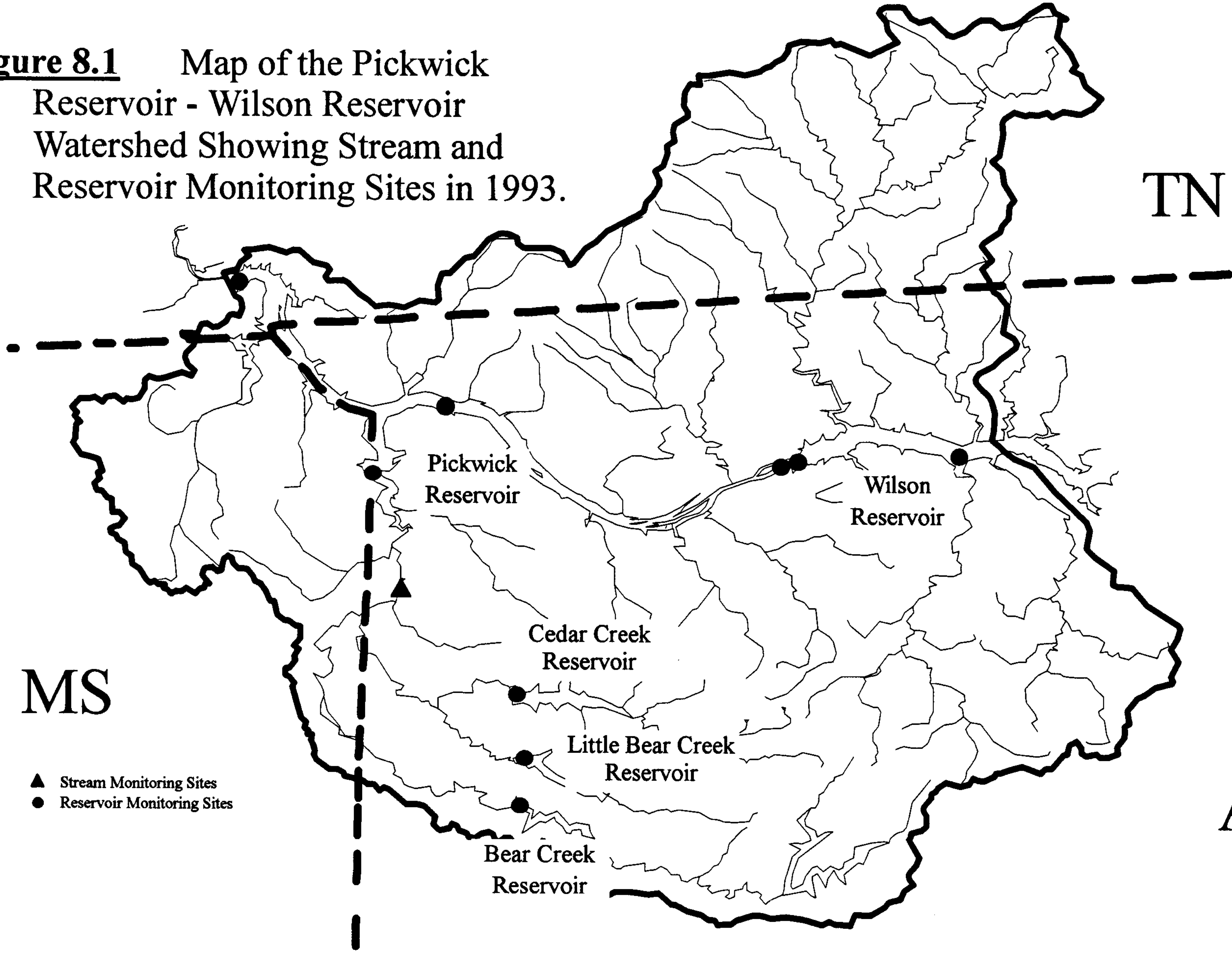
Four small reservoirs were built on Bear Creek in the late 1970s and early 1980s for flood control and recreation. These are Bear Creek, Little Bear Creek, Cedar Creek, and Upper Bear Creek Reservoirs.

Reservoir monitoring activities occur at the forebay, transition zone, and inflow on Pickwick Reservoir and at the forebay and inflow on Wilson Reservoir (Figure 8.1). Wilson is relatively short and has no definable transition zone. Because of their smaller size, only the forebays of Bear Creek, Little Bear Creek, and Cedar Creek Reservoirs are monitored. No monitoring activities are conducted on Upper Bear Creek because of TVA's program to destratify and oxygenate water in the forebay.

The only stream monitoring site is on Bear Creek at Bear Creek mile 27.3. Results for 1993 reservoir and stream monitoring activities within this watershed are provided in the following sections:

- 8.1 Pickwick Reservoir
- 8.2 Wilson Reservoir
- 8.3 Bear Creek Reservoir
- 8.4 Little Bear Creek Reservoir
- 8.5 Cedar Creek Reservoir
- 8.6 Bear Creek Stream Monitoring Site

Figure 8.1 Map of the Pickwick Reservoir - Wilson Reservoir Watershed Showing Stream and Reservoir Monitoring Sites in 1993.



8.1 Pickwick Reservoir

Physical Description

Pickwick Reservoir is immediately upstream of Kentucky Reservoir on the Tennessee River. Pickwick Dam is located at TRM 206.7. Like the rest of the mainstream, run-of-the-river reservoirs, Pickwick is much shorter (53 miles long) and smaller (43,100 acres and shoreline of 496 miles) than Kentucky Reservoir. Average annual discharge is about 55,000 cfs, which provides an average hydraulic retention time of about eight days. Additional information about reservoir characteristics is in Table 4.1.

A major tributary, Bear Creek, joins the Tennessee River in Pickwick Reservoir at about mile 225. Bear Creek provides, on the average, about 2.5 percent of the flow through Pickwick Reservoir.

Reservoir Monitoring activities were expanded on Pickwick Reservoir in 1993 to include a Vital Signs monitoring site in Bear Creek embayment. This rather large embayment (7200 acres) extends from the mouth of Bear Creek upstream about 17 miles to the point where flow is not affected by backwater from Pickwick Dam.

Ecological Health

The ecological health of Pickwick Reservoir was fair to good in 1993 (73 percent), similar to 1992 and 1991. All ecological health indicators rated between fair and excellent at all locations, except chlorophyll, which rated very poor (indicating high algal productivity) at the new sample site in Bear Creek embayment. There was a general decline in DO conditions throughout the reservoir in 1993 with DO rated fair to good at all locations. In 1992 DO was good to excellent at all locations. Summer 1993 was characterized by low rainfall, low flows, and high temperatures, hence lower DO concentrations were expected.

Conditions at the transition zone improved in 1993 for chlorophyll and sediment quality. Sediments contained lower mercury concentrations than in previous years; however, concentrations were still slightly above background. Although chlorophyll concentrations were in the fair range in 1993 (because of relatively high average concentrations), this was an improvement over 1992 when concentrations were even higher.

Benthic macroinvertebrates at the inflow location, downstream of Wilson Dam, were improved in 1993, rating excellent as compared to fair in 1992 and poor in 1991. The improvement

between 1991 and 1992 was partly due to an improved evaluation system and partly due to actual improvements in the health of the community of bottom animals. The 1993 results indicate continued improvements in the benthos.

At the forebay, the fish assemblage evaluation has shown substantial variation from year to year. The rating was good in 1991, poor in 1992 (very few fish collected), and good in 1993. Interestingly, a low number of fish were collected from this location by electrofishing in 1993, yet an abundance of fish were collected by gill netting. The 1992 rating was based only on electrofishing results, whereas the 1993 rating was based on results from both techniques. Overall, there appeared to be little change in the fish assemblage among years.

The new sample site in Bear Creek embayment had one very poor indicator (chlorophyll--too high), three fair indicators (DO--zero on bottom; sediment--toxicity to test organisms; benthos--mostly tolerant organisms present), and one good indicator (fish). Of the four sites sampled on Pickwick Reservoir in 1993, the Bear Creek embayment site had the poorest ecological health. If results for this site were deleted from calculating the overall reservoir score, the reservoir score would be 80 percent.

There were only about 105 acres of aquatic plants on Pickwick Reservoir in 1993, similar to the 100 acres in 1992.

Reservoir Use Suitability

Use Suitability monitoring did not identify bacteriological nor fish tissue contamination problems. There are no fish consumption advisories on Pickwick Reservoir based on fish collected from 1988 through 1992. Concentrations of metals, PCBs, and pesticides in composited catfish fillets were relatively low except for total DDT concentrations in the fall 1992 inflow sample. Given the rare occurrence of elevated total DDT concentrations in fish from Pickwick, it is likely that one of the catfish in the composite came from Wheeler Reservoir, which has a significant, localized DDT contamination problem. Fecal coliform bacteria concentrations were low at ten swimming areas sampled in 1993. Bacteria concentrations at the Vital Signs locations sampled since 1990 have been low.

8.2 Wilson Reservoir

Physical Description

Wilson Reservoir is quite different from other mainstream Tennessee River reservoirs in both length and depth. Wilson Dam is located at TRM 259.4 and Wheeler Dam is at TRM 274.9, providing a length of only 15.5 miles, a shoreline of 154 miles, and surface area of 15,500 acres. Water depth in the forebay is slightly over 100 feet. This short, deep pool, coupled with the largest hydroelectric generating plant in the TVA system, provides for short hydraulic retention times (six days). Average annual discharge from Wilson is 51,500 cfs. Because of the physical characteristics, design, and operation of Wilson Dam (primarily upper strata withdrawal for hydropower generation), low DO conditions develop in deeper strata of the forebay during summer months.

Ecological Health

Ecological health of Wilson Reservoir improved somewhat in 1993 compared to 1992 and 1991. Overall, Wilson Reservoir rated fair to good (71 percent) in 1993 compared to 60-70 percent in previous years. One of the persistent problems in Wilson Reservoir is low concentrations of dissolved oxygen (< 1 mg/L) in the forebay during summer months. The problem was more severe in summer 1993 due to the drought conditions (high temperatures, low rainfall, and low flows). Anoxia developed near the bottom, and a large proportion of the bottom and water column had DO concentrations < 2.0 mg/L, leading to a very poor rating.

A massive algal bloom caused extremely high chlorophyll concentrations at the forebay in 1992 resulting in a poor rating that year. Chlorophyll concentrations were lower in 1993, but still relatively high and, therefore, rated fair in 1993. The benthic macroinvertebrate community at the forebay rated better in 1993 (fair) compared to previous years (consistently poor). Poor ratings had been attributed to the low concentrations of DO near bottom during summer. Given that benthos collections were made in March 1993, prior to the severe DO problems later that summer, these samples would have been more representative of 1992 conditions. Even though DO concentrations in summer 1992 were not good, they were the best documented on Wilson since the Vital Signs monitoring program began in 1990. The duration of low DO concentrations was relatively short in 1992 and the proportion of bottom with low DO concentrations was small. These conditions may have provided sufficient opportunity for recolonization of several benthic species resulting in the improved community rating for 1993. Samples to be collected in March 1994 will help determine

whether this hypothesis is correct. If correct, the benthos rating for 1994 should be poor because of the severe DO conditions in summer 1993.

Sediment quality at the forebay was good in 1992 and 1993, indicating no impairment due to bottom substrates. This was an improvement over 1991 when fair sediment quality conditions were found due to lower survival rates for test organisms. All ecological health indicators measured at the inflow location (DO, fish, and benthos) were good or excellent in 1993.

There were only 54 acres of aquatic plants on Wilson Reservoir in 1993.

Reservoir Use Suitability

There are no fish consumption advisories on Wilson Reservoir based on fish tissue studies conducted over the past several years.

Fecal coliform bacteria concentrations were very low at the two boat ramps tested in 1993 and at the Vital Signs location in the forebay. The low rainfall in 1993 may have contributed to low concentrations at the boat ramps. All fecal coliform samples collected in the forebay since 1990 have been low.

8.3 Bear Creek Reservoir

Physical Description

With a surface of only 700 acres, Bear Creek is one of the smallest reservoirs in the TVA system. It is relatively long (16 miles), narrow, and deep (74 feet at the dam). The average annual discharge is 380 cfs providing an average hydraulic retention time of about 13 days. Average annual drawdown is about 11 feet. Bear Creek Reservoir stratifies in the summer and develops hypolimnetic anoxia. Another water quality concern is abandoned strip mines in the watershed.

Ecological Health

The ecological health of Bear Creek Reservoir rated fair (60 percent) in 1993. Vital Signs monitoring previously had not been conducted on this reservoir. This reservoir appears to have a high rate of primary productivity and significant hypolimnetic DO depletion. Summer chlorophyll concentrations were higher on Bear Creek Reservoir than on any of the other tributary reservoirs monitored in 1993. Only one of the five indicators (benthic macroinvertebrates) rated excellent and one rated good (fish). Such high ratings would not be expected given the very poor rating for DO (anoxia and large proportion of the water column with low DO concentrations) and poor rating for sediment quality (high ammonia and toxicity to test animals). Continued monitoring in future years will help to better define the ecological health of Bear Creek Reservoir.

Use Suitability

Fecal coliform bacteria concentrations were low at both of the swimming areas surveyed in 1993. The low rainfall in 1993 may have contributed to low concentrations. During a wetter period in 1991, fecal coliform concentrations were higher, but still well within water quality criteria for recreation. A single composite of channel catfish was collected from the forebay in autumn 1992. All metal and organic analytes were low or not detected, except for mercury which was high enough to warrant reexamination in autumn 1993 but not high enough to indicate a need for an in-depth, intensive study.

8.4 Little Bear Creek Reservoir

Physical Description

Little Bear Creek Reservoir is relatively short (7.1 miles long) and deep (84 feet at the dam). It has a surface area of 1600 acres. With an average annual discharge of 101 cfs, the hydraulic retention time is 225 days. Compared to Bear Creek Reservoir, the lower flow into the reservoir and larger reservoir volume make the retention time much longer in Little Bear Creek Reservoir. Average annual drawdown is about 12 feet.

Ecological Health

Little Bear Creek Reservoir had a fair (64 percent) ecological health rating in 1993. This was the first year for Vital Signs monitoring on Little Bear Creek Reservoir. Similar to the other reservoirs in the Bear Creek watershed, the most obvious problem was very poor DO conditions at the forebay. Other indicators rated good (chlorophyll and fish assemblage) or fair (sediment quality and benthos). Given the hot, dry summer of 1993, additional information in future years will help to better evaluate and define the ecological health of Little Bear Creek Reservoir.

Reservoir Use Suitability

Fecal coliform bacteria concentrations were very low at both swimming areas tested in 1993. The low rainfall in 1993 may have contributed to low concentrations. During a wetter period in 1991, fecal coliform concentrations were much higher at both beaches. During the 1991 survey period, bacteriological water quality at both sites was within state water quality criteria for recreation; however, both exceeded one of EPA's recommended guidelines--more than 10 percent of the samples had fecal coliform concentrations greater than 400/100 mL.

A composite of channel catfish was collected from the forebay of Little Bear Creek Reservoir in autumn 1992. Only one metal analyte (mercury) was detected, and no PCB or pesticide analytes were detected. The mercury concentration (0.56 $\mu g/g$) was relatively high. As a result, channel catfish from this site were reexamined in autumn 1993. Results were not available at the time this report was prepared.

8.5 Cedar Creek Reservoir

Physical Description

Like the other reservoirs in the Bear Creek watershed, Cedar Creek Reservoir is small (only nine miles long and 4200 acres surface area) and deep (79 feet at the dam). The low average annual discharge from the dam (282 cfs) creates a relatively long average retention time (168 days). This combination of physical features lead to thermal stratification and hypolimnetic anoxia in the summer. Average annual drawdown is about 14 feet.

Ecological Health

The ecological health of Cedar Creek Reservoir rated poor-fair (56 percent) in 1993, the first year of Vital Signs monitoring. As expected based on the other reservoirs in the Bear Creek watershed, DO rated very poor because of anoxic conditions and a very large proportion of both the bottom and the water column with DO concentrations <2.0 mg/L. Chlorophyll, benthos, and fish assemblage all rated fair. The only fair to good rating was for sediment quality. There were no excellent ratings.

Reservoir Use Suitability

Fecal coliform bacteria concentrations were low at the Slickrock Ford swimming area in 1993. The low rainfall in 1993 may have contributed to low concentrations. During a previous survey period in 1991 with more normal rainfall, higher fecal coliform concentrations were found. Despite being higher, they were within state water quality criteria for recreation.

A single composite of channel catfish fillets collected from the forebay of Cedar Creek Reservoir in autumn 1992 did not have detectable concentrations of any pesticide or PCB analyte. Mercury, found at a low concentration, was the only metal analyte detected.

8.6 Bear Creek Stream Monitoring Site

Physical Description

Bear Creek flows through the southwest boundary of the Highland Rim physiographic province in northwestern Alabama (85 percent) and northeastern Mississippi to join the Tennessee River as an embayment of Pickwick Reservoir. The Bear Creek watershed is approximately 65 miles long and 15 miles wide and drains 946 square miles.

The watershed area above the Bishop, Alabama, monitoring location is 667 square miles or 70 percent of the entire Bear Creek basin. Within the monitored area, Cedar Creek, with a drainage area of 329 square miles, is the principal tributary. There are four reservoirs (Cedar Creek, Little Bear Creek, Bear Creek, and Upper Bear Creek) that control the runoff from about half of the watershed.

The Bear Creek basin is underlain by sandstone or has limestone outcroppings. Approximately 70 percent of the watershed is forested, the remainder agricultural. Some iron ore has been mined in the basin and bacterial pollution from agricultural operations has been recognized as a water quality concern. Several active and abandoned coal mines are located on the uppermost portions of the watershed above the upper Bear Creek Reservoir. Russellville and Haleyville, Alabama, are the primary urban areas.

Ecological Health

The monitoring location on Bear Creek, far upstream of any influence of impoundment from Pickwick Reservoir, showed fair ecological health in 1993. The fish community was fair in 1993; but not as good as in 1992, which was much improved over past years. Benthic macroinvertebrates also rated fair in 1993, similar to 1992.

Use Suitability

The only bacteriological samples collected from the Bear Creek watershed in 1993 were those collected for reservoir Vital Signs monitoring and are reported with those sections.

Fish for tissue analysis are not collected from the Bear Creek stream monitoring site.

9.0 WHEELER RESERVOIR - ELK RIVER WATERSHED

The Wheeler Reservoir - Elk River watershed drains about 5140 square miles in north central Alabama and south central Tennessee. Wheeler Reservoir is the fourth of nine reservoirs on the Tennessee River. About 24,500 square miles of the Tennessee Valley are upstream of this watershed. Wheeler Reservoir receives an average annual inflow of 40,700 cfs from Guntersville Dam. Discharges from Wheeler Dam average 49,400 cfs on an annual basis leaving 8700 cfs which originate within the watershed.

The largest tributary to Wheeler Reservoir is the Elk River, which has a drainage area of about 2250 square miles and contributes about 3000 cfs. The remaining flow enters from tributaries directly to Wheeler Reservoir.

Wheeler Reservoir is the largest reservoir within this watershed followed by Tims Ford Reservoir on the Elk River. There are four Vital Signs monitoring sites on Wheeler Reservoir--forebay, transition zone, inflow, and the Elk River embayment (Figure 9.1 and Table 2.1). Two sites are monitored for Vital Signs on Tims Ford Reservoir--forebay and mid-reservoir. Woods Reservoir on the Elk River is not included in this monitoring program because it is property of the Arnold Engineering Development Center, Arnold Air Force Base.

The only stream monitoring site within this watershed is on the Elk River at mile 36.5.

Results from 1993 monitoring activities are provided in Section 9.1 for Wheeler Reservoir, Section 9.2 for Tims Ford Reservoir, and Section 9.3 for the stream site on the Elk River.

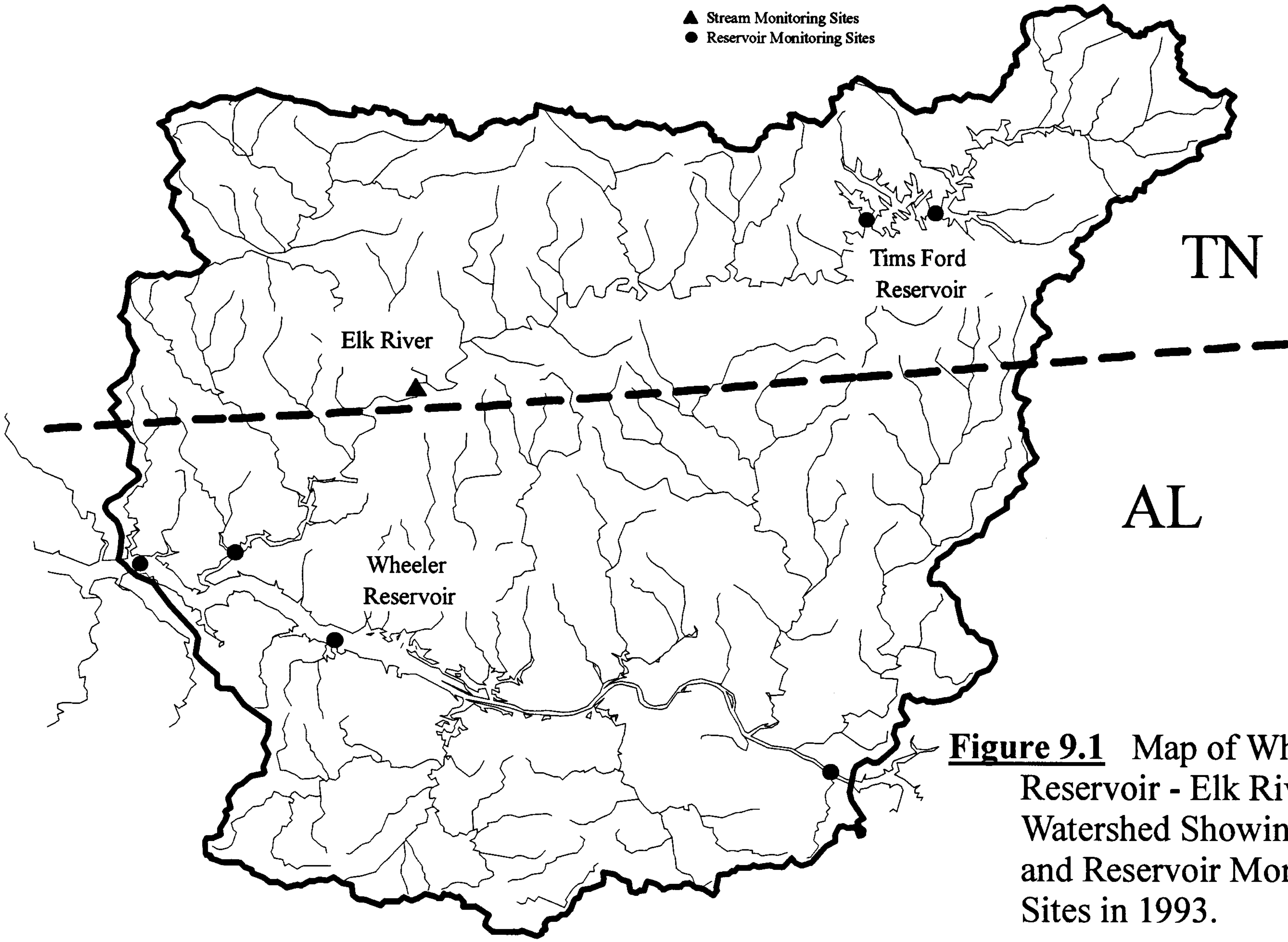


Figure 9.1 Map of Wheeler Reservoir - Elk River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.

9.1 Wheeler Reservoir

Physical Description

Wheeler Reservoir has the third-largest surface area (67,100 acres) of all reservoirs in the TVA system. It is 74 miles long (dam at TRM 274.9) and has 1063 miles of shoreline. Average annual discharge is about 49,400 cfs which provides an average hydraulic retention time of about 11 days. Information collected in 1990 and 1991 indicated a more riverine than transition environment at TRM 307.5; consequently, in 1992 the transition zone sampling location was relocated further downstream to TRM 295.9. Results for 1992 and 1993 are being evaluated to determine if this new site is suitably located or if it needs to be moved further downstream.

The Elk River joins the Tennessee River in the downstream portion of Wheeler Reservoir at about mile 284 and provides, on the average, about 6 percent of the flow through Wheeler Reservoir.

Vital Signs monitoring activities were expanded in 1993 to include a site in the Elk River embayment. This was one of four embayments added to the Vital Signs program in 1993. The Elk River embayment covers about 4900 acres. Given the relatively high flows in the Elk River (about 3000 cfs annual average), there is substantial water exchange in this embayment.

Reservoir Health

Like several other Tennessee River reservoirs, the overall ecological health index of Wheeler Reservoir was lower in 1993 compared to 1992 and 1991. Overall, Wheeler Reservoir rated fair to good (72 percent) in 1993 compared to good in 1992 (80 percent) and in 1991 (87 percent). The primary contributor to this lower reservoir rating was addition of information from the Elk River embayment, which had three poor ratings (chlorophyll--very poor; DO and benthos--poor). Of the four sites monitored on Wheeler Reservoir in 1993, the Elk River embayment site had the poorest ecological health. If data from the Elk River site were deleted from the overall score, Wheeler would rate good (82 percent), consistent with findings in 1991 and 1992.

DOs less than 2 mg/L were measured at lower depths in the forebay during summer with an anoxic area near bottom. As a result, DO rated poor at the forebay. (Ratings for DO at the forebay had been good in 1991 and fair in 1992.) This stressed condition was likely related to the low flows during the 1993 summer. Interestingly, DO rated excellent at the inflow and transition zone, indicating the problem developed within the downstream, forebay region of the reservoir. When low reservoir flows and high water temperatures occur, respiration and oxygen demand

(both sediment and biological) increase and can exceed the DO made available by reaeration and photosynthesis. This downstream portion of Wheeler Reservoir usually has relatively high algal productivity due to input of high levels of phosphorus from Elk River. The combination of stagnant water and a high oxygen demand required to decompose dead algae settling to the bottom contributes to low DOs in lower depths at the forebay. All other ecological health indicators rated fair, good, or excellent, similar to previous years. The transition zone and inflow had mostly good or excellent rating for all indicators. The fish assemblage and sediment quality were fair, good, or excellent at all sample sites.

Aquatic macrophytes colonized about 6600 acres on Wheeler Reservoir in 1993, compared to about 4400 acres in 1992 and 3500 acres in 1991.

Reservoir Use Suitability

No bacteriological studies were conducted at recreation sites in Wheeler Reservoir in 1993. In 1990, bacteriological water quality met the Alabama criterion for recreation at the four swimming beaches and four boat ramps tested. Fecal coliform bacteria concentrations have generally been low at the Vital Signs locations in the forebay and transition zones. Since 1990, only two samples have been high, one in 1990 and one in 1993, both in the transition zone.

The Alabama Department of Public Health advises that most fish species from within the Indian Creek embayment on Wheeler Reservoir should not be eaten due to DDT contamination. An intensive study was conducted in autumn 1991 to determine if high concentrations existed in fish from the Tennessee River in an area 15 miles downstream to five miles upstream of the Indian Creek embayment. Based on the 1991 results the public was further advised not to eat largemouth bass, channel catfish, and smallmouth buffalo from within one mile either side of the area where Indian Creek and the Tennessee River join. Other bottom feeding fish species (such as carp and suckers) from the area should also be avoided. Furthermore, channel catfish caught from the Tennessee River between Indian Creek and the Interstate 65 bridge should not be eaten. Fish were again collected from these areas in the Tennessee River in 1992 to continue examining DDT concentrations. The 1992 fish had much lower concentrations than those in 1991. The study was reported in autumn 1993, but results were not available at the time this report was prepared.

9.2 Tims Ford Reservoir

Physical Description

Tims Ford Reservoir in middle Tennessee is formed by Tims Ford Dam at Elk River mile (ERM) 133.3. The reservoir is 34 miles long at full pool and has a surface area of 10,600 acres. The depth at the dam is 143 feet and the average depth is about 50 feet. Average annual discharges from Tims Ford Dam are about 940 cfs, resulting in a hydraulic residence time of about 280 days. Tims Ford Reservoir is designed for a useful controlled drawdown of 30 feet (895-865 feet MSL) for flood protection; however, annual drawdowns average about 18 feet.

Ecological Health

The ecological health of Tims Ford Reservoir rated poor-fair (58 percent) in 1993 with very little change from previous years of Vital Signs monitoring. The most obvious ecological health problem was the low concentrations of DO near bottom (rated very poor at both the forebay and mid-reservoir sites in 1993). Although undesirable, low DO concentrations often exist in deep, tributary storage reservoirs like Tims Ford with long detention times and strong summer stratification. In spite of these low dissolved oxygen conditions, the fish assemblage rated good at both monitoring sites in 1993. However, the benthos, sampled for the first time in 1993, rated very poor at the forebay and poor at the mid-reservoir site. Sediment quality, also sampled for the first time in 1993, had high levels of ammonia at both locations and toxicity to test animals at the mid-reservoir site which rated poor. Chlorophyll ratings at both locations on Tims Ford Reservoir were good in 1993, indicating adequate primary productivity to support the food web, but not overly productive, potentially leading to eutrophic conditions.

Reservoir Use Suitability

Four sites were tested for fecal coliform bacteria in 1992; two sites were retested in 1993 because of high concentrations. The 1993 concentrations were low at the Estill Springs Park, but at the Dry Fork swimming area, bacteria concentrations were within state criteria only if samples collected within 24-hours of rainfall are excluded.

There are no fish consumption advisories for Tims Ford Reservoir. All analytes were either not detected or found in only low concentrations in channel catfish composites collected from the forebay and transition zone in autumn 1992.

9.3 Elk River Stream Monitoring Site

Physical Description

The Elk River flows for more than 200 miles from its headwaters near Monteagle, Tennessee, on the edge of the Cumberland plateau, southwest through south-central Tennessee into northern Alabama where it meets the Tennessee River about nine miles above Wheeler Dam. The basin, which lies principally in the Highland Rim province, is approximately 100 miles long and 50 miles wide at its greatest width, but it averages only 25 miles wide. Approximately one-third of the north central basin above the Elk River lies in the Nashville basin. The Elk River drainage basin area is 2249 square miles.

The TVA monitoring station is located at the USGS stream gage near Prospect, Tennessee. At this location, 1784 square miles or 79 percent of the entire Elk River basin is monitored. Major tributaries of the Elk River basin include Sugar Creek (177 square miles), Richland Creek (488 square miles), Cane Creek (106 square miles), Mulberry Creek (99 square miles), and Beans Creek (92 square miles). Tims Ford Dam and Elk River Dam control most of the runoff from the upper quarter of the watershed.

The Elk River drains an area underlain for the most part by limestone. Consequently, the water is high in dissolved minerals and fairly hard. About 60 percent of the Elk River basin is farmland. Urban areas include Pulaski, Fayetteville, Tullahoma, and Winchester, Tennessee.

Ecological Health

The monitoring site on the Elk River, far upstream of any influence of backwater from Wheeler Reservoir, was rated poor to fair in 1993, a slight improvement over 1992. Improvements were noted in sediment quality and benthic macroinvertebrates. (Fish were not sampled in 1993.) Nutrient concentrations were quite high, resulting from phosphorus-rich soils in the watershed. These high nutrient inflows from the Elk River can stimulate algal blooms in Wheeler Reservoir.

Use Suitability

Bacteriological water quality at an access location about one and one-half miles downstream of Tims Ford Dam was poor immediately after rainfall, but met recreation criterion if samples collected within 24-hours of rainstorms were excluded.

All analytes in fish tissue samples collected in summer 1992 were either not detected or found in low concentrations.

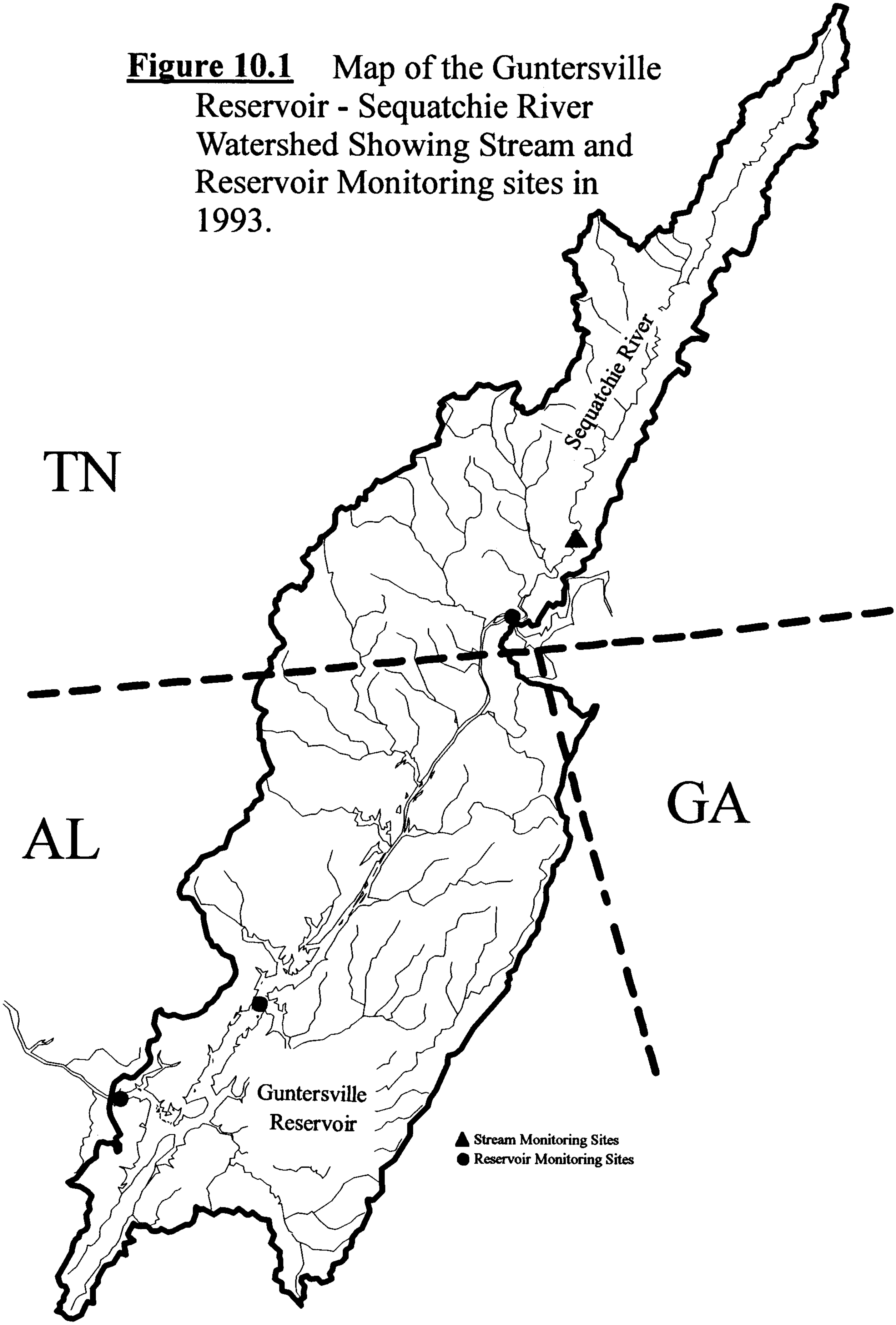
10.0 GUNTERSVILLE RESERVOIR - SEQUATCHIE RIVER WATERSHED

This watershed includes Guntersville Reservoir and all tributaries draining directly to Guntersville Reservoir. As with the other watershed areas on the mainstem of the Tennessee River, most of the water leaving the watershed through Guntersville Dam enters the watershed area through discharges from the upstream dam (Nickajack). About 35,900 cfs enter from Nickajack Dam and about 40,700 cfs is discharged from Guntersville Dam on an annual average basis. The remaining 4800 cfs originates with the Guntersville Reservoir-Sequatchie River watershed area. The largest contributor of this flow is the Sequatchie River (about 800 cfs). The total watershed area is 2669 square miles. The area drained by the Sequatchie River is about 600 square miles.

Guntersville Reservoir is the dominant characteristic of this watershed. There are three Vital Signs monitoring site on Guntersville Reservoir: forebay, transition zone, and inflow (Figure 10.1 and Table 2.1). Information from 1993 monitoring activities is provided in Section 10.1.

There is a stream monitoring site on the Sequatchie River at mile 6.3. Monitoring information for this site for 1993 is provided in Section 10.2.

Figure 10.1 Map of the Guntersville Reservoir - Sequatchie River Watershed Showing Stream and Reservoir Monitoring sites in 1993.



10.1 Guntersville Reservoir

Guntersville Dam, located at TRM 349.0, creates a 76 mile long reservoir with a surface area of 67,900 acres and a shoreline of 949 miles at full pool. Average annual discharge is about 40,700 cfs, corresponding to an average hydraulic retention time of about 13 days.

Guntersville Reservoir is similar to Wheeler Reservoir in several size characteristics, but it differs in one important feature. The average controlled storage volume of Guntersville is about half that of Wheeler. This is due to the shallow nature of Guntersville Reservoir at the inflow area and extensive shallow overbank areas. As a result, winter drawdown on Guntersville Reservoir is nominal to maintain navigation. The shallow drawdown allows the large overbank areas to be permanently wetted creating good habitat for aquatic macrophytes. Guntersville has the greatest area coverage of aquatic plants of any TVA reservoir.

The Sequatchie River joins the Tennessee River at about TRM 423, in the upstream portion of Guntersville Reservoir, just downstream from Nickajack Dam. On the average the Sequatchie River contributes less than 2 percent to the total flow of the Tennessee River through Guntersville Reservoir.

Data collected in 1990 and 1991, indicated a more riverine than transition environment at TRM 396.8. Consequently, in 1992 the transition zone sampling location was relocated further downstream to TRM 375.2. Results from the new site are being reviewed to determine if it is suitably located.

Ecological Health

Ecological health conditions were good (78 percent) in Guntersville Reservoir in 1993, similar to those observed in 1992 (83 percent). All ecological health indicators rated fair, good, or excellent at all reservoir sites, except for DO at the inflow, which rated very poor (compared to fair in previous years). A very low DO concentration (1.8 mg/L, the lowest ever recorded in the discharge from Nickajack Dam) was measured in July and was related to the usual flow patterns associated with the summer drought and special hydroelectric operations.

As in 1992, 1993 results indicated the transition zone had the best ecological health of the three sample sites on Guntersville Reservoir. Four of the five aquatic health indicators from this site had excellent ratings both years; only the fish assemblage rated less than excellent (fair).

Aquatic macrophytes covered about 7600 acres in 1993 compared to 5993 acres in 1992 and 5165 acres in 1991. Guntersville Reservoir contains more acres of aquatic plants than any other reservoir in the TVA system.

Reservoir Use Suitability

All sites tested for fecal coliform bacteria in 1992 and 1993 in Guntersville Reservoir met the Alabama water quality criterion for recreation. At most sites, bacteria concentrations were quite low. High fecal coliform concentrations were found in the Vital Signs sampling at the forebay in 1990 and 1991, but bacteria concentrations at both the forebay and transition zone were very low in 1992 and 1993.

There are no fish consumption advisories on Guntersville Reservoir. Channel catfish composites collected from Guntersville Reservoir in autumn 1990 had sufficiently high PCB concentrations to warrant further examination but were not high enough for the state to issue an advisory. Catfish collected from the same locations in 1991 and 1992 had progressively lower concentrations than those from 1990 with the 1992 concentrations generally indicative of "background" levels found in channel catfish throughout the Tennessee River. Other analytes were low or nondetectable in the 1992 samples.

10.2 Sequatchie River Stream Monitoring Site

Physical Description

The Sequatchie River basin is a narrow limestone valley of the Valley and Ridge physiographic province, surrounded by the Cumberland Plateau to the west and Walden Ridge to the east. The Sequatchie flows from its headwaters south of the Emory-Obed River basin for more than 110 miles to form an embayment at the upstream end of Guntersville Reservoir, just downstream from Nickajack Dam. The Sequatchie River drainage basin is 605 square miles.

The TVA monitoring station is located at the Valley Road bridge near Jasper, Tennessee. The upstream drainage basin is 575 square miles or 95 percent of the entire Sequatchie River basin. Principal tributaries in the monitored area include the Little Sequatchie River (132 square miles) and Big Brush Creek (69 square miles).

Dolomite and limestone underlie the floor of the Sequatchie River valley, which is predominantly farmland. Sandstones underlie the surrounding steep escarpments and plateaus, which are predominantly forested. Coal mines operate in some areas of the Cumberland Plateau. Whitwell, Dunlap, and Pikeville, Tennessee, are the primary urban area in the basin.

Ecological Health

The ecological health of the Sequatchie River monitoring site was good in 1993. All ecological health indicators were either good or fair. Coal mining activities may be hindering the fish community and bottom-dwelling animals as indicated by deposits of coal fines and other sediments.

Use Suitability

Four canoe sites were sampled in 1992 and 1993 for fecal coliform bacteria. Although some samples collected after rainfall had high concentrations, all sites met Tennessee water quality criterion for recreation both years.

Fish tissue samples from the Sequatchie River collected during summer 1992 had nondetectable or only low concentrations of all analytes.

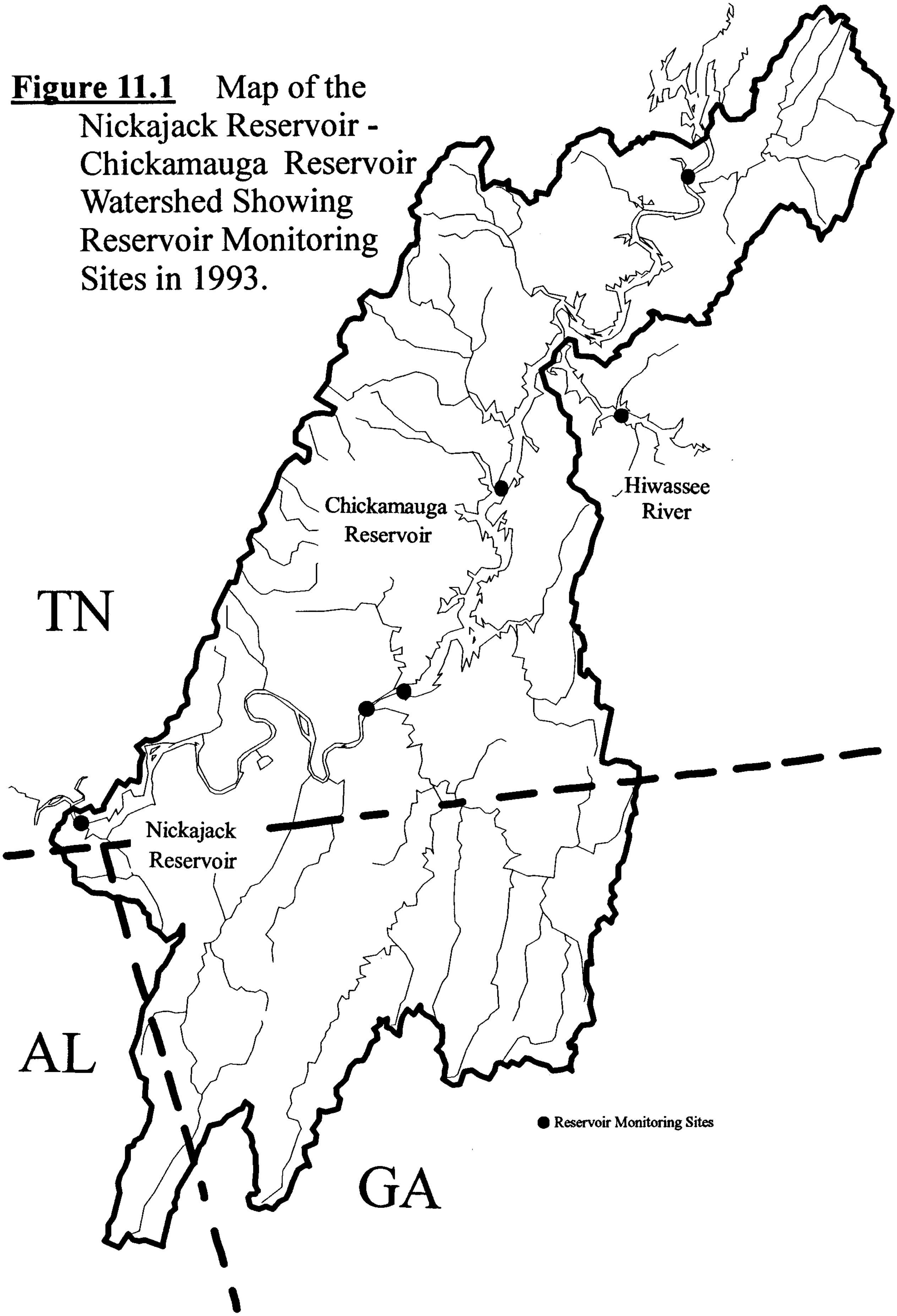
11.0 NICKAJACK RESERVOIR - CHICKAMAUGA RESERVOIR WATERSHED

Nickajack and Chickamauga Reservoirs are primary features of this watershed. The Hiwassee River is the only sizeable tributary which merges with the Tennessee River within the watershed area. The drainage basin of the Hiwassee River is large enough to be designated a separate watershed (see Section 12). The remaining area drained by tributaries to these two reservoirs is 1780 square miles. On an annual average basis, about 3200 cfs is contributed to the Tennessee River from streams within this watershed. This compares to 27,100 cfs entering the upper end of Chickamauga Reservoir from Watts Bar Dam and 5600 cfs from the Hiwassee River, for a total average annual discharge from Nickajack Dam of 35,900 cfs.

There are two Vital Signs monitoring sites on Nickajack Reservoir, one at the forebay and one at the inflow. There is no transition zone site on Nickajack because the reservoir is short and water exchange is quite rapid. This causes conditions at the location that might be considered the transition zone to be similar to those at the forebay. Chickamauga Reservoir has four Vital Signs monitoring sites--the forebay, the transition zone, the inflow, and a new site established in 1993 in the Hiwassee River embayment (Figure 11.1).

Results from 1993 monitoring activities are in Section 11.1 for Nickajack Reservoir and 11.2 for Chickamauga Reservoir.

Figure 11.1 Map of the Nickajack Reservoir - Chickamauga Reservoir Watershed Showing Reservoir Monitoring Sites in 1993.



11.1 Nickajack Reservoir

Physical Description

Nickajack Reservoir is one of the smallest reservoirs on the mainstem of the Tennessee River. With the dam at TRM 424.7, Nickajack has a length of 46 miles, surface area of 10,370 acres, and a shoreline of 192 miles at full pool. Average annual discharge from Nickajack is approximately 35,900 cfs which provides an average hydraulic retention time of only about three or four days, the shortest retention time among the reservoirs monitored in this program.

Results from the 1990 and 1991 monitoring indicated that both the forebay and transition zone sampling sites had quite similar water quality. This was expected since the two sites are relatively close together (separated by only 7.5 river miles), and Nickajack is a well-mixed, run-of-the-river reservoir. Therefore, sampling at the transition zone in Nickajack Reservoir was discontinued in 1992.

Ecological Health

Nickajack Reservoir had a good ecological health rating (88 percent) in 1993, the same as in 1992 and 1991 (83 percent both years). Nickajack had the highest overall ecological health rating of all Vital Signs reservoirs in 1993. The only poor rating was for DO at the upper end of Nickajack Reservoir. This was due to low DOs (minimum 2.2 mg/L) in the releases from Chickamauga Dam in July 1993. Low DO concentrations had been observed there in previous years, but concentrations measured in 1993 were the lowest ever recorded from Chickamauga Dam. These concentrations were not low enough to cause mortality for common species present, but were low enough to affect organism health and growth. Although the DO rating at the Nickajack forebay was excellent (no DO concentrations less than 2.0 mg/L were measured), it cannot be concluded that no DO problems existed. Because low DO concentrations were found in water entering Nickajack Reservoir from Chickamauga Dam and low DO concentrations were found in water leaving Nickajack Dam, it is clear that low DOs existed in the Nickajack forebay at some time. The lack of low measurements at the forebay likely is due to the timing of monthly measurements; sampling dates in July and August bracketed the period with most severe DO problems.

Other than the poor DO rating for the inflow, all other ecological health indicators at the forebay and inflow sample sites scored good or excellent. Even if low DO concentrations had been

measured at the forebay, the high scores for the other indicators would have kept the overall rating for Nickajack Reservoir in the good range.

Aquatic macrophytes on Nickajack Reservoir covered about 1000 acres in 1993 compared to 830 acres in 1991 to 580 acres in 1992.

Reservoir Use Suitability

The Tennessee Department of Environment and Conservation has issued an advisory that catfish should not be eaten by children, pregnant women, and nursing mothers because of PCB levels (about 1.0 $\mu g/g$); other individuals should limit consumption to no more than 1.2 pounds per month. Fillets from catfish collected autumn 1992 had PCB concentrations about half those previously found in the five years of fish tissue studies on Nickajack Reservoir. The study was repeated in autumn 1993 to determine if lower PCB concentrations are found again. Results were not available at the time this report was prepared.

Fecal coliform bacteria concentrations in areas of Nickajack Reservoir tested during the recreation site sampling in 1992 and 1993 and Vital Signs sampling since 1990 were generally low. Exceptions include the boat ramp at Smith's Camp-On-The-Lake, where large populations of geese probably account for the high concentrations, and North Chickamauga Creek after rainfall.

11.2 Chickamauga Reservoir

Physical Description

Chickamauga Dam is located at TRM 471.0. The reservoir is 59 miles long, has 810 miles of shoreline, and has a surface area of 35,400 acres at full pool. The average annual discharge is approximately 34,200 cfs which provides an average hydraulic retention of nine to ten days (Table 4.1).

The Hiwassee River, a major tributary to the Tennessee River, flows into the middle portion of Chickamauga Reservoir at about TRM 499. The flow from the entire Hiwassee River watershed contributes approximately 16.5 percent of the flow through Chickamauga Reservoir. About 10 percent of the 16.5 percent is from the Ocoee River and tributaries in the lower end of the Hiwassee watershed (i.e., downstream of Apalachia Dam).

Vital Signs monitoring activities were expanded in 1993 to include a site in the Hiwassee River embayment, which covers about 6500 acres. Given the relatively high flows in the Hiwassee River (about 5600 cfs annual average), there is substantial water exchange in this embayment, much greater than in any of the other three embayments monitored.

Ecological Health

The overall ecological health rating for Chickamauga Reservoir was good in 1993 (83 percent), the second-highest rating of all reservoirs. This is an improvement over the fair to good rating in 1992 (73 percent) and is more like the good rating in 1991 (90 percent). Unlike the other three reservoirs which had a major embayment monitored for the first time in 1993 (Kentucky, Pickwick, and Wheeler), results from the Hiwassee River embayment did not lower the overall rating of Chickamauga Reservoir. Of the five ecological health indicators, two were excellent (chlorophyll and DO) and three were good (sediment quality, benthos, and fish assemblage) at the Hiwassee embayment site. If results from the Hiwassee River embayment site were excluded from determining the overall score for Chickamauga Reservoir, the score would be changed slightly to 81 percent.

Several health indicators had higher ratings in 1993 than in 1992. In particular, the sediment quality rating improved from poor in 1992 to fair in 1993 at both the forebay and transition zone. The poor ratings at these two sites in 1992 resulted from elevated concentrations of copper and zinc and toxicity to test organisms. In 1993 copper and zinc (in addition to trace levels of chlordane) were again found at the forebay, but no toxicity was found, resulting in a fair rating. The fair rating

at the transition zone in 1993 was caused by an indication of toxicity (some mortality of rotifers, although not significantly different from controls) and presence of chlordane in the sediment; copper and zinc were not elevated. Chlordane in sediments was detected for the first time in 1993. This is related to improved laboratory methods rather than a true environmental change. New equipment which allowed better extraction of organic contaminants from sediments was used on 1993 samples.

DO levels on Chickamauga Reservoir were not impacted as much by the hot, dry summer as on several other Tennessee River reservoirs in 1993. The DO ratings at the forebay and transition zone were good, but there were small areas during June and July with very low DO concentrations. These areas are thought to have been too short in duration and too small in area to have had a significant impact. DO at the inflow rated fair due to a relatively low concentration (3.7 mg/L) in one sample from the releases of Watts Bar Dam.

Improvements in ratings for both the benthos (poor in 1992 and fair in 1993) and fish assemblage (fair in 1992 and excellent in 1993) were noted at the inflow. About twice as many benthic macroinvertebrate taxa were found in 1993 as in 1992, indicating improved conditions. Most fish assemblage metrics were excellent; this was a distinct improvement over 1992 results. Aquatic macrophytes on Chickamauga Reservoir covered 1185 acres in 1993 compared to 387 acres in 1992 and 680 acres in 1991. Aquatic macrophytes peaked at about 7500 acres in 1988 and continuously declined until summer 1993.

Reservoir Use Suitability

There are no fish consumption advisories for Chickamauga Reservoir. Fillets from Chickamauga Reservoir catfish have been examined for several years as part of a variety of studies. Study results have indicated no consistent or reservoir-wide problems. Results from most of these studies have usually found higher concentrations of PCBs in catfish from the inflow area than from other sites in the reservoir. Channel catfish were collected for screening purposes in autumn 1992 from the inflow, transition zone, and forebay. Concentrations of all analytes from all locations were low, including PCBs.

No bacteriological studies were conducted at recreation sites on Chickamauga Reservoir in 1993. Bacteriological water quality met the Tennessee criterion for recreation at the ten sites tested in 1989 and 1990. Fecal coliform bacteria concentrations have generally been low at the Vital Signs locations during all years monitoring activities have occurred.

12.0 HIWASSEE RIVER WATERSHED

The headwaters of the Hiwassee River extend into the Blue Ridge Mountains in Tennessee, North Carolina, and Georgia. Streams in this watershed have naturally low concentrations of nutrients and dissolved minerals. These streams change from steep gradient, cold water trout streams in the mountains to lower gradient warm water streams in the valley.

The Hiwassee River Watershed has an area of 2700 square miles and an average annual discharge to the Tennessee River of 5640 cfs. The confluence of the Hiwassee River with the Tennessee River is in Chickamauga Reservoir at Tennessee River Mile 499.4. The lower portion of the Hiwassee River is impounded by backwater from Chickamauga Dam. The impounded portion of the Hiwassee River forms a large embayment (about 6500 surface acres) which extends over 20 miles up the Hiwassee River.

The largest tributary to the Hiwassee River is the Ocoee River, with a drainage area of about 640 square miles. Due to past copper mining and industrial activities in the Copperhill area, several streams and reservoirs in the Ocoee River basin have degraded water quality.

There are eight TVA reservoirs in the Hiwassee River watershed (Figure 12.1 and Table 2.1). Vital Signs monitoring activities are conducted on the five largest reservoirs: Hiwassee Reservoir (forebay, mid-reservoir, and inflow); Chatuge Reservoir (forebay sites on the Hiwassee River and Shooting Creek arms); Nottely Reservoir (forebay and mid-reservoir); Ocoee Reservoir No. 1 (forebay only); and Blue Ridge Reservoir (forebay only). Apalachia, Ocoee No. 2, and Ocoee No. 3 Reservoirs are not included in this monitoring because of their small size.

There is a stream monitoring site on the Hiwassee River at HiRM 36.9, about 2.5 miles upstream of the confluence of the Ocoee River. A new site will be added in 1994 on the Ocoee River at mile 2.5. Vital Signs monitoring also includes a site on the Hiwassee River embayment (at HiRM 10) of Chickamauga Reservoir. Results from that monitoring site are provided in Chapter 11.

Results from 1993 reservoir and stream Vital Signs and Use Suitability monitoring activities are provided in the following sections:

12.1 Hiwassee Reservoir

12.2 Chatuge Reservoir

12.3 Nottely Reservoir

12.4 Blue Ridge Reservoir

12.5 Ocoee Reservoir No. 1 (Parksville Reservoir)

12.6 Hiwassee River Stream Monitoring Site

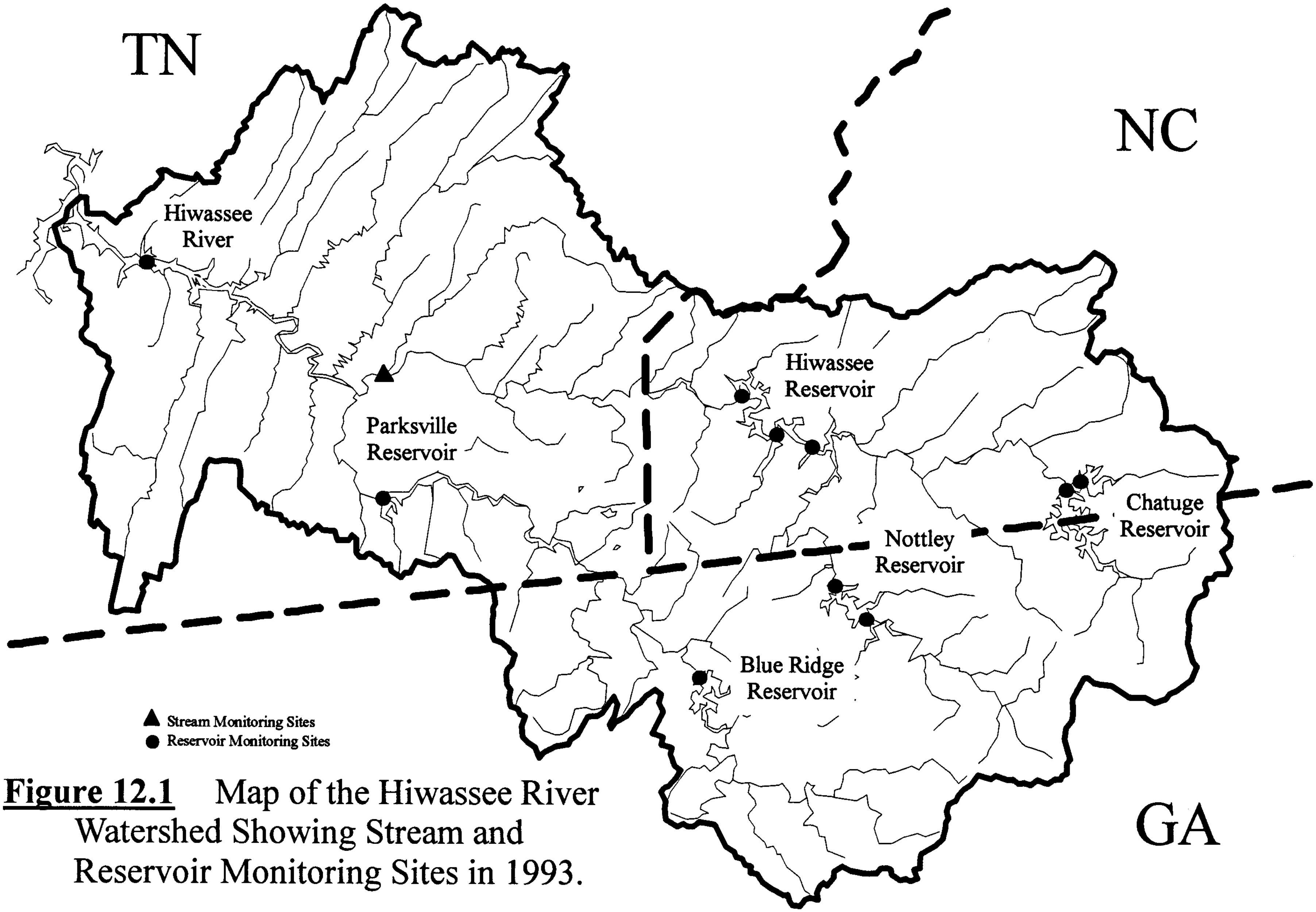


Figure 12.1 Map of the Hiwassee River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.

12.1 Hiwassee Reservoir

Physical Description

Hiwassee Reservoir, in the southwestern corner of North Carolina, is the second-largest of the five reservoirs in the Hiwassee River watershed included in the Vital Signs monitoring program. Hiwassee Reservoir is impounded by Hiwassee Dam at river mile 75.8. At full pool level, its backwater storage pool is about 22 miles long, 6100 acres in surface area, and has a mean depth of about 69 feet (with a maximum depth of about 255 feet at the dam). It has an average annual discharge of about 2020 cfs and average residence time of about 105 days. Hiwassee Reservoir has an average annual drawdown of 45 feet.

Ecological Health

Ecological health of Hiwassee Reservoir rated poor-fair (58 percent) in 1993; lower than in 1992 and 1991. The primary factor contributing to reduced ecological health rating was addition of sediment quality and benthic macroinvertebrates sampling in 1993. Both these indicators rated poor or very poor at both the forebay and mid-reservoir sites. There were no other poor ratings for any indicator, not even for DO, which was poor at the forebay in 1992. If scores for these two new indicators (sediment quality and benthos) were deleted from calculating the overall ecological health rating for Hiwassee Reservoir, the rating would change substantially to fair-good (72 percent), consistent with rating for previous years. Poor ratings for sediment quality were due to toxicity to test organisms and detectable concentrations of chlordane. Most benthos metrics were very poor and received the lowest score possible.

Like most deep, tributary storage reservoirs with long retention times, thermal stratification occurs during the summer in Hiwassee Reservoir. During periods of extended thermal stratification, low concentrations of dissolved oxygen develop near the bottom of the reservoir when oxygen is consumed by respiration and biochemical processes in the reservoir and in the sediment at a faster rate than it is replenished by photosynthesis and reaeration from the atmosphere. Although this low DO area develops in Hiwassee Reservoir, especially in the forebay, it is relatively small. Hence, DO rated fair at the forebay and good at the mid-reservoir site in 1993.

The upper Hiwassee River watershed is largely forested with few sources of waste to the river. Consequently, concentrations of nutrients are generally low and primary productivity in the Hiwassee watershed reservoirs is also generally low. This can be seen in the fair chlorophyll rating

at the Hiwassee Reservoir forebay in 1993 caused by low chlorophyll concentrations. Chlorophyll concentrations were just high enough at the mid-reservoir site to rate in the good range. As is frequently the case in oligotrophic reservoirs, lower standing stocks of fish reflect the small food base. The fish assemblage rated fair at all locations.

Reservoir Use Suitability

No bacteriological studies were conducted in 1993. In 1990, bacteriological water quality at four boat ramps was sampled. Fecal coliform bacteria concentrations were very low at all four sites.

There are no fish consumption advisories on Hiwassee Reservoir. The most recent fish tissue information is for a channel catfish composite from the forebay collected in autumn 1991. No pesticide or PCB analytes were detected. With the exception of mercury, metal concentrations in fish tissue were low or at expected concentrations. The mercury concentration, however, was relatively high (0.69 $\mu g/g$) and so was further investigated in autumn 1993. Both channel catfish and largemouth bass composites were collected from the forebay and transition zone during autumn 1993. Results were not available at the time this report was prepared.

12.2 Chatuge Reservoir

Physical Description

Chatuge Reservoir is located on the Georgia-North Carolina state line in northeastern Georgia and is formed by Chatuge Dam at Hiwassee River mile (HiRM) 121.0. At full pool elevation, the reservoir is 13 miles long and has a surface area of about 7000 acres. Its maximum depth at the dam is 124 feet, and it has a mean depth of 33 feet. An average annual discharge of 459 cfs results in an average hydraulic residence time of about 260 days. Chatuge Reservoir has a potential useful controlled storage of 23 feet (1928-1905 feet MSL), however, the annual drawdown averages only ten feet.

Only the forebay of Chatuge Reservoir was monitored prior to 1993. A new monitoring site was added in 1993 in the Shooting Creek arm to further evaluate this rather large part of the lake. Because of its physical features, the Shooting Creek site would be expected to be representative of forebay conditions.

Ecological Health

The ecological health of Chatuge Reservoir rated better in 1993 than in previous years of Vital Signs monitoring. Chatuge rated fair (67 percent) in 1993 compared to poor-fair in 1992 (56 percent) and 1991 (60 percent). One of the reasons for the higher rating in 1993 was improved scores for DO, which rated good at the forebay site on the Hiwassee River and fair at the forebay site on Shooting Creek. In 1992 DO rated poor at the forebay and a mid-reservoir site. Besides an actual slight improvement in DO conditions, the higher DO rating in 1993 was due to an improvement in the method for scoring for DO. Also, inclusion of scores for benthic macroinvertebrates, sampled for the first time in 1993 and rated good at both sample sites, helped to elevate the overall ecological health rating for Chatuge.

All other indicators (chlorophyll, sediment quality, and fish assemblage) rated fair at both sample sites. The fair ratings for chlorophyll were due to naturally low concentrations, indicative of the low availability of nutrients characteristic of the Hiwassee watershed. The fair ratings for sediment quality were due to toxicity to test organisms at the forebay site on the Hiwassee River and elevated concentrations of chromium, copper, and nickel at the Shooting Creek site.

Reservoir Use Suitability

There are no fish consumption advisories on Chatuge Reservoir. The most recent information available is from a channel catfish composite collected from the forebay in autumn 1991. None of the pesticide or PCB analytes were detected. Although several metals were detected, they occurred at low or expected concentrations.

No bacteriological studies were conducted in 1993. In 1990, bacteriological water quality at three swimming beaches, three boat ramps, and five locations in the middle of the channel were sampled. Fecal coliform bacteria concentrations were very low at all sites.

12.3 Nottely Reservoir

Physical Description

Nottely Reservoir is formed by Nottely Dam at Nottely River mile 21.0 in northern Georgia. At full pool elevation, the reservoir is 20 miles long, covers 4200 acres, and has a mean depth of 40 feet, with a maximum depth of about 165 feet at the dam. Long-term flows from Nottely Dam average about 415 cfs which result in an average hydraulic retention time of about 206 days. The annual drawdown averages about 24 feet on Nottely Reservoir.

Ecological Health

The ecological health of Nottely Reservoir rated fair again in 1993 (64 percent), slightly higher than the fair rating in 1992 and 1991 (60 percent). The primary concern in Nottely Reservoir is low DO conditions near bottom as evidenced by very poor DO ratings at both the forebay and mid-reservoir locations in 1993. The only other poor rating for an indicator in 1993 was benthos at the forebay. Interestingly, the benthos rated good at the mid-reservoir despite the very poor DO conditions. Chlorophyll rated good at both sample sites in 1993 and sediment quality rated excellent at the mid-reservoir site. The fish assemblage rated fair at both sample sites in 1993.

Nottely Reservoir's ecological health may not be as good as these monitoring results suggest, however. For example, there was a fish kill near the dam in the fall of 1992 which was probably related to low dissolved oxygen. Also, the water in Nottely Reservoir is frequently turbid due to excessive erosion on the lands surrounding the reservoir. Of the five reservoirs in the Hiwassee watershed (Hiwassee, Chatuge, Nottely, Blue Ridge, and Ocoee No. 1), Nottely has had the lowest water clarity, highest chlorophyll concentrations, and highest phosphorus concentrations over the last three years.

Reservoir Use Suitability

No fish consumption advisories have been issued for Nottely Reservoir. The most recent fish tissue results are for a channel catfish composite collected from the forebay in autumn 1991. The only organic analyte detected was PCBs (at a concentration of 0.2 μg/g) just above the detection limit. A few metals were detected but only mercury (0.47 μg/g) was sufficiently high to be of interest. Similar concentrations have been found, although not consistently, in previous screening studies on reservoirs in the Hiwassee basin. Both channel catfish and largemouth bass composites were collected

from the forebay in autumn 1993 and analyzed for mercury to further examine this situation. Results were not available at the time this report was prepared.

No information was collected for bacteriological contamination at recreation areas on Nottely Reservoir in 1993. However, the recreation area at Poteet Creek was sampled in 1990 for fecal coliform bacteria and found to fully support water contact recreation.

12.4 Blue Ridge Reservoir

Physical Description

Blue Ridge Dam impounds the Toccoa River at mile 53.0 in rural northwest Georgia. The watershed is mountainous and forested, with a significant portion of the basin lying within the Chattahoochee National Forest. At full pool, Blue Ridge Reservoir is about 11 miles long, 3300 acres in surface area, and 155 feet deep at the dam, with a average depth of 59 feet. The rate of discharge of water from Blue Ridge Reservoir averages about 610 cfs, which results in an average theoretical residence time of about 159 days. The annual drawdown of Blue Ridge Reservoir averages 36 feet.

Ecological Health

The ecological health of Blue Ridge Reservoir was good in 1993 (72 percent), similar to that found in 1992 and 1991. Blue Ridge is an oligotrophic reservoir as evidenced by very low summer chlorophyll concentrations at the forebay, rated fair in 1993. The excellent rating for DO was in part related to the low primary productivity because a low oxygen demand would be required to decompose relatively few dead algal cells. The benthic macroinvertebrate community, sampled for the first time in 1993, rated excellent at the forebay. The fish assemblage rated poor due to low abundance and diversity, as might be expected in an oligotrophic reservoir. Compared to the other reservoirs in the Hiwassee watershed, Blue Ridge has had the highest water clarity and lowest nitrogen concentrations over the three years of Vital Signs monitoring.

Reservoir Use Suitability

There are no fish consumption advisories on Blue Ridge Reservoir. The most recent fish tissue information from Blue Ridge Reservoir is from a channel catfish composite from the forebay collected in autumn 1991. Most pesticide and PCB analytes were not detected; those that were, occurred in low concentrations. Likewise, all metal analytes were either not detected or were found in low or expected concentrations.

No bacteriological studies were conducted in 1993. In 1990, bacteriological water quality at one swimming beach was sampled. Fecal coliform bacteria concentrations were very low.

12.5 Ocoee Reservoir No. 1 (Parksville Reservoir)

Physical Description

Ocoee No. 1 Reservoir, also known as Parksville Reservoir, is formed by Ocoee No. 1 Dam at Ocoee River mile 11.9. At full pool elevation, the reservoir has a surface area of about 1900 acres and length of 7.5 miles. Ocoee No. 1 Reservoir is located downstream from the Copper Basin, and decades of erosion have caused significant filling of the reservoir. Ocoee No. 1 Reservoir has lost about 25 percent of its original volume, has an average depth of 45 feet and is about 115 feet deep at the dam. An average annual discharge of about 1400 cfs from Ocoee No. 1 Dam results in a reservoir retention time of approximately 30 days. Although Ocoee No. 1 Reservoir is not operated for flood control (only for peaking power generation), its annual drawdown averages about seven feet.

Ecological Health

The ecological health of Ocoee No. 1 Reservoir rated poor in 1993 (52 percent), with little change from the previous years of Vital Signs monitoring activities. Four indicators rated poor--chlorophyll, sediment quality, benthic macroinvertebrates, and the fish assemblage. The reservoir is recovering from years of pollution problems related to copper mining and industrial activities at Copperhill. Sediment quality, sampled for the first time in 1993, reflected these historic problems with very high concentrations of copper, lead, and zinc. Also, PCBs were detected in forebay sediments in 1993.

In spite of the apparent availability of nutrients, algal productivity was low. High DO concentrations (rated excellent in 1993) existed in Parksville Reservoir throughout the year. High DO concentrations were present even in the hypolimnion at the forebay. As expected under such conditions, the fish assemblage rated poor in 1993, comparable to previous years.

Reservoir Use Suitability

There are no fish consumption advisories in effect for Parksville Reservoir. However, screening studies over the past several years have found PCB concentrations near the level used by the state of Tennessee to issue a "Limit Consumption" advisory. As a result, TVA and the state designed and conducted a more detailed sampling of fish in autumn 1992. Results of the 1992 effort confirmed previous results of relatively high PCB concentrations in channel catfish; the average of ten

fish was 1.5 $\mu g/g$ at the forebay and 1.0 $\mu g/g$ at an upper reservoir location. Largemouth bass were also examined and found to have lower concentrations than catfish; averages at the two sites were 0.6 and 0.7 $\mu g/g$, respectively. Bluegill sunfish and rainbow trout composites from these areas had low PCB concentrations (≤ 0.3 $\mu g/g$). The state of Tennessee had taken no action on these results at the time this report was prepared.

No bacteriological studies were conducted in 1993. In 1991, the swimming area at Mac Point was surveyed. Fecal coliform bacteria concentrations were low.

12.6 Hiwassee River Stream Monitoring Site

Physical Description

The headwaters of the Hiwassee River are in the Chattahoochee, Nantahala, and Cherokee Forests of the Blue Ridge physiographic province. It emerges from the mountains to flow through the Valley and Ridge province to join the Tennessee River as an embayment of Chickamauga Reservoir.

The TVA monitoring station is located at the Patty Bridge near Benton, Tennessee. The watershed area above the sampling site is 1300 square miles or 48 percent of the Hiwassee River basin. Principal tributaries in the Hiwassee watershed include the Valley River (117 square miles), Nottely River (287 square miles), Conasauga Creek (103 square miles), Toccoa-Ocoee River (639 square miles), Chestuee Creek (132 square miles), and Oostanaula Creek (69 square miles). Oostanaula Creek, Chestuee Creek, and the Ocoee River are located below this station.

Igneous and metamorphic rocks underlie much of the basin yielding water that is very soft and low in dissolved minerals. The major urban areas of the Hiwassee River basin include Athens, Etowah, and Cleveland, Tennessee, in the lower basin. The smaller urban communities of the mountains include Andrews and Murphy in North Carolina, Blue Ridge and McCaysville in Georgia, and Copperhill in Tennessee. Runoff from land denuded by historical mining and ore processing near Copperhill affects water quality in the Ocoee River and its three reservoirs downstream to the confluence with the Hiwassee River.

Ecological Health

The ecological health of the stream monitoring site on the Hiwassee River was good in 1993, as in 1992. All ecological health indicators (nutrients, sediment quality, benthos, and fish community) rated either good or fair.

Use Suitability

No fecal coliform samples were collected in 1993. In 1989, the canoe sites, Shallow Ford Bridge on Toccoa River upstream of Blue Ridge Reservoir, and at Mission Dam on the Hiwassee River between Chatuge and Hiwassee Reservoirs were sampled. In 1991, the two access locations on the Ocoee River upstream of Parksville Reservoir, and the three access sites on Hiwassee River upstream of Chickamauga Reservoir were sampled. Bacteriological water quality at each of the sites met the appropriate state's criterion for recreation.

All metal and organic analytes in fish tissue samples were either not detected or found in low concentrations.

13.0 WATTS BAR RESERVOIR, FORT LOUDOUN RESERVOIR, AND MELTON HILL RESERVOIR WATERSHED

This watershed area is relatively small (1370 square miles) and includes three reservoirs: Fort Loudoun and Watts Bar Reservoirs on the Tennessee River and Melton Hill Reservoir on the Clinch River. All three are run-of-the-river reservoirs with relatively short retention times and annual pool drawdowns of only a few feet. The inflow of Fort Loudoun Reservoir is actually the origin of the Tennessee River. The Holston and French Broad Rivers merge at that point to form the Tennessee River. The Little Tennessee River, another major tributary to the Tennessee River, enters Fort Loudoun Reservoir near the forebay. Watts Bar Reservoir is immediately downstream of Fort Loudoun. The Clinch River, another major tributary, merges with the Tennessee River upstream of the transition zone on Watts Bar Reservoir. Melton Hill Dam bounds the upper end of Watts Bar Reservoir on the Clinch River and Fort Loudoun Reservoir bounds it on the Tennessee River.

Like the other watershed areas formed around one or more of the reservoirs on the mainstream of the Tennessee River, very little of the water leaving this watershed area originates from within. The average annual discharge through Watts Bar Reservoir is about 27,000 cfs. Of this, about 25 percent (6800 cfs) enters from the French Broad River, 16 percent (4500 cfs) from the Holston River, 21 percent (5700 cfs) from the Little Tennessee River, and 15 percent (4200 cfs) from the Melton Hill Dam on the Clinch River. Another five percent (1400 cfs) is contributed by the Emory River, a tributary to the Clinch River near the confluence with the Tennessee River. The remaining 18 percent (4800 cfs) originates from streams which drain directly to one of these reservoirs.

Vital Signs monitoring activities are conducted at the forebays, transition zones, and inflows of all three of these reservoirs. Watt Bar Reservoir has two inflow sites, one near Fort Loudoun Dam and one near Melton Hill Dam. There is one stream monitoring site on the Emory River at Emory River Mile 18.3 (Figure 13.1).

Results for 1993 monitoring activities are provided in the following sections:

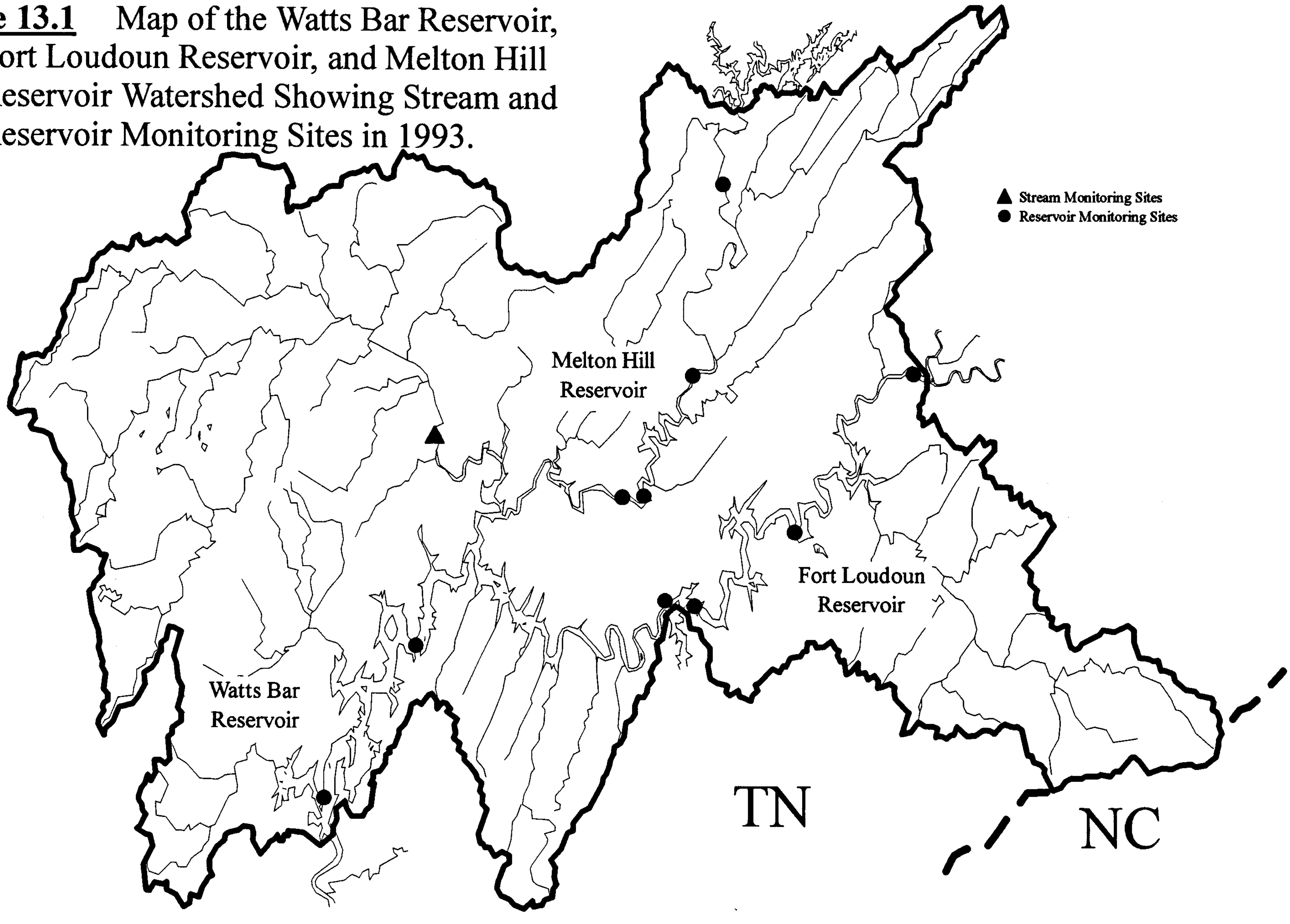
13.1 Watts Bar Reservoir

13.2 Fort Loudoun Reservoir

13.3 Melton Hill Reservoir

13.4 Emory River Stream Monitoring Site

Figure 13.1 Map of the Watts Bar Reservoir, Fort Loudoun Reservoir, and Melton Hill Reservoir Watershed Showing Stream and Reservoir Monitoring Sites in 1993.



13.1 Watts Bar Reservoir

Physical Description

Watts Bar Reservoir impounds water from both the Tennessee River and one of the major tributaries to the Tennessee River, the Clinch River. The three dams which bound Watts Bar Reservoir are: Watts Bar Dam located at Tennessee River Mile (TRM) 529.9, Fort Loudoun Dam located at TRM 602.3, and Melton Hill Dam located at Clinch River mile (CRM) 23.1. The total length of Watts Bar Reservoir, including the Clinch River arm is 96 miles, the shoreline length is 783 miles, and the surface area is 39,000 acres. The average annual discharge from Watts Bar is approximately 27,000 cfs, providing an average hydraulic retention time of about 19 days.

The confluence of the Clinch and Tennessee Rivers is upstream of the transition zone sampling location in Watts Bar, so biological sampling was conducted at the forebay, transition zone, and both the Tennessee River and Clinch River inflows. Water entering Watts Bar from Melton Hill Reservoir is quite cool due to the hypolimnetic withdrawal from Norris Reservoir (a deep storage impoundment) upstream from Melton Hill. Water entering Watts Bar Reservoir from Fort Loudoun Dam is usually warmer and lower in DO during summer months than water entering from Melton Hill Dam.

The Emory River is a major tributary to the Clinch River arm of Watts Bar Reservoir and supplies about 5 percent of the average annual flow through Watts Bar Reservoir. The Tennessee and Little Tennessee Rivers (i.e., discharge from Fort Loudoun Dam) account for about 75 percent of the flow, and the Clinch River (i.e., discharge from Melton Hill Dam) accounts for about 15 percent through Watts Bar Reservoir.

Ecological Health

The ecological health of Watts Bar Reservoir was fair in 1993 (68 percent), similar to 1992 (71 percent) and 1991 (69 percent). Chlorophyll rated good at both the forebay and transition zone locations. Sediment quality testing at the forebay found low survival of test organisms and high concentrations of ammonia, leading to a poor rating. A fair to good rating for sediments at the transition zone was due to traces of chlordane; no other chemical analyte was problematic and no toxicity was found. Because of the release of water with low DOs from Fort Loudoun Dam, DO concentrations were less than 5 mg/L (minimum 3.9 mg/L) in the Tennessee River inflow to Watts Bar Reservoir. Benthic macroinvertebrates rated poor in 1993 at this site (as in both 1992 and 1991),

possibly related to the low DO concentrations. The fish assemblage was also poor at this inflow site in 1993. The inflow site on the Clinch River, downstream of Melton Hill Dam, had good DOs, but the benthos were poor and fish assemblage fair. Compared to 1992, this was a slight decrease for the benthos, but was similar to the previous results. All aquatic health indicators were good or excellent at the transition zone, generally similar to 1992 observations.

Aquatic plants have declined from about 700 acres in the late 1980s to about ten acres in 1993.

Reservoir Use Suitability

Fourteen swimming areas were tested for fecal coliform concentrations in 1993. Two other swimming sites were tested in 1990. Bacteriological water quality was within criteria at 14 sites. The other two sites met criteria if rainfall samples are excluded. Fecal coliform concentrations at Watts Bar swimming beaches are generally higher than at other Tennessee River Reservoirs. Monthly fecal coliform bacteria samples have been collected at the Vital Signs locations since 1990. All samples collected from April through September have been very low.

As a result of PCB contamination, the Tennessee Department of Environment and Conservation (TDEC) has issued advisories on consumption of several fish species from Watts Bar Reservoir. In the Tennessee River portion a "do not consume" advisory exists for catfish, striped bass, and striped bass/white bass hybrids. A precautionary advisory (children and pregnant or lactating women do not eat fish; all others limit fish consumption to 1.2 pounds per month) is in effect for largemouth bass, white bass, sauger, carp and smallmouth buffalo. In the Clinch River arm striped bass should not be eaten, and a precautionary advisory is in effect for catfish and sauger.

Also, TDEC has issued a "do not consume" advisory for fish taken from the east fork of Poplar Creek due to mercury, metals, and organic chemical contamination.

13.2 Fort Loudoun Reservoir

Physical Description

Fort Loudoun Reservoir is the ninth and uppermost reservoir on the Tennessee River with the dam located at TRM 602.3. The surface area and shoreline are relatively small (14,600 acres and 360 miles, respectively) considering the length (61 miles), indicating it is mostly a run-of-the-river reservoir. The average annual discharge from Fort Loudoun Dam is 18,400 cfs which provides an average hydraulic retention time of about ten days.

Fort Loudoun Reservoir (and the Tennessee River) is formed by the confluence of the French Broad and Holston Rivers, with both of these rivers having a major reservoir upstream. Douglas Dam, 32.3 miles up the French Broad River, and Cherokee Dam, 52.3 miles up the Holston River, form deep storage impoundments, each having long retention times. Both of these deep storage impoundments become strongly stratified during summer months resulting in the release of cool, low DO, hypolimnetic water during operation of the hydroelectric units. Some warming and reaeration of the water occurs downstream from Cherokee and Douglas Dams, but both temperature and DO levels are sometimes low when the water reaches Fort Loudoun Reservoir.

Fort Loudoun Reservoir also receives surface waters from the Little Tennessee River, via the Tellico Reservoir canal, which connects the forebays of the two reservoirs. (Since Tellico Dam has no outlet, under most normal conditions, water flows into Fort Loudoun Reservoir from Tellico Reservoir.) Water from Tellico Reservoir (Little Tennessee River) is often cooler and higher in DO, and has a much lower conductivity than water in Fort Loudoun Reservoir (Tennessee River). In 1992, the forebay sampling location on Fort Loudoun Reservoir (originally located at TRM 603.2) was moved upstream to TRM 605.5. This resulted in a better assessment of the water quality conditions of the Tennessee River in the forebay portion of Fort Loudoun Reservoir by minimizing the effects of the Little Tennessee River and Tellico Reservoir on the data gathered in the forebay of Fort Loudoun Reservoir.

Although Fort Loudoun Reservoir is a mainstream reservoir, its complex set of hydrologic conditions (cool water inflows from the Holston, French Broad, and Little Tennessee Rivers) often causes it to exhibit several characteristics that are more typical of a storage impoundment. In fact, analysis of historical fisheries data for the Tennessee Valley indicates the fish community of Fort Loudoun Reservoir is more similar to that in Valley storage impoundments than in other mainstream reservoirs.

Ecological Health

Vital Signs monitoring information showed the ecological health of Fort Loudoun Reservoir was between fair and poor in 1993 (58 percent), basically similar to 1992 (53 percent) and 1991 (60 percent). The only ecological health indicator which rated good or excellent on Fort Loudoun was DO at the forebay and transitions zone (no data were available from the inflow). Such good ratings for DO were surprising based on observations of lower DOs in 1993 in other mainstream reservoirs and historical concerns about DO in Fort Loudoun Reservoir.

Several indicators rated poor or very poor. Sediment quality at the forebay rated poor due to high zinc concentrations, presence of chlordane, and toxicity to Ceriodaphnia. Transition zone sediments rated fair with similar conditions as the forebay, but no toxicity to test organisms was found. These findings are consistent with results found in previous years. The fish assemblage rated poor at all three sample sites (forebay, transition zone, and inflow) mostly due to low species richness and low capture rate of individuals (similar to previous years). Benthic macroinvertebrates rated very poor at the inflow site due to low species richness and abundance (comparable to previous years). Benthos rated fair at the forebay and transition zone. Similar results had been found at the transition zone in previous years, but benthic invertebrates at the forebay improved in several metrics, especially species richness and reduced dominance by tolerant organisms.

Aquatic macrophytes only covered 25 acres on Fort Loudoun Reservoir in 1993. Coverage over the past decade has ranged 25 to 140 acres.

Reservoir Use Suitability

TDEC has issued advisories on consumption of two fish species from Fort Loudoun Reservoir. Tennessee advises people not to eat catfish taken from Fort Loudoun Reservoir because of high levels of PCBs. Also, largemouth bass should not be eaten if they weigh over two pounds or are caught in the Little River embayment due to PCB contamination.

Fort Loudoun Reservoir has had a PCB problem for more than 20 years. Initially, TVA and state agencies examined a variety of species from throughout the reservoir to document the geographical and species variation. The study now continues as a trend study in which there is an annual collection of catfish from one location. PCB concentrations in catfish have varied over the years with no distinct trend.

Fecal coliform concentrations at one boat ramp tested in 1993 were within criteria for recreation. In 1989, 1990, and 1992, fecal coliform samples were collected at a total of three

swimming beaches and 16 other sites. Bacteria concentrations were low at the swimming beaches and other sites in the downstream portion of the reservoir. Concentrations in the upstream portion of the reservoir, especially near downtown Knoxville, were much higher, with four sites exceeding Tennessee criteria. Fecal coliform concentrations at the monthly Vital Signs locations sampled since 1990 have been very low except for the April 1993 samples.

13.3 Melton Hill Reservoir

Physical Description

Melton Hill Dam is located at mile 23.1 on the Clinch River and is 56.7 miles downstream of Norris Dam. Impounded water extends upstream from Melton Hill Dam about 44 miles. Melton Hill Reservoir has about 170 miles of shoreline and 5690 surface acres at full pool. Average flow through Melton Hill is about 4900 cfs resulting in an average retention time of approximately 12 days. Melton Hill is TVA's only tributary dam with a navigation lock.

The predominant factor influencing the aquatic resources of Melton Hill Reservoir, especially the inflow and mid-reservoir areas, is the cold water entering from Norris Dam discharges. During summer, water discharged from Norris is cold and low in oxygen content. Oxygen concentrations are improved by a re-regulation weir downstream of Norris Dam and by atmospheric reaeration in the river reach between Norris Dam and upper Melton Hill Reservoir. However, water is warmed little and is still quite cool when it enters upper Melton Hill Reservoir. Bull Run Steam Plant, located at about CRM 47, warms the water some, but water temperatures are still too cool to support warm water biota and too warm to support cold water biota.

Ecological Health

The ecological health of Melton Hill Reservoir was in the upper end of the fair range in 1993 (68 percent, similar to 1992 and 1991). Chlorophyll and DO were excellent at both the forebay and the transition zone. However, a poor fish assemblage was found at forebay and inflow, generally similar to previous years. Primary problems in the fish assemblage were low species richness and abundance in electrofishing samples. Cool water flowing in from the bottom layer of Norris Lake causes problems for fish in Melton Hill, especially in the middle and upper sections. The water is too cold to support fish that like warm water, but too warm to support fish that thrive in cold water. The benthic macroinvertebrate community rated poor at the forebay and very poor at the transition zone and inflow, generally similar to previous years. Components of the benthos resulting in poor metrics were absence of long-lived and intolerant species and dominance by tolerant species.

Aquatic macrophyte coverage on Melton Hill Lake in 1993 was about 240 acres. During the past decade, coverage has ranged from about 100 to 250 acres.

Reservoir Use Suitability

No bacteriological studies were conducted at recreation areas in 1993. In 1989, samples were collected at four boat ramps during a period of high rainfall, and fecal coliform concentrations were high. In 1990, two swimming beaches and six other sites were tested during a more normal rainfall period. Concentrations were lower and within recreation criteria. Fecal coliform concentrations at the monthly Vital Signs locations sampled since 1991 have generally been low.

TDEC has advised the public to avoid consumption of catfish from Melton Hill Reservoir because of PCB contamination. Samples are collected annually from the transition zone and near the inflow by TVA and from the forebay by the Oak Ridge National Laboratory as part of ongoing, cooperative studies. PCB concentrations in catfish collected in autumn 1992 generally fell within the range found in previous years.

13.4 Emory River Stream Monitoring Site

Physical Description

The majority of the Emory River drainage area lies in the Cumberland Plateau and flows through the Tennessee counties of Cumberland, Morgan, and Roane. The Emory River leaves the plateau and cuts more than 600 feet down the eastern escarpment to join the Clinch River in the Valley and Ridge physiographic province as a major embayment to Watts Bar Reservoir.

The TVA monitoring station is located at the USGS stream gage at Oakdale. The Emory River drainage above Oakdale is 764 square miles or 88 percent of the entire Emory River basin. The principal tributary to the Emory is the Obed River (520 square miles). The principal tributaries to the Obed are Clear Creek (173 square miles) and Daddy's Creek (175 square miles).

Sandstone, shale, and conglomerates underlie most of the Emory River basin. Most of the basin is forested. About one-fourth of the basin lies within the Catoosa Wildlife Management Area, while about 5 percent is used for agriculture and 1 percent is used for surface coal mining. The only urban area above Oakdale is Crossville, Tennessee, near the headwaters of the Obed River.

Ecological Health

The overall ecological health of the Emory River at the stream monitoring site was good in 1993. This is an improvement over 1992 when fair conditions were found. The primary problem found in 1992 was poor sediment quality, evidenced by poor survival of test organisms. This was not the case for 1993 as no sediment toxicity was found.

Use Suitability

There were no bacteriological studies conducted on the Emory River in 1993.

A five fish composite each of carp, channel catfish, and largemouth were collected during summer 1992 and analyzed for selected metals, pesticides, and PCBs. Only PCBs in channel catfish were high enough to be of interest. The concentration was near that used to indicate need of more intensive investigation. Samples collected in summer 1993 should help evaluation of this situation.

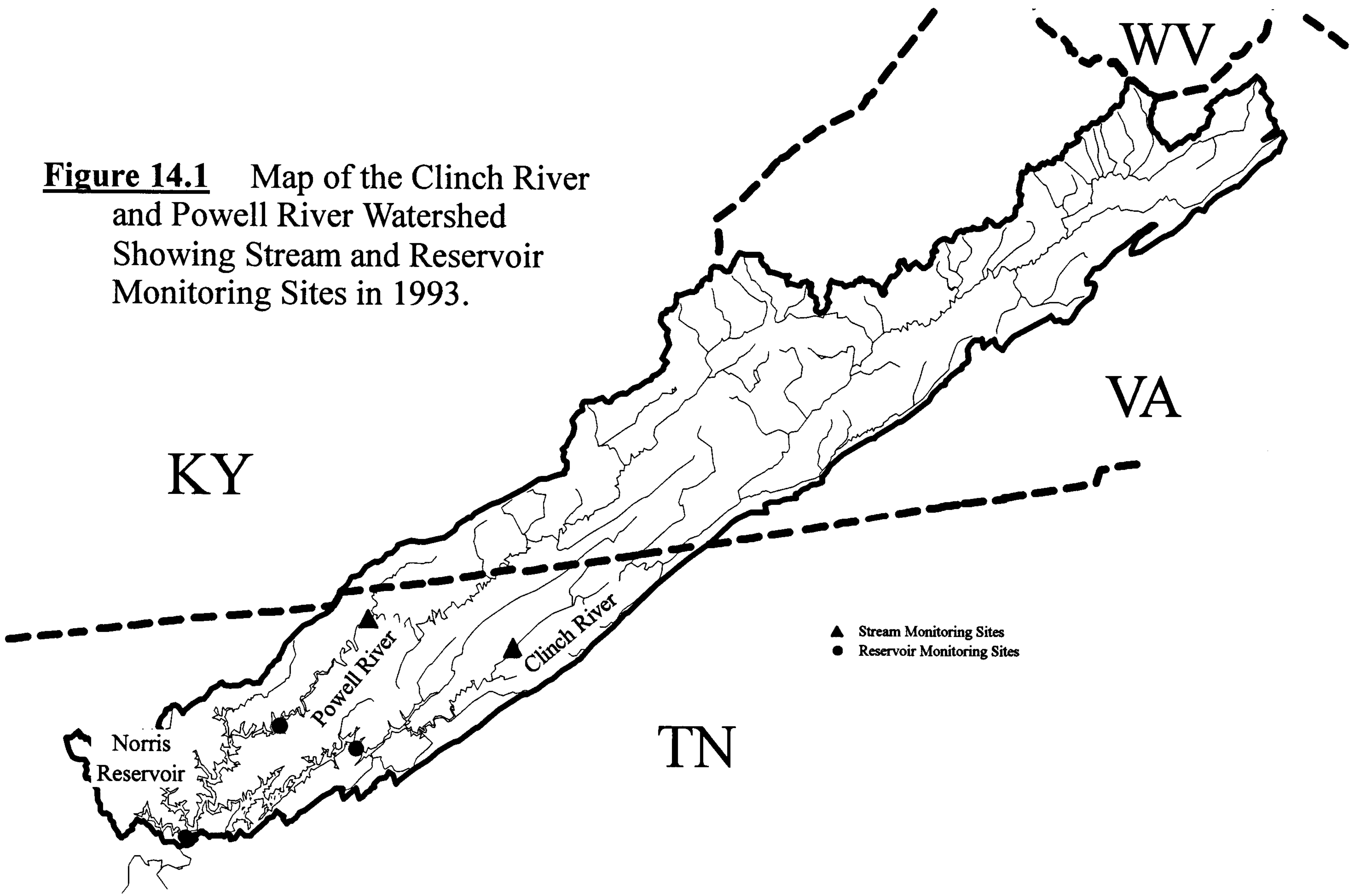
14.0 CLINCH RIVER AND POWELL RIVER WATERSHED

This long, narrow watershed lies in southwest Virginia and northeast Tennessee. Streams in the watershed have high concentrations of dissolved minerals and generally low concentrations of nutrients.

For management purposes, an artificial ending point of the watershed has been established at Norris Dam, which is near Clinch River mile 80. The remainder of the Clinch River is associated with the Watts Bar, Fort Loudoun, and Melton Hill Reservoir Watershed area. As defined, this watershed drains an area of 2912 square miles and has an average annual discharge of about 4200 cfs. The Clinch and Powell Rivers contribute about 80 percent of this flow.

Norris Reservoir is the only major reservoir in the watershed; essentially all streams upstream from Norris are free flowing. There are three Vital Signs monitoring sites in Norris Reservoir (forebay and mid-reservoir sites on the Clinch and Powell arms) and two stream sites, one each on the Clinch and Powell Rivers (Figure 14.1). Results from 1993 monitoring activities are in Section 14.1 for Norris Reservoir, Section 14.2 for the Clinch River stream monitoring site, and Section 14.3 for the Powell River stream monitoring site.

Figure 14.1 Map of the Clinch River and Powell River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.



14.1 Norris Reservoir

Physical Description

Norris Reservoir is formed by Norris Dam at Clinch River mile (CRM) 79.8. It is a large, dendritic, tributary storage impoundment of the Clinch and Powell Rivers which flow together about nine miles upstream of the dam. Norris is one of the deeper TVA tributary reservoirs, with depths over 200 feet. Annual drawdown averages about 32 feet. At full pool, the surface area of the reservoir is 34,200 acres, the shoreline is about 800 miles in length, and water is impounded 73 miles upstream on the Clinch River and 53 miles upstream on the Powell River. Norris Reservoir has a long average retention time (about 245 days) and an average annual discharge of approximately 4200 cfs. Due to the great depth and long retention time of Norris Reservoir, significant vertical stratification is expected. Additional information about the physical and hydrologic characteristics of Norris Reservoir are given in Table 4.1.

Because of the confluence of the Clinch and Powell Rivers relatively close to the dam, three reservoir sampling locations were established: one forebay site; and two mid-reservoir sites--one on the Clinch River and one on the Powell River.

Ecological Health

Norris is an oligotrophic reservoir with very clear water. There is little algal primary production because of phosphorus limitations. The ecological health of Norris Reservoir in 1993 was fair (67 percent), with conditions about the same as in 1992 and 1991 (60-67 percent). Dissolved oxygen concentrations in the deeper portions of Norris Reservoir, particularly at the mid-reservoir locations on the Clinch and Powell Rivers, have historically been low. This condition, although undesirable, is often observed in deep, thermally stratified tributary reservoirs with long retention times.

As expected, 1993 DO concentrations rated very poor at both mid-reservoir sites. The rating for DO at the forebay was poor in 1993 compared to fair in 1992. The 1992 results had indicated a slight improvement over 1991 conditions.

As in the past, low nutrient concentrations in the forebay resulted in low algal levels and a fair rating for chlorophyll in 1993. The effects of low primary productivity usually manifests itself throughout the food chain and results in a low overall abundance of fish. The fish assemblage rated fair at the forebay in 1993, primarily due to low abundance and low species richness. At both mid-

reservoir sites, both chlorophyll and fish assemblages rated good. The benthic macroinvertebrate community rated fair at the forebay and mid-reservoir site on the Clinch arm of Norris Reservoir and good at the mid-reservoir site on the Powell arm. Given the low DO concentrations near the bottom, fair to good ratings for benthic macroinvertebrates are better than would be expected. This suggests that the benthic community is able to recover quickly between autumn reoxygenation of bottom sediments and sample collection the following spring. Another possible explanation is that some of the samples collected along the transect were above the oxygen-stressed stratum. Results from individual samples suggest both factors contributed to the observed ratings.

Reservoir Use Suitability

There are no fish consumption advisories on Norris Reservoir. Channel catfish were collected for screening purposes in autumn 1992. All analytes were low or not detected except PCBs. The highest PCB concentration was 0.9 $\mu g/g$. Concentrations this high had not been found before. Areas were resampled in autumn 1993 to further examine PCB concentrations, but results were not available at the time this report was prepared.

Fecal coliform bacteria samples were collected at five sites in 1993. Concentrations were very low at all five sites. In 1991, ten sites were sampled. Fecal coliform concentrations were generally higher in 1991 than in 1993, possibly due to higher rainfall in 1991. However, in 1991 all sites met the geometric mean bacteriological water quality criterion for recreation. In 1991 three sites exceeded one of EPA's recommended guidelines; more than 10 percent of the samples had fecal coliform concentrations greater than 400/100 mL. Fecal coliform sampling at the Vital Signs locations was discontinued in 1993. Fecal coliform concentrations at the three Vital Signs stations sampled from 1990 to 1991 were very low.

14.2 Clinch River Stream Monitoring Site

Physical Description

The TVA stream monitoring station is located at the USGS stream gage near Tazewell, Tennessee, just upstream of the impounded water of Norris Reservoir, at CRM 159.8. The Clinch River basin above the monitoring site is 1474 square miles or 33 percent of the total Clinch River basin. Three-quarters of the monitored area lies within Virginia. Principal tributaries in the monitored area are the North Fork Clinch River (87 square miles), Guest River (102 square miles), Little River (126 square miles), Copper Creek (133 square miles), and Big Cedar Creek (86 square miles).

The headwaters of the upper Clinch River drain the eastern escarpment of the Cumberland Plateau (including portions of the Jefferson National Forest), then flow southwest through the Valley and Ridge physiographic province in a valley parallel to and southeast of the Powell River. Land use in the basin is 70 percent forestry and 30 percent agriculture. Coal mining occurs in some areas.

Ecological Health

The overall ecological health of the Clinch River at this site was good as in 1992. Conditions for fish and bottom-dwelling animals remained good in 1993. Sediment quality showed an improvement over 1992, with the rating changing from fair to good.

Use Suitability

Concentrations of fecal coliform bacteria were very low in 1993 at the weir and canoe launch site in the Clinch River downstream of Norris Dam. Concentrations were higher in 1991 when the canoe launch site had been tested.

All analytes in fish tissue samples collected during summer 1992 were either not detected or found in low concentrations.

14.3 Powell River Stream Monitoring Site

Physical Description

The Powell River joins the Clinch River 10 miles upstream from Norris Dam and forms a major embayment to Norris Reservoir. Most of the Powell River headwaters and tributary streams drain portions of the eastern border of the Cumberland Plateau, but the main river is predominantly in the Valley and Ridge physiographic province. The river flows for more than 195 miles through southwestern Virginia and northeastern Tennessee. The total drainage of the Powell River basin is 938 square miles.

The TVA monitoring station is located near Arthur, Tennessee. Above this location the area of the basin is 685 square miles or 73 percent of the entire Powell River watershed. Principal tributaries above Arthur include Indian Creek (66 square miles) and the North Fork Powell River (90 square miles).

Land use in the basin is 75 percent forest, 20 percent agriculture, and almost 5 percent surface mining, primarily in the upper reaches in southwestern Virginia. Only small urban areas are located in the Powell River watershed.

Ecological Health

Conditions for fish and bottom-dwelling animals improved to good in 1993. The change from a fair to a good classification was a result of greater numbers and higher quality bottom-dwelling organisms present. The Powell River watershed is heavily mined for coal and has a history of illegal discharges of blackwater into the river from coal washing facilities.

Use Suitability

There were no bacteriological studies conducted on the Powell River in 1993.

All analytes in fish tissue samples collected in summer 1993 wre either nondetectable or found low concentrations.

15.0 LITTLE TENNESSEE RIVER WATERSHED

The Little Tennessee River Watershed encompasses 2672 square miles, mostly in Tennessee and North Carolina with a small area in Georgia. Much of the watershed is forested, with the headwaters in the Blue Ridge Mountains. The basin is underlain mostly by crystalline and metasedimentary rocks of the Blue Ridge province. This watershed is home to a large variety of federally listed threatened and endangered species.

Most of the streams in the watershed are steep gradient and generally have low concentrations of both dissolved minerals and nutrients. The two largest tributaries to the Little Tennessee River are the Tuckasegee River which merges with the Little Tennessee in Fontana Reservoir and the Tellico River which merges with the Little Tennessee in Tellico Reservoir.

There are several reservoirs in the watershed but only Fontana Reservoir in the mountainous area and Tellico Reservoir at the lower end of the watershed are monitored (Figure 15.1). TVA does not monitor the other reservoirs either because of their small size or because they are owned by the Aluminum Company of America (ALCOA).

Two sites are monitored on Tellico Reservoir (the forebay and transition zone) and three sites on Fontana Reservoir (the forebay and mid-reservoir sites on the Little Tennessee River and Tuckasegee River). There is one stream monitoring site in the watershed, on the Little Tennessee River upstream of Fontana Reservoir. Another stream monitoring site (on the Tuckasegee River) is being added in 1994. Results of 1993 monitoring activities are provided in the following sections:

15.1 Tellico Reservoir

15.2 Fontana Reservoir

15.3 Little Tennessee River Stream Monitoring Site

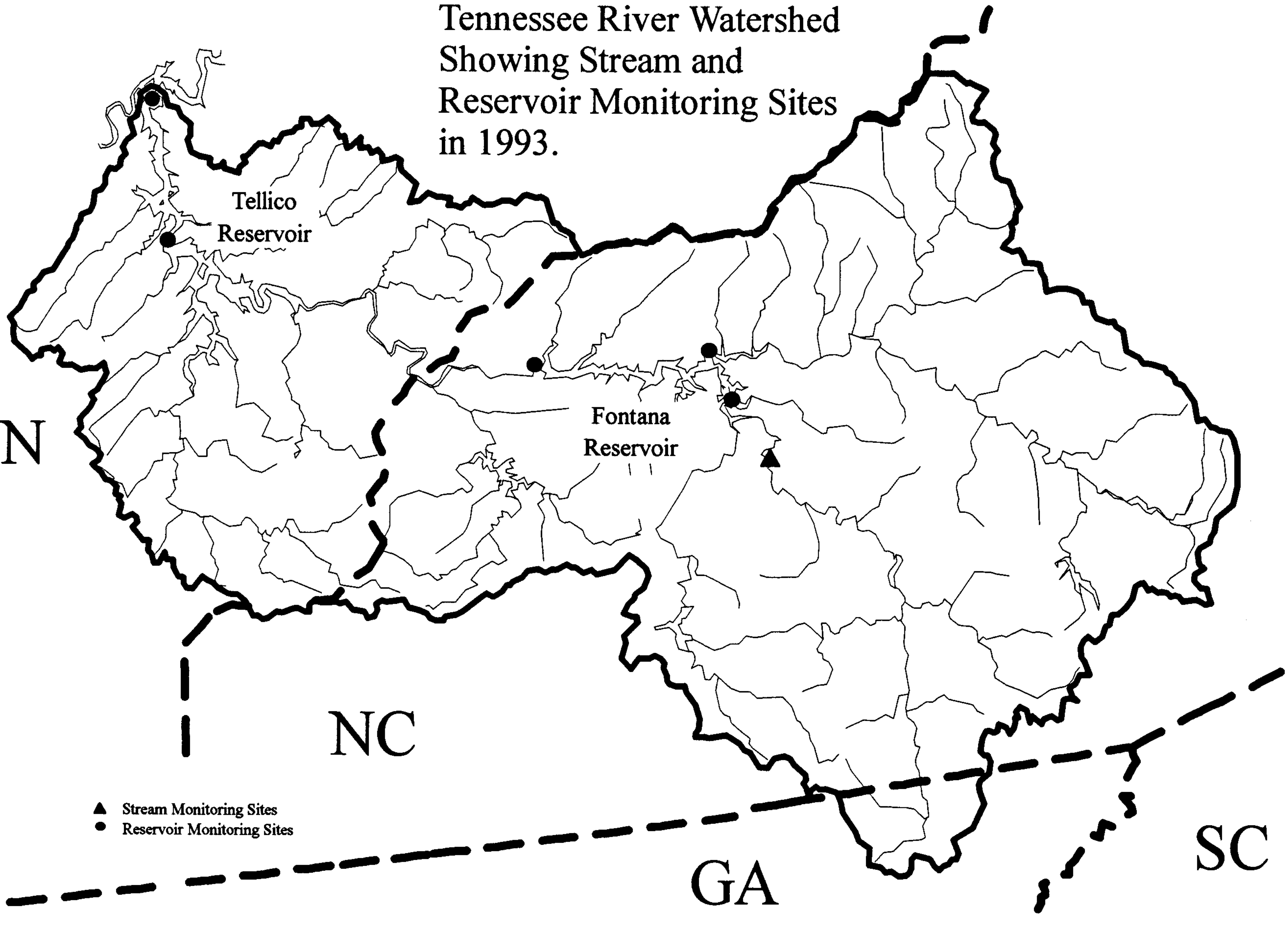


Figure 15.1 Map of the Little Tennessee River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.

15.1 Tellico Reservoir

Physical Description

Tellico Dam is located on the Little Tennessee River just upstream of the confluence of the Little Tennessee and Tennessee Rivers. It is the last dam completed in the TVA system with dam closure in 1979. Tellico Reservoir is 33 miles long, has a shoreline of 373 miles, and has a surface area of about 16,000 acres at full pool. The average estimated flow through Tellico Reservoir is approximately 5700 cfs which provides an average retention time of about 37 days. Very little of this water is discharged through Tellico Dam. Rather, it is diverted through a navigation canal to Fort Loudoun Reservoir near the dam for hydroelectric power production. Water characteristics in these two reservoirs differ considerably as discussed in Section 13.2, Fort Loudoun Reservoir. The hydrodynamics and exchange of water via the inter-connecting canal significantly affect water quality within Tellico Reservoir (and Fort Loudoun Reservoir). The canal is only 20-25 feet deep, but the depth of Tellico Reservoir at the forebay is about 80 feet. Thus, water at strata below about 25 feet is essentially trapped and becomes anoxic during much of the summer in the forebay of Tellico Reservoir.

The impounded water of Tellico Reservoir extends upstream of the confluence of the Little Tennessee and Tellico Rivers. The transition zone site selected for sample collection in 1990, 1991, and 1992 was in the Little Tennessee River, just upstream of the confluence with the Tellico River at Little Tennessee River Mile (LTRM) 21.0. Water conditions at that site are largely controlled by discharges from Chilhowee Dam at LTRM 33.6. This water is cold, nutrient poor, and has a low mineral content, conditions that are not conducive to establishing a diverse, abundant aquatic community. In 1993, the transition zone sampling location in Tellico Reservoir was moved six miles downstream to LTRM 15.0, just below the confluence of the Tellico River--a site more characteristic of lacustrine rather than riverine conditions.

Ecological Health

Tellico Reservoir received a better ecological health rating in 1993 than in previous years. The rating was 63 percent (fair) for 1993 compared to 48 percent in 1992 and 44 percent in 1991 (both poor). The primary causes of the higher score were better ratings for DO at the forebay (mostly the result of an improved, more accurate method of calculating the score for this indicator) and addition of information from the transition zone collection site which was relocated in 1993. The

change in DO scoring resulted in forebay DO being rated fair in 1993, whereas it had preciously been rated poor every year. Other than that change, all indicators at the forebay rated the same in 1993 as in previous years--poor sediment quality and benthic macroinvertebrate community, good chlorophyll, and fair fish assemblage.

Two indicators, chlorophyll and DO, received excellent ratings at the new transition zone site. The other three rated poor--sediment quality (presence of chlordane and significant toxicity), benthos (mostly due to absence of long-lived and sensitive organisms), and fish assemblage (few fish collected in gill netting efforts, which affected several metrics).

The higher ecological health score for 1993 is considered to be more representative of the true environmental conditions in Tellico Reservoir than previous scores.

Most of the 246 acres of aquatic macrophytes on Tellico Lake in 1993 were in the Tellico River arm of the reservoir.

Reservoir Use Suitability

No bacteriological studies were conducted at recreation areas in 1993. In 1992, fecal coliform samples were collected at four swimming beaches and five other sites on the reservoir. Bacteria concentrations were low. Fecal coliform concentrations at the monthly Vital Signs locations sampled since 1991 have been very low.

The state has advised that catfish from Tellico Reservoir should not be eaten because of PCB contamination. Fish were collected in autumn 1992 for tissue analysis. Channel catfish were collected as part of a continuing effort to examine the trend in PCB concentrations. Results indicate the PCB problem continued to exist with no downward trend.

15.2 Fontana Reservoir

Physical Description

Fontana Reservoir is located in the Blue Ridge Mountains of western North Carolina. Fontana is the deepest reservoir in the TVA system. At full pool it has a maximum depth of 460 feet, a length of 29 miles, a shoreline of 248 miles, and a surface area of 10,640 acres. Fontana Reservoir has a relatively large drawdown, which averages about 64 feet annually. Every fifth year Fontana is drawn even deeper to allow sluice gate access for maintenance.

Fontana Dam is located at Little Tennessee River Mile 61.0. Average annual discharge is 3840 cfs which provides an average hydraulic retention time in the reservoir of 186 days.

Water in Fontana Reservoir is quite clear due to limited photosynthetic activity and a mostly forested watershed. Water entering the reservoir is low in nutrients and dissolved minerals.

Ecological Health

Fontana Reservoir rated fair in 1993 (64 percent), the first year of Vital Signs monitoring. Fontana is an oligotrophic reservoir with very low chlorophyll concentrations resulting in fair ratings at all three sites. Further evidence of the low primary productivity is the clear, blue water (indicating low abundance of algae and lack of green phytoplankton pigments). Secchi depths averaged almost 6 meters in the forebay of Fontana in 1993. The fish assemblage also rated fair at all locations, probably related to the low primary productivity. Ratings for DO varied from excellent at the mid-reservoir site on the Little Tennessee River to poor at the mid-reservoir site on the Tuckasegee River, with a fair rating at the forebay. Sediment quality also varied greatly among the three locations--poor at the forebay, good at the mid-reservoir site on the Tuckasegee arm, and excellent on the Little Tennessee arm. Rating for the benthic macroinvertebrate community also varied greatly from very poor at the forebay to fair at the Little Tennessee River mid-reservoir site. The benthos rating at the forebay was not included in determining the overall ecological health score because part of the transect sampled was in the drawdown zone.

Reservoir Use Suitability

Channel catfish were collected in autumn 1992 from the forebay and mid-reservoir site on the Little Tennessee River. Analysis of composited fillets from each area found most analytes were not detected or had low concentrations. The exceptions to this were mercury at both locations

(maximum of 0.53 $\mu g/g$) and PCBs at the forebay (1.1 $\mu g/g$). Channel catfish were collected again in 1993 from both locations and analyzed for the same analytes with close attention for PCBs at the forebay. Largemouth bass were also collected in autumn 1993 from both locations to further examine mercury concentrations. Results were not available at the time this report was prepared.

There were no bacteriological studies conducted on Fontana Reservoir in 1993.

15.3 Little Tennessee River Stream Monitoring Site

Physical Description

The Little Tennessee River drains 2727 square miles and flows more than 140 miles through the Blue Ridge physiographic province of western North Carolina and the Valley and Ridge province of East Tennessee. It joins the Tennessee River near Lenoir City, Tennessee.

The TVA monitoring station is located near Needmore, North Carolina. The drainage area upstream from the monitoring site is 440 square miles or 16 percent of the entire Little Tennessee River basin. Principal tributaries to the Little Tennessee River include Abrams Creek (88 square miles), Cheoah River (215 square miles), Nantahala River (175 square miles), Cullasaja River (93 square miles), and the Tuckasegee-Oconaluftee River (734 square miles). The Cullasaja River is the only major tributary within the monitored area. The basin has been extensively developed with TVA reservoirs (Tellico and Fontana) and private power dams (Chilhowee, Calderwood, Cheoah, Santeetlah, Nantahala, Franklin, and Thorpe).

Igneous and metamorphic rock underlies all of the basin. Much of the basin is located within the federally managed lands of the Great Smoky Mountains National Park and Cherokee and Nantahala National Forests. Franklin, Sylva, Bryson City, and Robbinsville, North Carolina, are the primary urban areas in the basin.

Ecological Health

The stream monitoring site on the Little Tennessee River (at LTRM 94.5) had a very good ecological health rating in 1993 (as in 1992). All indicators (nutrients, sediment quality, benthos, and fish) were rated good.

Use Suitability

No bacteriological studies have been conducted in the streams of this watershed under this monitoring program.

All analytes in fish tissue samples collected during summer 1993 were either below detection limits or found in low concentrations.

16.0 FRENCH BROAD RIVER WATERSHED

The French Broad River watershed is one of the largest (5124 square miles) watersheds in the Tennessee Valley. About half the watershed is in Tennessee and half is in North Carolina. The French Broad River and its two large tributaries (Nolichucky and Pigeon Rivers) originate in the Blue Ridge Mountains. All three of these rivers merge at the upper end of Douglas Reservoir, the only sizable reservoir in the watershed. The water in the French Broad River is moderately hard and relatively high in nutrients.

There are three reservoir Vital Signs monitoring sites on Douglas Reservoir and one stream monitoring site each on the French Broad and Nolichucky Rivers (Figure 16.1). A stream monitoring site on the Pigeon River is being added in 1994. All stream monitoring sites are upstream of Douglas Reservoir.

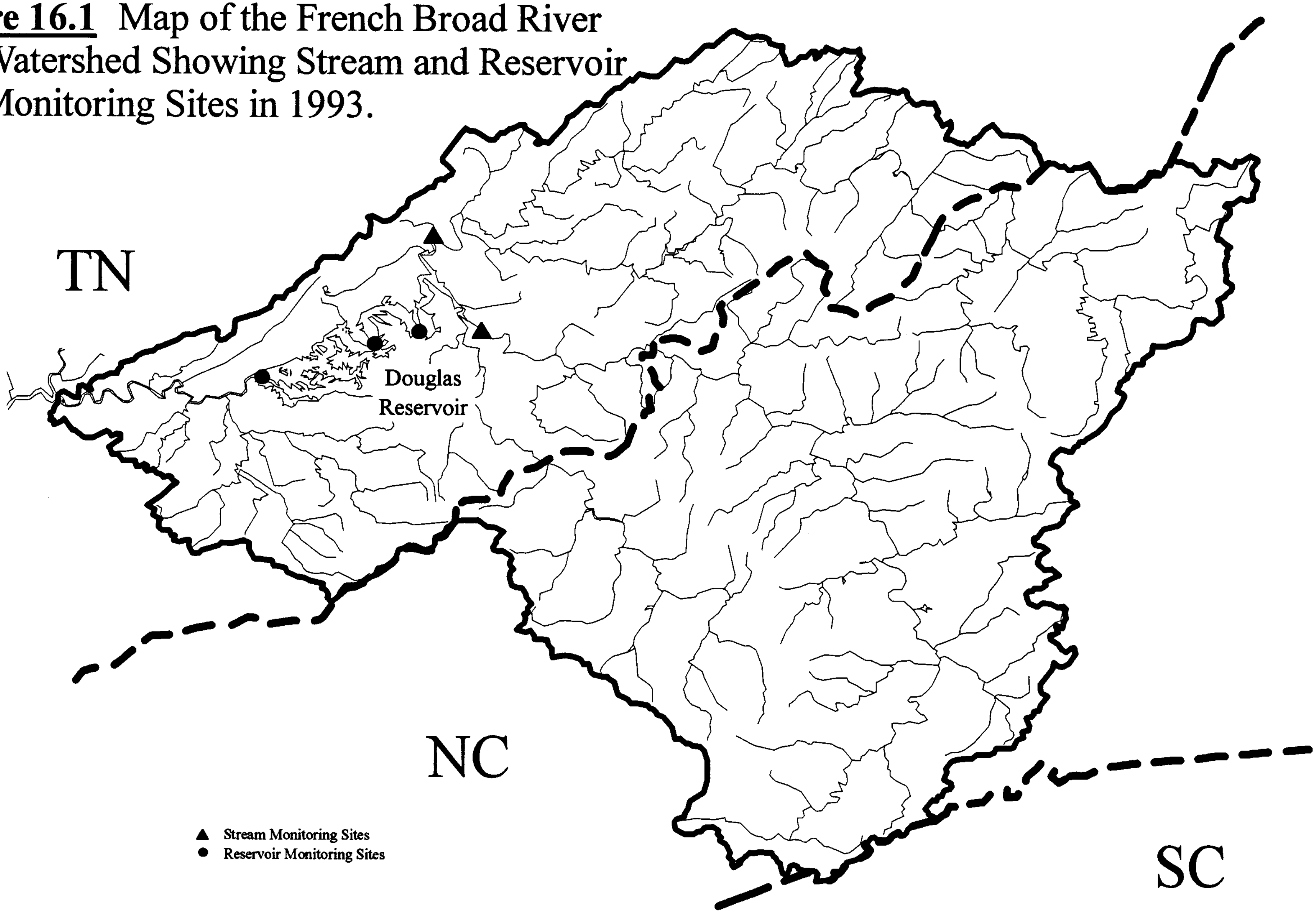
Results from 1993 Vital Signs monitoring activities are provided in the following sections:

16.1 Douglas Reservoir

16.2 French Broad River Stream Monitoring Site

16.3 Nolichucky River Stream Monitoring Site

Figure 16.1 Map of the French Broad River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.



16.1 Douglas Reservoir

Physical Description

Douglas Reservoir is a deep storage impoundment (tributary reservoir) on the French Broad River. Douglas Dam is located 32.3 miles upstream of the confluence of the French Broad and Holston Rivers which form the Tennessee River. Reservoir drawdown during late summer and autumn is rather large, with an annual average of about 48 feet. The large annual fluctuation in surface water elevation causes other physical characteristics such as surface area, reservoir length, and retention time to vary greatly during the year. At full pool, maximum depth at the dam is 127 feet, surface area is 30,400 acres, the shoreline is 555 miles, and the length is 43 miles. Average annual discharge is approximately 6780 cfs, which provides an average hydraulic retention time of about 105 days.

Lengthy retention times and lack of mixing due to their deep nature tend to cause storage impoundments to have strong thermal stratification during summer months. Undesirable conditions often develop in the hypolimnion due to anoxia, which in most cases extends from the forebay to the mid-reservoir sampling location.

Ecological Health

The ecological health of Douglas Reservoir was fair to poor (58 percent) in 1993, with little change compared to 1991 and 1992. Factors adversely affecting the ecological health of Douglas Reservoir were strong thermal stratification and high nutrient loadings. This combination results in hypolimnetic anoxia and release of iron and manganese, phosphorus, and ammonia from the sediment and excessive eutrophication of the reservoir. Ratings for DO were very poor at both the forebay and mid-reservoir sites in 1993 due to very low hypolimnetic DO at both locations and low surface DO at the forebay. This hypolimnetic anoxia promoted the release of ammonia (and sulfide) from the sediment and negatively impacted the benthic community. The benthic macroinvertebrates rated poor at the forebay (samples were not collected from the mid-reservoir site). Sediment quality rated good at the forebay but poor at the mid-reservoir site. The fish assemblage was fair at the forebay and good at the mid-reservoir site. Chlorophyll rated good at the forebay, but only fair at the mid-reservoir site because concentrations were relatively high, indicative of high nutrients and high primary productivity.

Reservoir Use Suitability

There are no fish consumption advisories on Douglas Reservoir. However, fish from the Pigeon River upstream of Douglas Reservoir should not be eaten because of dioxin contamination. The most recent collection of fish from Douglas Reservoir was in autumn 1992. TVA collected fish samples and provided fillets to the Tennessee Department of Environment and Conservation for analysis. Results were not available at the time this report was prepared.

Fecal coliform concentrations were very low at the swimming beach and two boat ramps tested in 1993. Fecal coliform bacteria sampling at the two Vital Signs stations was dropped in 1993. From 1990 to 1992, concentrations were very low.

16.2 French Broad River Stream Monitoring Site

Physical Description

The French Broad River is a major tributary to the Tennessee River system, flowing westward out of the Appalachian Mountains for more than 220 miles to meet the Holston River and form the Tennessee River.

The drainage basin above the stream monitoring site at the USGS stream gage at near Newport, Tennessee, is 1858 square miles or 36 percent of the watershed. Principal tributaries in the monitored area include Big Laurel Creek (132 square miles), Ivy Creek (161 square miles), the Swannanoa River (133 square miles), Hominy Creek (104 square miles), and Mud Creek (113 square miles). Two major tributaries enter the French Broad River below the monitoring site. They include the Nolichucky River (1756 square miles) and the Pigeon River (689 square miles).

Ecological Health

The ecological health of the stream monitoring site at the French Broad River site rated poor in both 1993 and 1992. Nutrients rated poor because of high concentrations of phosphorus. Inflows of nutrients promote the excessive algal productivity in Douglas Reservoir. The fish community on the French Broad River was poor in 1993, same as in 1992. Given the poor water quality of the Nolichucky and French Broad Rivers flowing into Douglas Reservoir, the poor-fair ecological health of the reservoir is not unexpected. Together the Nolichucky and French Broad Rivers provide about 75 percent of the total inflow to Douglas Reservoir.

Use Suitability

No bacteriological studies were conducted as part of the monitoring program in 1993. All analytes in fish tissue samples collected during summer 1993 were either not detected or found in low concentrations.

16.3 Nolichucky River Stream Monitoring Site

Physical Description

The Nolichucky River is a major tributary to the French Broad River basin and joins the French Broad River at the upstream end of Douglas Reservoir. The Nolichucky River Basin is 1756 square miles. The upper portion of the basin (approximately 60 percent) lies in the Blue Ridge physiographic province while the remainder lies in the Valley and Ridge province.

The stream monitoring location is at the TVA stream gage at the David Thomas bridge near Lowlands, Tennessee. The Nolichucky River basin above the monitoring site is 1686 square miles or 96 percent of the entire Nolichucky River basin. Principal tributaries in the monitored area include North Toe River (442 square miles) and Cane River (158 square miles) in the Blue Ridge physiographic province and Lick Creek (266 square miles) in the lower Valley and Ridge province.

The upper portion of the Nolichucky River basin is primarily forested, while the lower portion is agricultural. High concentrations of solids from mica and feldspar mining and processing near Spruce Pine on the North Toe River have severely impacted the streambed downstream. In addition to Spruce Pine, other urbanized areas include Greeneville and Erwin, Tennessee.

Ecological Health

The overall ecological health of the Nolichucky River at this site was good in 1993, as opposed to fair in 1992. The change was driven by improvements in the fish community, the absence of acute sediment toxicity, and improvements in nutrient concentrations. The conditions for bottom-dwelling animals remained unchanged.

Use Suitability

Bacteriological studies were not conducted as part of this monitoring program in this watershed in 1993.

All analytes in fish tissue samples collected during summer 1993 were either not detected or found in low concentrations.

17.0 HOLSTON RIVER WATERSHED

The Holston River Watershed encompasses 3776 square miles, mostly in upper east Tennessee and southwest Virginia and a small area in North Carolina. The area is relatively highly populated with substantial industrial development.

Much of the area is underlain with limestone and dolomite which results in high concentrations of dissolved minerals in the streams. There is also substantial zinc mining in the watershed.

There are several reservoirs in the watershed with varying size, depth, flow, and water quality characteristics. The largest is Cherokee Reservoir on the Holston River near the lower end of the watershed. The uppermost reservoirs are Watauga Reservoir on the Watauga River and South Holston Reservoir on the South Fork Holston River. Downstream from these reservoirs, the Watauga and South Holston Rivers merge in Boone Reservoir. Immediately downstream from Boone Dam is Fort Patrick Henry Reservoir, the smallest of the five reservoirs in this watershed included in the Vital Signs Monitoring Program. A few miles downstream from Fort Patrick Henry Dam the South Fork and North Fork Holston Rivers merge to form the Holston River.

Vital Signs monitoring activities are conducted at one, two, or three locations depending on reservoir size and characteristics (Figure 17.1). There is also a stream monitoring site on the Holston River upstream of Cherokee Reservoir.

The average annual discharge from Cherokee Dam is 4460 cfs. The Holston River merges with the French Broad River at Knoxville to form the Tennessee River.

Results from Vital Signs monitoring activities in 1993 are in the following sections:

17.1 Cherokee Reservoir

17.2 Fort Patrick Henry Reservoir

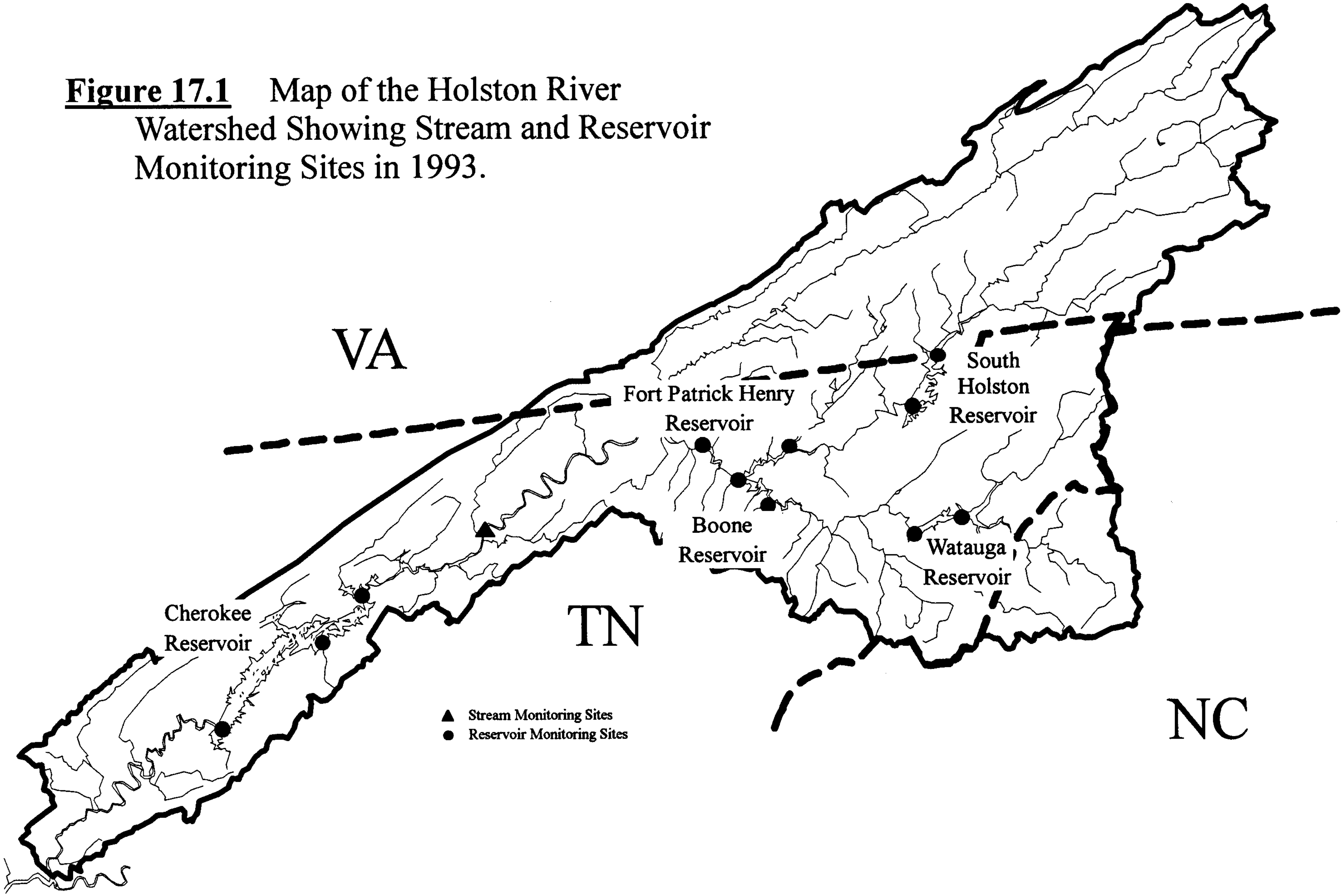
17.3 Boone Reservoir

17.4 South Holston Reservoir

17.5 Watauga Reservoir

17.6 Holston River Stream Monitoring Site

Figure 17.1 Map of the Holston River Watershed Showing Stream and Reservoir Monitoring Sites in 1993.



17.1 Cherokee Reservoir

Physical Description

Cherokee Reservoir is formed by Cherokee Dam at Holston River mile (HRM) 52.3. Like Norris and Douglas Reservoirs, it is a large, relatively deep, tributary storage impoundment with a substantial drawdown which begins in late summer. When the water surface is at full pool, maximum depth at the dam is 163 feet and winter drawdown is 53 feet. However, full pool is not reached most years, and the long-term average drawdown is about 28 feet. At full pool, Cherokee Reservoir is 54 miles long, has a surface area of 30,300 acres, and a shoreline of 393 miles. Average annual discharge is about 4500 cfs which provides an average hydraulic retention time (at full pool) of approximately 165 days.

Like other deep storage impoundments with long retention times, Cherokee Reservoir exhibits strong vertical stratification during summer months. The hypolimnetic oxygen deficit on Cherokee is one of the worst of all Vital Signs monitoring reservoirs and has been well documented in numerous past studies (Iwanski, 1978; Iwanski et al., 1980; Hauser et al., 1987).

Ecological Health

The ecological health of Cherokee Reservoir rated fair (64 percent) in 1993, which was higher than poor ratings in 1992 (55 percent) and poor to fair ratings in 1991 (60 percent). The improved ecological health rating compared to 1992 resulted mostly from addition of benthic macroinvertebrate information from the upper reservoir sample site, and from slight improvements (decreases) in chlorophyll concentrations at the mid-reservoir site. Although benthos data were collected from Cherokee Reservoir in 1992, ratings were not available for 1992 results because of an insufficient data base to establish expected (reference) conditions for the benthic macroinvertebrate community in tributary storage reservoirs. Additional benthos sampling in 1993 on Cherokee plus several other similar reservoirs provided sufficient data to establish at least preliminary expectations for reservoirs of this type. The benthic community rated fair at the forebay and excellent at the upper monitoring site indicating very good conditions there. Improvements noted for chlorophyll at the mid-reservoir site in 1993, rated good compared to fair in 1992 (due to high averages during summer), also helped elevate the overall ecological rating in 1993 compared to 1992.

A problem consistently found in Cherokee Reservoir is very low DO concentrations at the forebay and mid-reservoir sites. Both rated very poor in 1993. This near-bottom low dissolved

oxygen condition, often observed in deep tributary reservoirs with long retention times, is especially severe in Cherokee Reservoir, resulting in high concentrations of un-ionized ammonia in sediment. The fair fish community observed at all monitoring sites in 1993 was probably also influenced to some extent by the low oxygen concentrations in Cherokee Reservoir. Sediment quality rated poor at the mid-reservoir site due to high ammonia and copper concentrations coupled with significant toxicity to rotifers.

Reservoir Use Suitability

There are no fish consumption advisories on Cherokee Reservoir. Channel catfish for screening tissue analysis were collected in autumn 1992. All analytes were not detected or found in low concentrations except PCBs. Maximum PCB concentrations were 0.8 $\mu g/g$ at the forebay in 1992. Screening samples were collected again in 1993 to further examine PCB concentrations, but results were not available at the time this report was prepared.

Fecal coliform concentrations were low at all test sites in 1993--a swimming beach, seven boat ramps, and one other site tested. Fecal coliform bacteria sampling at the two Vital Signs stations was discontinued in 1993. From 1990 to 1992, concentrations were very low.

17.2 Fort Patrick Henry Reservoir

Physical Description

Fort Patrick Henry Reservoir is one of the smaller reservoirs included in the Vital Signs Monitoring Program. It is only ten miles long, has a surface area of about 870 acres, and has a shoreline of 37 miles. Although it is a tributary reservoir, it has characteristics of a run-of-river reservoir, rather than a storage reservoir. Annual fluctuation in elevation is only five feet. Also, retention time is short; with an average discharge of 2650 cfs, the hydraulic retention time is only about five days. Maximum depth is about 80 feet. Fort Patrick Henry Dam is located at South Fork Holston River mile 8.2.

This reservoir had not been sampled as part of this monitoring effort prior to 1993. Because of its small size, only the forebay is monitored for Vital Signs.

Ecological Health

The ecological health of Fort Patrick Henry Reservoir was fair to good (72 percent) in 1993. DO was the only indicator which rated excellent and sediment quality was the only indicator which rated good. Chlorophyll rated fair, with the average annual concentration only slightly above the level considered good. The benthos and fish assemblage also rated fair.

Reservoir Use Suitability

Fecal coliform concentrations at Warriors Path State Park were within Tennessee's criteria for recreation during 1993 studies. TVA's first fish tissue studies on this reservoir were conducted in autumn 1993; results were not available at the time this report was prepared.

17.3 Boone Reservoir

Physical Description

Boone Dam is located at South Fork Holston River mile (SFHRM) 18.6, approximately 1.4 miles downstream of the confluence of the South Fork Holston and the Watauga Rivers. At normal maximum pool (1384 feet MSL), Boone Reservoir extends upstream approximately 17.4 miles on the South Fork Holston River and 15.3 miles on the Watauga River for a total reservoir length of approximately 32.7 miles. Boone Reservoir has a surface area of 4300 acres, a shoreline length of approximately 122 miles, an average depth of 44 feet, and a maximum depth of 129 feet near the dam. Annual average discharge from Boone Dam is about 2500 cfs, which results in an average hydraulic residence time of about 38 days. Annual drawdowns of Boone Reservoir usually average about 25 feet.

Three locations were selected for ecological health monitoring in Boone Reservoir, one at the forebay and two mid-reservoir sampling locations, one on the Watauga River arm and one on the South Fork Holston River arm. Sediment and benthic macroinvertebrate sampling were added for the first time in 1993.

Ecological Health

The ecological health evaluation of Boone Reservoir was lower in 1993 compared to 1992. The rating for 1993 was toward the low end of the fair range (59 percent) whereas it was in the middle of the range in 1992 (64 percent). Ecological health ratings in both 1992 and 1993 were higher than in 1991 when poor conditions were found (51 percent). Primary contributors to lower scores in 1993 compared to 1992 were lower ratings for DO (fair at two locations and poor at one); lower ratings for the fish assemblage (poor at two locations and fair at one); and addition of ratings for the benthic macroinvertebrates (fair at two locations and poor at one). The ecological health indicator with the best rating in 1993 was chlorophyll, which rated good at the forebay.

The DO problem at the forebay and mid-reservoir site on the South Fork Holston River arm is different than other tributary, storage reservoirs. The typical problem is hypolimnetic anoxia, which is the case at the Watagua River mid-reservoir site. At the other two Boone Reservoir sites, the DO problem occurs in the middle stratum of the water column (metalimnion) due to oxygen demand of local sewage treatment plant discharges.

Reservoir Use Suitability

Studies conducted by the state of Tennessee found PCBs and chlordane in fish tissue, resulting in a state-issued advisory that catfish and carp should not be eaten by children, pregnant women, and nursing mothers. Further, all other people should limit their consumption of these particular fish. Additional fish samples were collected by TVA in autumn 1993, but results were not available at the time this report was prepared.

Bacteriological sampling was conducted at two swimming areas and four boat ramps in 1993. The geometric mean concentrations of fecal coliform bacteria were well within Tennessee's criteria for recreation, although one sample at the Boone Dam swimming area was high.

17.4 South Holston Reservoir

Physical Description

South Holston Reservoir in northeastern Tennessee and southwestern Virginia is created by South Holston Dam, located on the South Fork of the Holston River at mile 49.8. The dam creates a storage pool approximately 24 miles long, over 230 feet deep near the dam, with an average depth of 86.5 feet and approximately 7600 acres in surface area. With an average annual discharge of about 980 cfs from the dam, the average hydraulic residence time is almost one year (340 days)--one of the longest residence times of any TVA reservoir. Average annual drawdown of South Holston Reservoir is about 33 feet.

Two locations are monitored for Vital Signs--the forebay and mid-reservoir. Sediment and benthic macroinvertebrate sampling were added for the first time in 1993.

Ecological Health

The ecological health evaluation of South Holston Reservoir was fair (65 percent) in 1993, slightly better than in 1992 (57 percent) and 1991 (60 percent). A consistent problem has been with DO concentrations (as is the case with most deep storage impoundments), which rated poor at the forebay and very poor at the mid-reservoir site in 1993. Despite the poor ratings for DO, conditions were slightly improved at the forebay in 1993, compared to 1992. The ecological health indicator primarily responsible for the higher overall reservoir rating in 1993 was sediment quality (rated good at both sample sites). Sediments had not been sampled in previous years. Another indicator added in 1993, the benthic macroinvertebrate community, received a very poor rating at the forebay (with most metrics receiving the lowest score possible) and a fair rating at the mid-reservoir sample site. Interestingly, scores for the benthos do not parallel those for DO at the two sample sites, indicating other factor(s) may be affecting benthic macroinvertebrates at the forebay. The fish assemblage rated good at the forebay and fair at the mid-reservoir site.

Reservoir Use Suitability

There are no fish consumption advisories on South Holston Reservoir. The most recent TVA data for fish tissue samples for fish collected in autumn 1991 found low or nondetectable concentrations of all pesticides, PCBs, and metals (except mercury which was slightly elevated).

17.5 Watauga Reservoir

Physical Description

Watauga Dam in the northeastern corner of Tennessee impounds the Watauga River at mile 36.7. It forms a pool 16 miles in length, approximately 6400 acres in surface area, about 274 feet deep at the dam, and an average depth of about 89 feet, making it the second-deepest reservoir sampled as part of TVA's Vital Signs Monitoring Program. With an annual average discharge of about 700 cfs, Watauga Reservoir also has the longest hydraulic residence time of any of the Vital Signs reservoirs (about 400 days). Average annual drawdown of Watauga Reservoir is about 26 feet.

Two locations are monitored on Watauga Reservoir, the forebay and mid-reservoir. Sediment quality and benthic macroinvertebrates were examined for the first time in 1993.

Ecological Health

The overall ecological health for Watauga Reservoir was fair in 1993 (61 percent), about the same as in 1992 (57 percent). The ecological health in both 1992 and 1993 rated lower than in 1991, although all three years fell within the fair range. Similar to previous years, chlorophyll rated good at both sample sites in 1993. DO rated excellent at the forebay and fair at the mid-reservoir sites in 1993, a slight improvement compared to 1992. The fish assemblage was poor at the forebay in 1993 due to low abundance and diversity and rated fair at the mid-reservoir site, mostly due to low abundance. The benthic macroinvertebrate community, not sampled in Watauga Reservoir prior to 1993, was very poor at both locations. The benthos community was among the poorest in all Vital Signs reservoirs examined in 1993. This would not appear to be related to low DO concentrations; instead, the poor sediment quality at the forebay (due to toxicity to test animals and high ammonia) may have contributed to the poor benthos.

Reservoir Use Suitability

There are no fish consumption advisories on Watauga Reservoir. The most recent fish tissue collections by TVA were made in autumn 1991. All pesticides, PCBs, and metals (except mercury which was sightly elevated) were low or not detected.

Fecal coliform bacteria concentrations were very low at all five sites tested in 1993, which included one designated and an informal swimming area.

17.6 Holston River Stream Monitoring Site

Physical Description

The TVA stream monitoring station on the Holston River is located near Church Hill, Tennessee. The Holston River basin above this location is 2819 square miles or 74 percent of the entire Holston River basin. Two major tributaries, the North Fork Holston River (729 square miles) and the South Fork Holston River (2048 square miles), meet above Church Hill to form the Holston River. Principal tributaries to the South Fork Holston River include the Watauga River (869 square miles) and the Middle Fork Holston River (244 square miles). Two notable tributaries to the Watauga River include the Doe River (137 square miles) and Roan Creek (167 square miles).

There are five reservoirs in the basin. Fort Patrick Henry Dam and Boone Dam impound the lower South Fork Holston River. The South Fork Holston Dam impounds the upper South Fork Holston River and the Middle Fork Holston River. Wilbur Dam and Watauga Dam impound the Watauga River.

Although most of the basin land use is agricultural or forestry, several urban areas (Kingsport, Johnson City, and Elizabethton, Tennessee, and Marion and Abingdon, Virginia) are within the basin.

Ecological Health

The overall ecological health of the Holston River at this site was fair for 1993 as in 1992. Sediment quality improved from fair to good, and the fish community showed a slight improvement over 1992. Bottom-dwelling animals and nutrient ratings remain unchanged.

Use Suitability

Seven sites between Fort Patrick Henry Reservoir and South Holston Dam were tested for fecal coliform bacteria in 1993. South Fork Holston River met bacteriological water quality criteria for water contact recreation, and was only slightly impacted by the two tributaries tested. Thomas and Beidleman Creeks did not meet criteria.

A five fish composite each of carp, channel catfish, and largemouth bass were collected during summer 1992 and analyzed for selected metals, pesticides, and PCBs. All analytes were not detected or found in low concentrations except slightly elevated levels of mercury in largemouth (0.5 $\mu g/g$), PCBs in carp (0.6 $\mu g/g$), and chlordane in channel catfish (0.08 $\mu g/g$).

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