Biological Monitoring of the Tennessee River Near Sequoyah Nuclear Plant Discharge, Summer and Autumn 2011

May 2012
Tennessee Valley Authority
Biological and Water Resources
Knoxville, Tennessee

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

BIP	Balanced Indigenous Population
CCW	Condenser cooling water
CFS	Cubic feet per second
MW	Megawatts
NPDES	National Pollutant Discharge Elimination System
QA	Quality Assurance
RBI	Reservoir Benthic Macroinvertebrate Index
RFAI	Reservoir Fish Assemblage Index
SAHI	Shoreline Assessment Habitat Index
SQN	Sequoyah Nuclear Plant
TRM	Tennessee River Mile
TVA	Tennessee Valley Authority
VS	Vital Signs

Introduction

Section 316(a) of the Clean Water Act (CWA) authorizes alternative thermal limits (ATL) for the control of the thermal component of a discharge from a point source so long as the limits will assure the protection of Balanced Indigenous Populations (BIP) of aquatic life. The term "balanced indigenous population," as defined in EPA's regulations implementing Section 316(a), means a biotic community that is typically characterized by:

(1) diversity appropriate to ecoregion;

(2) the capacity to sustain itself through cyclic seasonal changes;

(3) the presence of necessary food chain species;

(4) lack of domination by pollution-tolerant species; and

Prior to 1999, the Tennessee Valley Authority's (TVA) Sequoyah Nuclear Plant (SQN) was operating under a 316(a) ATL that had been continued with each permit renewal based on studies conducted in the mid-1970s. In 1999, EPA Region IV began requesting additional data in conjunction with NPDES permit renewal applications to verify that BIP was being maintained at TVA's thermal plants with ATLs. TVA proposed that its existing Vital Signs (VS) monitoring program, supplemented with additional fish and benthic macroinvertebrate community monitoring upstream and downstream of thermal plants with ATLs, was appropriate for that purpose. The VS monitoring program began in 1990 in the Tennessee River System. This program was implemented to evaluate ecological health conditions in major reservoirs as part of TVA's stewardship role. One of the 5 indicators used in the VS program to evaluate reservoir health is the Reservoir Fish Assemblage Index (RFAI) methodology. RFAI has been thoroughly tested on TVA and other reservoirs and published in peer-reviewed literature (Jennings, et al., 1995; Hickman and McDonough, 1996; McDonough and Hickman, 1999). Fish communities are used to evaluate ecological conditions because of their importance in the aquatic food web and because fish life cycles are long enough to integrate conditions over time. Benthic macroinvertebrate populations are assessed using the Reservoir Benthic Index (RBI) methodology. Because benthic macroinvertebrates are relatively immobile, negative impacts to aquatic ecosystems can be detected earlier in benthic macroinvertebrate communities than in fish communities. These data are used to supplement RFAI results to provide a more thorough examination of differences in aquatic communities upstream and downstream of thermal discharges.

TVA initiated a study to evaluate fish and benthic macroinvertebrate communities in areas immediately upstream and downstream of SQN during autumn 1999-2011 using RFAI and RBI multi-metric evaluation techniques. Beginning in 2011, evaluations of plankton and wildlife communities were included as well. This report presents the results of summer and autumn 2011 RFAI, RBI, plankton, and wildlife data collected upstream and downstream of SQN.

Plant Description

Sequoyah Nuclear Power Plant (SQN) is located on the right (west) bank of Chickamauga Reservoir at Tennessee River Mile (TRM) 484.5 approximately 18 miles northeast of Chattanooga, Tennessee, and 7 miles southwest of Soddy-Daisy, Tennessee. SQN is situated approximately 54.5 river miles downstream from Watts Bar Dam and 13.5 river miles upstream from Chickamauga Dam (Figure 1).

SQN Unit 1 began commercial operation on July 1, 1981, and Unit 2 on June 1, 1982. Net operating capacity is about 2,400 MW of electricity. Waste heat load is about 4,800 MW of thermal energy. Waste heat is transferred to the condenser cooling water (CCW), pumped from the river at TRM 484.8 (Figure 2). This heat is then dissipated either to the atmosphere using two natural-draft cooling towers, to the river through a two-leg submerged multiport diffuser located at TRM 483.6, or by a combination of the two. With both units operating at maximum power, maximum CCW water demand is 2,558 cfs.

Methods

Aquatic Habitat in the Vicinity of SQN

Shoreline and river bottom habitat data presented in this report were collected during autumn 2009. TVA assumes habitat data to be valid for three years, barring any major changes to the river/reservoir (e.g., flood). Since no significant changes have occurred in the river system from the initial characterization, habitat will be sampled again during the next autumn sampling event. In the event of a major change to the river/reservoir, habitat would be re-sampled the following autumn.

Shoreline Aquatic Habitat Assessment

An integrative multi-metric index (Shoreline Aquatic Habitat Index or SAHI), including several habitat parameters important to resident fish species, was used to measure existing fish habitat quality in the vicinity of Sequoyah Nuclear Plant. Using the general format developed by Plafkin et al. (1989), seven metrics were established to characterize selected physical habitat attributes important to resident fish populations which rely heavily on the littoral or shoreline zone for reproductive success, juvenile development, and/or adult feeding (Table 1). Habitat Suitability Indices (US Fish and Wildlife Service), along with other sources of information on biology and habitat requirements (Etnier and Starnes 1993), were consulted to develop "reference" criteria or "expected" conditions from a high quality environment for each parameter. Some generalizations were necessary in setting up scoring criteria to cover the various requirements of all species into one index.

Individual metrics are scored through comparison of observed conditions with these "reference" conditions and assigned a corresponding value: good-5; fair-3; or poor-1 (Table 1). The scores for each metric are summed to obtain the SAHI value. The range of potential SAHI values (7-35) is trisected to provide some descriptor of habitat quality (poor: 7-16; fair: 17-26; and good: 27-35).

The quality of shoreline aquatic habitat was assessed while traveling parallel to the shoreline in a boat and evaluating the habitat within 10 vertical feet of full pool. This was much easier to accomplish when the reservoir was at least 10 feet below full pool during the assessment allowing accurate determination of near-shore aquatic habitat quality. To sample river bottom habitat, eight line-of-sight transects were established across the width of Chickamauga reservoir within the SQN downstream (TRMs 481.1 to 483.6) and upstream (TRMs 487.9 to 491.1) fish community sampling areas (Figure 5). Near-shore aquatic habitat was assessed along sections of shoreline corresponding to the left descending (LDB) and right descending (RDB) bank locations for each of the eight line-of-sight transects. These individual sections (8 on the LDB and 8 on the RDB for a total of 16 shoreline assessments) were scored using SAHI criteria. Percentages of aquatic macrophytes in the littoral areas of the 8 LDB and 8 RDB shoreline sections were also estimated.

River Bottom Habitat

Along each of the 8 line-of-sight transects described above, 10 benthic grab samples were collected with a Ponar sampler at equally spaced points from the LDB to RDB. Substrate material collected with the Ponar was dumped into a screen and substrate percentages were estimated to determine existing benthic habitat across the width of the river. Water depths at each sample location were recorded (feet). If no substrate was collected after multiple Ponar drops, it was assumed that the substrate was bedrock. For example, when the Ponar was pulled shut, collectors could feel substrate consistency; if it shut easily and was not embedded in the substrate on numerous drops within the same location, substrate was recorded as bedrock.

Fish Community Sampling Methods and Data Analysis for Sites Upstream and Downstream of SQN

Two sample locations, one upstream and one downstream of the plant discharge were selected in Chickamauga Reservoir. The SQN discharge enters the Tennessee River at TRM 483.6 (Figure 2). The upstream monitoring site was centered at TRM 490.5 (Figure 3) and the downstream site was centered at TRM 482.0 (Figure 4).

Fish sampling methods included boat electrofishing and gill netting (Hubert, 1996; Reynolds, 1996). Electrofishing methodology consisted of fifteen boat electrofishing runs near the shoreline, each 300 meters long with a duration of approximately 10 minutes each. The total near-shore area sampled was approximately 4,500 meters (15,000 feet).

Experimental gill nets (so called because of their use for research as opposed to commercial fishing) were used as an additional gear type to collect fish from deeper habitats not effectively sampled by electrofishing. Each experimental gill net consists of five 6.1-meter panels for a total length of 30.5 meters (100.1 feet). The distinguishing characteristic of experimental gill nets is mesh size that varies between panels. For this application, each net has panels with mesh sizes of 2.5, 5.1, 7.6, 10.2, and 12.7 cm. Experimental gill nets are typically set perpendicular to river flow extending from near-shore toward the main channel of the reservoir. Ten overnight experimental gill net sets were used at each area.

Fish collected were identified by species, counted, and examined for anomalies (such as disease, deformations, parasites, or hybridization). The resulting data were analyzed using RFAI methodology.

The RFAI uses 12 fish community metrics from four general categories: Species Richness and Composition; Trophic Composition; Abundance; and Fish Health. Individual species can be utilized for more than one metric. Together, these 12 metrics provide a balanced evaluation of fish community integrity. The individual metrics are described below, grouped by category:

Species Richness and Composition

(1) **Total number of indigenous species** -- Greater numbers of indigenous species are considered representative of healthier aquatic ecosystems. As conditions degrade, numbers of species at an area decline.

(2) **Number of centrarchid species** -- Sunfish species (excluding black basses) are invertivores and a high diversity of this group is indicative of reduced siltation and suitable sediment quality in littoral areas.

(3) **Number of benthic invertivore species** -- Due to the special dietary requirements of this species group and the limitations of their food source in degraded environments, numbers of benthic invertivore species increase with better environmental quality.

(4) **Number of intolerant species** -- This group is made up of species that are particularly intolerant of physical, chemical, and thermal habitat degradation. Higher numbers of intolerant species suggest the presence of fewer environmental stressors.

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

(6) **Percent dominance by one species** -- Ecological quality is considered reduced if one species inordinately dominates the resident fish community.

(7) **Percentage of non-indigenous species** -- Based on the assumption that non-indigenous species reduce the quality of resident fish communities.

(8) Number of top carnivore species -- Higher diversity of piscivores is indicative of the availability of diverse and plentiful forage species and the presence of suitable habitat.

Trophic Composition

(9) Percentage of individuals as top carnivores -- A measure of the functional aspect of top carnivores which feed on major planktivore populations.

(10) 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.

Abundance

(11) Average number per run -- (number of individuals) -- This metric is based upon the assumption that high quality fish assemblages support large numbers of individuals.

Fish Health

(12) Percentage of 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 less favorable environmental conditions.

RFAI methodology addresses all four attributes or characteristics of a "balanced indigenous population" defined by the CWA, as described below:

(1.) A biotic community characterized by diversity appropriate to the ecoregion: Diversity is addressed by the metrics in the Species Richness and Composition category, especially metric 1 – "total number of indigenous species." Determination of reference conditions based on the forebay and transition zones of upper mainstem Tennessee River reservoirs (as described below) ensures appropriate species expectations for the ecoregion.

(2.) The capacity for the community to sustain itself through cyclic seasonal change: TVA uses an autumn data collection period for biological indicators, both VS and upstream/downstream monitoring. Autumn monitoring is used to document community condition or health after being subjected to the wide variety of stressors throughout the year. One of the main benefits of using biological indicators is their ability to integrate stressors through time. Examining the condition or health of a community at the end of the "biological year" (i.e., autumn) provides insight into how well the community has dealt with the stresses through an annual seasonal cycle. Likewise, evaluation of the condition of individuals in the community (in this case, individual fish as reflected in Metric 12) provides insight into how well the community can be expected to withstand stressors through winter. Further, multiple sampling years during the permit renewal cycle add to the evidence of whether or not the autumn

monitoring approach has correctly demonstrated the ability of the community to sustain itself through repeated seasonal changes.

Summer sampling was conducted during August 2011. This time of year is considered a stressful time for the biotic community. Summer sampling was conducted to collect data on the biotic community during a high stress period near SQN plant. These data were compared with data collected during summer 2010.

(3.) The presence of necessary food chain species: Integrity of the food chain is measured by the Trophic Composition metrics, with support from the Abundance metric and Species Richness and Composition metrics. Existence of a healthy fish community indicates presence of necessary food chain species because the fish community is comprised of species that utilize multiple feeding mechanisms that transcend various levels in the aquatic food web. Basing evaluations on a sound multi-metric system such as the RFAI enhances the ability to discern alterations in the aquatic food chain.

Three dominant fish trophic levels exist within Tennessee River reservoirs; insectivores, omnivores, and top carnivores. To determine the presence of necessary food chain species, these three groups should be well represented within the overall fish community. Other fish trophic levels include benthic invertivores, planktivores, herbivores, and parasitic species. Insectivores include most sunfish, minnows, and silversides. Omnivores include gizzard shad, common carp, carpsuckers, buffalo, channel catfish, and blue catfish. Top carnivores include black bass, gar, skipjack herring, crappie, flathead catfish, sauger, and walleye. Benthic invertivores include freshwater drum, suckers, and darters. Planktivores include alewife, threadfin shad, and paddlefish. Herbivores include largescale stonerollers. Lampreys in the genus *Ichthyomyzon* are the only parasitic species occurring in Tennessee River reservoirs.

To establish expected proportions of each trophic guild and the expected number of species included in each guild occurring in upper mainstem Tennessee River reservoirs (Nickajack, Chickamauga, Watts Bar, and Fort Loudon reservoirs), data collected from 1993 to 2010 during autumn were analyzed for each reservoir zone where upstream and downstream sample stations were established to monitor effects of the SQN discharge (forebay- downstream of SQN and transition- upstream of SQN). Samples collected in the downstream vicinity of thermal discharges were not included in this analysis so that accurate expectations could be calculated with the assumption that these data represent what should occur in upper mainstem Tennessee River reservoirs absent from point source effects (i.e. power plant discharges). Therefore, data from the monitoring site downstream of SQN at TRM 482 were not included in this analysis. Data from 900 electrofishing runs (a total of 270,000 meters of shoreline sampled) and from 600 overnight experimental gill net sets were included in this analysis for forebay areas in upper mainstem Tennessee River reservoirs. For upper mainstem Tennessee River transition zones, data from 750 electrofishing runs and 500 overnight experimental gill net sets were included. From these data, the range of proportional values for each trophic level and the range of the number of species included in each trophic level were trisected. This trisection is intended to show less than expected, expected and above expected values for trophic level proportions and species occurring within each reservoir zone in upper mainstem Tennessee River reservoirs (Table 2). These data were also averaged and bound by confidence intervals (95%) to further

evaluate expected values for proportions of each trophic level and the number of species expected for each trophic level by reservoir zone (Table 3).

(4.) A lack of domination by pollution-tolerant species: Domination by pollution-tolerant species is measured by metrics 3 ("Number of benthic invertivore species"), 4 ("Number of intolerant species"), 5 ("Percentage of tolerant individuals"), 6 ("Percent dominance by one species"), and 10 ("Percentage of individuals as omnivores").

Scoring categories are based on "expected" fish community characteristics in the absence of human-induced impacts other than impoundment of the reservoir. These categories were developed from historical fish assemblage data representative of forebay and transition zones from upper mainstem Tennessee River reservoirs (Hickman and McDonough, 1996). Attained values for each of the 12 metrics were compared to the scoring criteria and assigned scores to represent relative degrees of degradation: least degraded (5); intermediate degraded (3); and most degraded (1). Scoring criteria for upper mainstem Tennessee River reservoirs are shown in Table 4.

If a metric was calculated as a percentage (e.g., "Percentage of tolerant individuals"), data from electrofishing and gill netting were scored separately and allotted half the total score for that individual metric. Individual metric scores for a sampling area (e.g., upstream or downstream) are summed to obtain the RFAI score for the area.

TVA uses RFAI results to determine maintenance of BIP using two approaches. One is "absolute" in that it compares the RFAI scores and individual metrics to predetermined values. The other is "relative" in that it compares RFAI scores attained downstream to the upstream control site. The "absolute" approach is based on Jennings et al. (1995) who suggested that favorable comparisons of the attained RFAI score from the potential impact zone to a predetermined criterion can be used to identify the presence of normal community structure and function and hence existence of BIP. For multi-metric indices, TVA uses two criteria to ensure a conservative screening of BIP. First, if an RFAI score reaches 70% of the highest attainable score of 60 (adjusted upward to include sample variability as described below), and second, if fewer than half of RFAI metrics receive a low (1) or moderate (3) score, then normal community structure and function would be present indicating that BIP had been maintained, thus no further evaluation would be needed.

RFAI scores range from 12 to 60. Ecological health ratings (12-21 ["Very Poor"], 22-31 ["Poor"], 32-40 ["Fair"], 41-50 ["Good"], or 51-60 ["Excellent"]) are then applied to scores. As discussed in detail below, the average variation for RFAI scores in TVA reservoirs is 6 ($\pm$ 3). Therefore, any location that attains an RFAI score of 45 or higher would be considered to have BIP. It must be stressed that scores below this threshold do not necessarily reflect an adversely impacted fish community. The threshold is used to serve as a conservative screening level; i.e., any fish community that meets these criteria is obviously not adversely impacted. RFAI scores below this level would require a more in-depth look to determine if BIP exists. An inspection of individual RFAI metric results and species of fish used in each metric would be an initial step to help identify if operation of SQN is a contributing factor. This approach is appropriate because a validated multi-metric index is being used and scoring criteria applicable to the zone of study are available.

A difference in RFAI scores attained at the downstream area compared to the upstream (control) area is used as one basis for determining presence or absence of impacts on the resident fish community from SQN's operations. The definition of "similar" is integral to accepting the validity of these interpretations. The Quality Assurance (QA) component of the Vital Signs monitoring program deals with how well the RFAI scores can be repeated and is accomplished by collecting a second set of samples at 15%-20% of the areas each year. Comparison of paired-sample QA data collected over seven years shows that the difference in RFAI index scores ranges from 0 to 18 points. The mean difference between these 54 paired scores is 4.6 points with 95% confidence limits of 3.4 and 5.8. The 75^{th} percentile of the sample differences is 6, and the 90^{th} percentile is 12. Based on these results, a difference of 6 points or less in the overall RFAI scores is the value selected for defining "similar" scores between upstream and downstream fish communities. That is, if the downstream RFAI score is within 6 points of the upstream score and if there are no major differences in overall fish community composition, then the two locations are considered similar. It is important to bear in mind that differences greater than 6 points can be expected simply due to method variation (i.e., 25% of the QA paired sample sets exceeded a difference of 6). An examination of the 12 metrics (with emphases on fish species used for each metric) is conducted to determine any difference in scores and the potential for the difference to be thermally related.

Traditional Analyses

In addition to RFAI analyses, data were analyzed using traditional statistical methods. Data from the survey were used to calculate catch per unit effort (CPUE), which was expressed as number of fish per electrofishing run or fish per net night. CPUE values were calculated by pollution tolerance, trophic guilds (e.g., benthic invertivores, top carnivores, etc.), thermal sensitivity (Yoder et al. 2006), and indigenousness. CPUE, species richness, and diversity values were computed for each electrofishing effort (to maximize sample size; n = 30) and compared upstream and downstream to assess potential effects of power plant discharges.

Diversity was quantified using two commonly used diversity indices: Shannon diversity index (Shannon 1948) and Simpson diversity index (Simpson 1949). Both indices account for the number of species present, as well as the relative abundance of each species.

Shannon diversity index values were computed using the formula:

$$H' = -\sum_{i=1}^{S} \left(\frac{n_i}{N}\right) \ln\left(\frac{n_i}{N}\right)$$

where:
S = total number of species
N = total number of individuals
n_i = total number of individuals in the i^{th} species

The Simpson diversity index was calculated as follows:

$$D_S = \left(\sum_{i=1}^{S} \left(\frac{n_i}{N}\right)^2\right) - 1$$

where:
S = total number of species
N = total number of individuals
n_i = total number of individuals in the i^{th} species

An independent two-sample *t*-test was used to test for differences in CPUE, species richness, and diversity values upstream and downstream of SQN ($\alpha = 0.05$). Before statistical tests were performed using this method, data were analyzed for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965) and homogeneity of variance using Levene's test (Levene, 1960). Non-normal count data or data with unequal variances were transformed using square root conversion; the transformation ln(x+1) was used for CPUE data without a normal distribution or unequal variance. Transformed data was reanalyzed for normal distribution and equal variances. If transformation normalized the data and/ or resulted in homogeneous variances, transformed data were tested using an independent two-sample *t*-test. If transformed data were not normally distributed or had unequal variances, statistical analysis was conducted using the Wilcoxon-Mann-Whitney test (Mann and Whitney, 1947; Wilcoxon, 1945).

Benthic Macroinvertebrate Community Sampling Methods and Data Analysis for Sites Upstream and Downstream of SQN

During summer 2011, benthic macroinvertebrate data were collected along transects established across the full width of the reservoir at TRMs 481.3 and 483.4 downstream of SQN (Figure 3) and TRMs 488.0 and 490.5 upstream of SQN (Figure 4). Autumn 2011 sites included only TRM 481.3, TRM 483.4 and TRM 490.5. TRM 488.0 was not used as a collection site in autumn 2011 because TRM 490.5 is a long-term data collection site for the autumn seasons. Historically, the benthic macroinvertebrate community downstream of SQN was sampled at TRM 482.0; however during summer and autumn 2011, benthic macroinvertebrates were sampled at two transects (TRM 481.3 and TRM 483.4) to more accurately depict the health of the downstream benthic community.

Benthic grab samples were used to collect samples at equally spaced points along the upstream and downstream transects. During summer 2011, benthic grab samples were collected from five points along the two upstream transects. Autumn 2011 samples were collected from ten points along the transect located at TRM 490.5 and five points at TRM 488.0. Samples were collected from ten points along each downstream transect during summer and autumn 2011.

A Ponar sampler (area per sample 0.06 m^2) was used for most samples. When heavier substrate was encountered, a Peterson sampler (area per sample 0.11 m^2) was used. Collection and processing techniques followed standard VS procedures (OER-ESP-RRES-AMM-21.11; Quantitative Sample Collection - Benthic Macroinvertebrate Sampling with a Ponar Dredge). Bottom sediments were washed on a 533µ screen; organisms were then picked from the screen and any remaining substrate. For each sample, organisms and substrate were placed in a sample

jar and fixed in formalin. Samples were sent to an independent consultant who identified each organism collected to the lowest possible taxonomic level.

Benthic community results were evaluated using seven community characteristics or metrics. Results for each metric were assigned a score of 1, 3, or 5 depending upon how they scored based on reference conditions developed for VS reservoir inflow sample sites. Scoring criteria for upper mainstem Tennessee River reservoirs are shown in Table 5. The scores for the seven metrics were summed to produce a benthic score for each sample site. Potential scores ranged from 7 to 35. Ecological health ratings (7-12 ["Very Poor"], 13-18 ["Poor"], 19-23 ["Fair"], 24-29 ["Good"], or 30-35 ["Excellent"]) were then applied to scores. The individual metrics are shown below:

(1) **Average number of taxa**—This metric is calculated by averaging the total number of taxa present in each sample at a site. Taxa generally mean family or order level because samples are processed in the field. For chironomids, taxa refers to obviously different organisms (i.e., separated by body size, head capsule size and shape, color, etc.). Greater taxa richness indicates better conditions than lower taxa richness.

(2) **Proportion of samples with long-lived organisms**—This is a presence/absence metric which is evaluated based on the proportion of samples with at least one long-lived organism (*Corbicula, Hexagenia*, mussels, and snails) present. The presence of long-lived taxa is indicative of conditions which allow long-term survival.

(3) **Average number of EPT taxa**—This metric is calculated by averaging the number of *Ephemeroptera*, *Plecoptera*, and *Trichoptera* taxa present in each sample at a site. Higher diversity of these taxa indicates good water quality and better habitat conditions.

(4) **Percentage as oligochaetes**—This metric is calculated by averaging the percentage of oligochaetes in each sample at a site. Oligochaetes are considered tolerant organisms so a higher proportion indicates poorer water quality.

(5) **Percentage as dominant taxa**—This metric is calculated by selecting the two most abundant taxa in a sample, summing the number of individuals in those two taxa, dividing that sum by the total number of animals in the sample, and converting to a percentage for that sample. The percentage is then averaged for the 10 samples at each site. Often, the most abundant taxa differed among the 10 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 a site. This metric is used as an evenness indicator. Dominance of one or two taxa indicates poor conditions.

(6) **Average density excluding Chironomids and Oligochaetes**—This metric is calculated by first summing the number of organisms, excluding chironomids and oligochaetes, present in each sample and then averaging these densities for the 10

samples at a site. This metric examines the community, excluding taxa which often dominate under adverse conditions. A high abundance of non-chironomids and non-oligochaetes indicates good water quality conditions.

(7) **Zero-samples: Proportion of samples with containing no organisms**—This metric is the proportion of samples at a site which have no organisms present. "Zero-samples" indicate living conditions unsuitable to support aquatic life (i.e. toxicity, unsuitable substrate, etc.). Any site having one empty sample was assigned a score of three, and any site with two or more empty samples received a score of one. Sites with no empty samples were assigned a score of five.

A similar or higher benthic index score at the downstream site compared to the upstream site is used as basis for determining absence of impact on the benthic macroinvertebrate community related to SQN's thermal discharge. The QA component of VS monitoring shows that the comparison of benthic index scores from 49 paired sample sets collected over the past seven years range from 0 to 14 points, the 75th percentile is 4, the 90th percentile is 6. The mean difference between these 49 paired scores is 3.1 points with 95% confidence limits of 2.2 and 4.1. Based on these results, a difference of 4 points or less is the value selected for defining "similar" scores between upstream and downstream benthic communities. That is, if the downstream benthic score is within 4 points of the upstream score, the communities will be considered similar and it will be concluded that SQN has had no effect. Once again, it is important to bear in mind that differences greater than 4 points can be expected simply due to method variation (25% of the QA paired sample sets exceeded that value). When such occurs, a metric-by-metric examination will be conducted to determine what caused the difference in scores and the potential for the difference to be thermally related.

Plankton Community Sampling Methods and Data Analysis for Sites Upstream and Downstream of SQN

Samples for analysis of the phytoplankton and zooplankton communities were collected in the mid-channel at four locations, two upstream of SQN at TRM 490.1 and 487.9 and two downstream at TRM 483.4 and 481.1, on August 25 and October 10, 2011. Two replicate samples for both phytoplankton and zooplankton were collected at each site on each sample date.

Phytoplankton

A low-volume peristaltic pump and tubing apparatus were used to collect integrated water samples along a vertical gradient from the bottom to the top of the photic zone, which was defined as the zone from the surface to twice the Secchi depth reading or from the surface to four meters, whichever was greater. From each of these water samples, a subsample was removed and preserved in glutaraldehyde for taxonomic identification and enumeration of the phytoplankton community. A second subsample was removed from each water sample for analysis of phytopigment (chlorophyll) concentrations.

Zooplankton

Samples for taxonomic identification and enumeration of the zooplankton community were collected using a conical net with 80 µm mesh, towed vertically through the water column from two meters off the bottom to the surface of the reservoir. Samples were preserved in 70% ethyl alcohol (EtOH).

Data Analysis

Basic summary statistics were used to compare abundances among sites. Two separate measures of diversity, percent similarity and the Bray-Curtis Index of similarity, were used to examine spatial variability within the plankton communities, taking into account both the taxa richness and the uniformity of distribution of individuals among the taxa. Species or taxa richness is expressed simply as the number of species or distinct taxa in the community.

One measure of spatial variability between plankton communities was the calculation of Percent Similarity (PS). To calculate PS, the number of individuals in each species was calculated as the fractional proportion of the total community. For each species, the proportion in community 1 was then compared to the proportion in community 2, and the lower of the two values was tabulated. When all taxa had been compared in this manner, the tabulated list (of the lower of each pair of values) was summed, and this sum defined as the PS of the two communities.

Within the plankton community, spatial variability was also analyzed using hierarchical clustering based on the Bray-Curtis index of similarity. Samples were sorted into groups (clusters) based on the overall resemblance to each other. Cluster analyses were interpreted graphically on dendrograms to relate the similarity of communities among the sampling stations.

Before calculating the measures of diversity for the zooplankton data, the immature specimens identified as Cladocera and Bosminidae (one sample each) were removed; the taxa *Eurytemora affinis* and *Eurytemora* sp. were combined in one sample; and in October samples, specimens from all taxa under the group Sididae were combined.

Visual Encounter Surveys (Observations of Wildlife)

Two permanent transects were established both upstream and downstream of the SQN thermal discharge. The midpoint of the upstream transect was positioned at the RFAI upstream study area and spanned a distance of 2,100 m within this transect (Figure 3). The downstream transect was collected directly below the power plant and likewise spanned a distance 2,100 m (Figure 4). The beginning and ending point of each transect were marked with GPS for relocation. Transects were positioned approximately 30 m offshore and parallel to the shoreline occurring on both right and left descending banks. Visual Encounter Surveys were conducted to provide a representative sampling of wildlife present during summer (August) and autumn (October).

Each transect was surveyed by steadily traversing the length by boat and simultaneously recording observations of wildlife. Sampling frame of each transect generally followed the strip or belt transect concept with all individual species enumerated that crossed the center-line of each transect landward to an area that included the shoreline and riparian zone (i.e., belt width generally averages 60 m where vision is not obscured). Information recorded was identified to

the lowest taxonomic trophic level that was observed visually and a direct count of individuals observed per trophic level. If flocks of a species or mixed flock of a group of species were observed, an estimate of the number of individuals present was generated. Time was recorded at the start and end points of each transect to provide a general measure of effort expended. If times varied among transects, it was primarily due to the difficulty in approaching some wildlife species without inadvertently flushing them from basking or perching sites. To compensate for the variation of effort expended per transect, observations were standardized to numbers per minute or numbers per hectare in preparation for analysis.

The principal objective and purpose behind the surveys were to provide a preliminary set of observations to verify trophic levels of birds, mammals, amphibians and reptiles have not been affected by thermal effects from the SQN discharge. If trophic levels were not represented, further investigations will be used to target specific species and/or species groups (guilds) in an attempt to determine the cause.

Chickamauga Reservoir Flow and SQN Temperature

Total daily average discharge from Watts Bar, Apalachia (Hiwassee River), and Ocoee 1 (Ocoee River) dams was used to describe the volume of water flowing past SQN and was obtained from TVA's River Operations database.

Water temperature data were also obtained from TVA's River Operations database. Locations of water temperature monitoring stations used to compare water temperatures upstream of SQN intake and downstream of SQN discharge are depicted in Figure 6. Station 14 (TRM 490.4) was used to measure the ambient temperature upstream of the SQN intake. Station 8 (TRM 483.4) was used to measure temperatures downstream of SQN discharge. Water temperatures at both stations were computed as the average of temperatures measured at the 3-, 5-, and 7-ft depths.

Thermal Plume Characterization

Physical measurements were taken to characterize and map the SQN thermal plume concurrent with biological field sampling during both summer and fall sampling events. The plume was characterized under representative thermal maxima and seasonally expected low flow conditions. Measurements were collected during periods of high power production from SQN, as reasonably practicable, to capture maximum extent of the thermal plume under existing river flow/reservoir elevation conditions. This effort allowed general delineation of the "Primary Study Area" per the EPA (1977) draft guidance defined as the "*entire geographic area bounded annually by the locus of the 2°C above ambient surface isotherms as these isotherms are distributed throughout an annual period*", ensuring placement of the biological sampling locations within thermally influenced areas.

However, it is important to emphasize that the ≥2°C isopleth boundary is not a bright line; it is dynamic, changing geometrically in response to changes in ambient river flows and temperatures and SQN operations. As such, samples collected outside of, but generally proximate to the Primary Study Area boundary should not be discounted as non-thermally influenced. Every

effort was made to collect biological samples in thermally affected areas as guided by the Primary Study Area definition.

Field activities included measurement of surface to bottom temperature profiles along transects across the plume. One transect was located proximate to the thermal discharge point; subsequent downstream transects were concentrated in the near field area of the plume where the change in plume temperature was expected to be most rapid. The distance between transects in the remainder of the Primary Study Area increased with distance downstream or away from the discharge point. The farthest downstream transect was just outside of the Primary Study Area. A transect upstream of the discharge that is not affected by the thermal plume was included for determining ambient temperature conditions. The total number of transects needed to fully characterize and delineate the plume were determined in the field.

Temperature profile measurement (surface to bottom) points along a given transect were spaced equally across the river channel. Points began at or near the shoreline from which the discharge originated and continued across the plume [based on surface (0.1 m or 0.3 ft depth) measurements] until the far shore was reached. Measurements along transects were conducted at points 10%, 30%, 50%, 70%, and 90% from the originating shoreline. The distances between transects and measurement points depended on the size of the discharge plume.

The temperature measurement instrument (Hydrolab®) was calibrated to a thermometer whose calibration is traceable to the National Institute of Standards and Technology. Temperature data were compiled and analyzed to present the horizontal and vertical dimensions of the SQN thermal plume, which was used to demonstrate the existence of a zone of passage under and/or around the plume.

Water Quality Parameters at Fish Sampling Sites during RFAI Samples

Water quality conditions were measured using a Hydrolab® which provided readings for dissolved oxygen (ppm), water temperature (°C and °F), conductivity (µs/cm), and pH. Readings were taken along a vertical gradient from just above the bottom of the river to approximately 0.3 m from the surface at 1- to 2-m intervals. Readings were conducted in the mid-channel at the most downstream and upstream boundaries of the electrofishing sample area at stations upstream and downstream of SQN.

Results and Discussion

Aquatic Habitat in the Vicinity of SQN

Shoreline Aquatic Habitat Assessment

Of the sixteen shoreline sections sampled upstream of SQN; 6% (1 transect) rated "Good," 88% (14 transects) rated "Fair," and 6% (1 transect) rated "Poor." The average scores for transects on the left and right descending banks were similar at 22 ("Fair") and 21 ("Fair"), respectively. No aquatic macrophytes were present on either shoreline (Table 6).

Of the sixteen shoreline transects sampled downstream of SQN, 19% (3 transects) rated "Good," 56% (9 transects) rated "Fair," and 25% (4 transects) rated "Poor" (Table 7). The average scores for transects on the left and right descending banks were identical at 22 ("Fair"). Aquatic macrophyte coverage averaged 2% on the left descending bank and 5% on the right descending bank (Table 7).

River Bottom Habitat

Figures 7-10 display substrate percentages as well as water depth at each sample point along each of the 8 transects downstream of SQN. Figures 11-14 display substrate percentages as well as water depth at each sample point along each of the 8 transects upstream of SQN.

The three most dominant substrate types encountered along the 8 transects downstream of SQN were mollusk shell (27.6%), silt (19.9%) and clay (16.4%). The three most dominant substrate types encountered along the 8 transects upstream of SQN were silt (51.2%), mollusk shell (18.4%), and bedrock (8.8%). Overall average water depth was similar upstream and downstream of SQN (Table 8).

Fish Community

During summer 2011, RFAI scores of 41 ("Good") and 38 ("Fair") were recorded for the downstream and upstream sites, respectively (Table 9). Given the downstream site scored higher than the upstream (control), it was concluded that BIP was maintained at the downstream site during summer 2011.

During autumn 2011, an RFAI score of 35 ("Fair") was recorded at both the downstream and upstream sites (Table 10). Because both sites received the same score, it can be concluded that BIP was maintained at the downstream site during autumn 2011.

For each season, the upstream and downstream sites were compared using the four characteristics of BIP. For the discussion of each characteristic, the downstream site was compared to the upstream site (control) using the RFAI metrics applicable to each characteristic.

(1) A biotic community characterized by diversity appropriate to the ecoregion

Summer 2011

Total number of indigenous species (> 27 required for highest score for the site downstream of SQN; > 29 required for highest score for the site upstream of SQN)

Twenty-eight indigenous species were collected at the downstream site, while 29 indigenous species were collected at the upstream site, resulting in the highest score for the downstream site and a mid-range score for the upstream site for this metric (Table 9). River redhorse and sauger were collected at the upstream site only, while white bass were only collected at the downstream site; all other species were collected at both sites (Tables 11 and 12).

Total number of centrarchid species (> 4 required for highest score)

Both upstream and downstream sites received the highest possible score for the metric "Number of centrarchid species." The same eight sunfish species were collected at both sites (Tables 9, 11, and 12).

Total number of benthic invertivore species (> 7 required for highest score)

Only three benthic invertivore species were collected at the downstream site, resulting in the lowest score (1) for the metric "Number of benthic invertivore species." Freshwater drum, logperch, and spotted sucker were collected at both upstream and downstream sites; river redhorse was only collected at the upstream site. As a result of this one additional species, the upstream site received a moderate score of 3 (Tables 9, 11, and 12).

Total number of intolerant species (> 4 required for highest score)

Both the upstream and downstream sites received the highest score for the metric "Number of intolerant species." Five of the six intolerant species were collected at both sites; river redhorse was collected at the upstream site only (Tables 9, 11, and 12).

Total number of top carnivore species (> 6 required for highest score)

Ten top carnivore species were collected at both sites resulting in both sites receiving the highest score (5) for the metric "Number of top carnivore species." White bass were only collected downstream of SQN, while sauger were only collected at the upstream site. All other top carnivore species (black crappie, flathead catfish, largemouth bass, skipjack herring, smallmouth bass, spotted bass, spotted gar, white crappie, and yellow bass) were collected at both sites (Tables 9, 11, and 12).

The overall RFAI score for the downstream site was 41 ("Good") and for the upstream site 38 ("Fair"). These similar scores indicated that the species richness and composition for the five previous metrics described above were similar between sites (Table 9).

Autumn 2011

Total number of indigenous species (> 27 required for highest score for site downstream of SQN; > 29 required for highest score for site upstream of SQN)

Twenty-five indigenous species were collected at the downstream site, while 27 indigenous species were collected at the upstream site resulting in the mid-range score (3) for this metric at both sites. Longear sunfish and golden redhorse were collected at the downstream site, but not at the upstream site. White crappie, largescale stoneroller, yellow perch, logperch, and walleye were collected only at the upstream site (Tables 10, 13, and 14).

Total number of centrarchid species (> 4 required for highest score)

Both the upstream and downstream sites received the highest possible score (5) for the metric "Number of centrarchid species." Six of the seven centrarchid species were collected at both sites while white crappie was only collected at the upstream site and longear sunfish only at the downstream site (Tables 10, 13, and 14).

Total number of benthic invertivore species (> 7 required for highest score)

With only 3 benthic invertivore species each, both sites received the lowest score for the metric "Number of benthic invertivore species." Golden redhorse was collected at the downstream site only and logperch was only collected upstream of SQN (Tables 10, 13, and 14).

Total number of intolerant species (> 4 required for highest score)

Both the upstream and downstream sites received the mid-range score (3) for the metric "Number of intolerant species." Three of the four intolerant species (skipjack herring, smallmouth bass, and spotted sucker) were collected at each site; longear sunfish was collected downstream of SQN only (Tables 10, 13, and 14).

Total number of top carnivore species (> 6 required for highest score)

Nine top carnivore species were collected at the downstream site and 11 at the upstream site. However, both the upstream and downstream sites received the highest score (5) for this metric. Walleye and white crappie were only collected at the upstream site; the remaining nine top carnivore species were collected at both sites (Tables 10, 13, and 14).

Both sites received the same overall score (35-"Fair") for the five aforementioned RFAI diversity metrics, indicating that fish community diversity during autumn 2011was similar upstream and downstream of SQN (Table 10).

(2) The capacity for the community to sustain itself through cyclic seasonal change

Autumn RFAI sampling was conducted downstream of SQN during 1996 and from 1999 through 2011. RFAI scores during this period averaged 41 which rated "Good." With the exception of 1998, autumn RFAI sampling was conducted upstream of SQN from 1993 through 2011. RFAI scores during this period averaged 44 ("Good") (Table 17).

The downstream site during summer 2011 received a score of 41 ("Good") and the upstream site scored 38 ("Fair") (Table 9). During autumn 2011, both sites received the same score of 35 ("Fair") (Table 10). These scores are below the historical average for these sites, but fall within the historical range of overall RFAI scores (upstream: 34-51; downstream: 35-48) (Table 17).

The composition of the autumn 2011 sample should be indicative of the ability of the fish community to withstand the stressors of an annual seasonal cycle. The numbers of indigenous species collected during autumn RFAI samples downstream of SQN during 1996 and from 1999 through 2011 ranged from 23 to 31 and the average was 27 (Figure 15). During the periods from 1993 to 1997 and 1999 to 2011, the numbers of indigenous species collected during autumn RFAI samples upstream of SQN ranged from 20 to 31 and the average number of indigenous species was 28 (Figure 16). Although the long term average of indigenous species was similar between sites, the upstream site has consistently contained a higher number of species. Regardless, a diverse fish community has continued to persist and has exhibited the ability to sustain itself through cyclic seasonal change at both sites.

During summer 2011, 28 indigenous species were collected downstream of SQN and 29 at the upstream site. During autumn 2011, twenty-five indigenous species were collected downstream, and 27 upstream of SQN. These numbers from both summer and autumn were within the

average range for this metric when compared to the historical data (Figures 15, 16), indicating that the indigenous fish community was similar upstream and downstream of SQN.

Percentage of anomalies (< 2 % required for highest score)

The percentage of anomalies (e.g., visible lesions, bacterial and fungal infections parasites, muscular and skeletal deformities, and hybridization) in the summer sample should be indicative of the ability of the fish community to withstand the stressors of an annual seasonal cycle. Both upstream and downstream sites recorded the highest score for this metric during summer 2011 due to a low percentage of observed anomalies (Tables 9 and 10).

(3) The presence of necessary food chain species

Summer 2011

Insectivores constituted 52.0%, omnivores 35.2%, top carnivores 11.0%, benthic invertivores 1.7%, and planktivores 0.1% of the overall fish sample downstream of SQN during summer 2011. Proportions of insectivores and omnivores met the expectations calculated from historical data for upper mainstem Tennessee River reservoir forebay areas. Proportions of benthic invertivores and top carnivores were below historical averages. Percentages of planktivores were low which is indicative of a healthy environment. No parasitic species were collected (Tables 2 and 3). Trophic levels were represented with 10 insectivorous species, 10 top carnivore species, 7 omnivorous species, 3 benthic invertivore species, and 1 planktivore species (Tables 2, 3, and 11). The number of species for each observed trophic guild met or exceeded expectations, which were calculated from historical data for upper mainstem Tennessee River forebay zones (Tables 2 and 3).

At the upstream site during summer 2011, composition by trophic guild was insectivores 52.0%, omnivores 36.3%, top carnivores 8.8%, benthic invertivores 2.6%, and planktivores 0.1% of the overall fish sample. Proportions of planktivores and insectivores exceeded the expectations calculated from historical data for upper mainstem Tennessee River reservoir transition areas, proportions of benthic invertivores met average expectations, proportions of omnivores and top carnivores were less than expected (Tables 2 and 3). Ten insectivorous species, 10 top carnivore species, 7 omnivorous species, 4 benthic invertivore species, and 1 plantivorous species made up the overall fish sample at the upstream site (Tables 2, 3, and 11). The number of species for each trophic guild, except for omnivores, met or exceeded expectations calculated from historical data for upper mainstem Tennessee River transition zones. Omnivore species were less than the expected number (Tables 2 and 3).

Overall, trophic guild proportions and composition were similar between sites upstream and downstream of SQN during summer 2011, indicating that the thermal discharge did not affect fish community composition downstream of SQN.

Autumn 2011

Insectivores composed 48.3%, omnivores 29.7%, top carnivores 5.2%, planktivores 16.1%, and benthic invertivores 0.8% of the overall fish sample downstream of SQN. Proportions of insectivores, omnivores, and plantivores either met or exceeded expectations calculated from historical data for upper mainstem Tennessee River reservoir forebay areas. Proportions of top

carnivores and benthic invertivores were low and did not meet the average proportional expectations. No parasitic species were collected (Tables 2 and 3). Trophic levels were represented with 8 insectivore species, 9 top carnivore species, 6 omnivore species, 1 planktivore species and 3 benthic invertivore species (Tables 2, 3, and 13). The number of species for each observed trophic guild met or exceeded expectations, which were calculated from historical data for upper mainstem Tennessee River forebay zones (Tables 2 and 3).

At the upstream site, insectivores constituted 45.6%, omnivores 33.3%, top carnivores 8.2%, benthic invertivores 1.3%, herbivores 0.7%, and planktivores 1.1% of the overall fish sample. Proportions of insectivores and omnivores met the expectations calculated from historical data for upper mainstem Tennessee River reservoir transition areas. Proportions of benthic invertivores and top carnivores were lower than expectations, while proportions of planktivores exceeded historical expectations (Tables 2 and 3). Trophic levels were represented with 8 insectivore species, 11 top carnivore species, 6 omnivore species, 3 benthic invertivore species, 1 herbivore species, and 1 plantivorous species (Table 11). The number of species for each observed trophic guild met or exceeded expectations, which were calculated from historical data for upper mainstem Tennessee River transition zones (Tables 2 and 3).

Overall, trophic guild proportions and composition were similar between sites upstream and downstream of SQN, indicating that the thermal discharge did not affect fish community composition downstream of SQN.

(4) A lack of domination by pollution-tolerant species

Summer 2011

Number of intolerant species (> 4 required for highest score)

Five pollution intolerant species were collected at the downstream site during summer 2011, while 6 were collected at the upstream site. Both sites received the highest RFAI score for this metric (Table 9).

Percentage of tolerant individuals (< 31% required for highest electrofishing score upstream and downstream of SQN; < 14% required for highest gill net score downstream of SQN-forebay criteria; < 16% required for highest gill net score upstream of SQN- transition criteria)

Both sites received the lowest RFAI score (0.5) for the electrofishing and gill net portions of this metric. At both sites, this was primarily due to collection of a high percentage of bluegill and gizzard shad in the electrofishing samples and collection of large percentages of gizzard shad in the gill net samples (Table 9).

Percentage of omnivores (< 24% required for highest electrofishing score downstream of SQN-forebay criteria; < 22% required for highest electrofishing score upstream of SQN-transition criteria; < 17% required for highest gill net score downstream of SQN; < 23% required for highest gill net score upstream of SQN)

Omnivores constituted 31.2% of the electrofishing sample downstream of SQN and 35.1% upstream of SQN. Although only 3.9% difference, the downstream site received a mid-range score and the upstream site a low score for the metric during summer 2011. Proportions of

omnivores in the gill net samples at each site were much higher due to large numbers of gizzard shad, resulting in the lowest score for this portion of the metric for both sites (Table 9). The overall proportion of omnivores (electrofishing and gill net combined) was 36.3% at the upstream site and 35.2% at the downstream site. These proportions met expectations for this trophic guild in upper mainstem Tennessee River reservoirs (Tables 2 and 3).

Percent dominance by one species (< 25% required for highest electrofishing score downstream of SQN-forebay criteria; < 20% required for highest electrofishing score upstream of SQN-transition criteria; < 15% required for highest gill net score downstream of SQN; < 14% required for highest gill net score upstream of SQN)

This metric received the lowest RFAI score for the electrofishing sample at the upstream site, while receiving the mid-range score at the downstream site. Both sites received the lowest score for the gill net sample. The electrofishing samples both downstream and upstream of SQN were dominated by bluegill. Gill net samples at both sites were dominated by gizzard shad (Table 9).

Autumn 2011

Number of intolerant species (> 4 required for highest score)

Four pollution intolerant species were collected at the downstream site and three at the upstream site during autumn 2011, one more that at the upstream site. Both sites received the mid-range RFAI score for this metric (Table 9).

Percentage of tolerant individuals (< 31 % required for highest electrofishing score upstream and downstream of SQN; < 14% required for highest gill net score downstream of SQN-forebay criteria; < 16% required for highest gill net score upstream of SQN- transition criteria)

The percentage of tolerant individuals in electrofishing samples was almost twice as large (80.8%) at the upstream site compared to the downstream site (42.6%), resulting in the lowest score for the upstream site and mid-range for the downstream site. The difference was mostly due to higher numbers of bluegill in the electrofishing sample at the upstream site. The gill netting samples contained high percentages of gizzard shad and received the lowest scores at both sites (Table 10).

Percentage of omnivores (< 24% required for highest electrofishing score downstream of SQN-forebay criteria; < 22% required for highest electrofishing score upstream of SQN-transition criteria; < 17% required for highest gill net score downstream of SQN; < 23% required for highest gill net score upstream of SQN)

Omnivores made up 27.5% of the electrofishing sample downstream of SQN and 31.9% upstream of SQN, resulting in a mid-range score for this metric at both sites. Proportions of omnivores in the gill net samples at each site were higher due to large numbers of gizzard shad, resulting in the lowest score for this portion of the metric for both sites. The overall proportion of omnivores (electrofishing and gill net combined) at the upstream site was 33.3% and 29.7% at the downstream site (Table 10). These proportions met expectations for this trophic guild in upper mainstem Tennessee River reservoirs (Tables 2 and 3).

Percent dominance by one species (< 25% required for highest electrofishing score downstream of SQN-forebay criteria; < 20% required for highest electrofishing score upstream of SQN-transition criteria; < 15% required for highest gill net score downstream of SQN; < 14% required for highest gill net score upstream of SQN)

The downstream site received the mid-range RFAI score for the electrofishing sample and the lowest score for the gill net sample. The upstream site received the lowest score for this metric for both electrofishing and gill net samples. The electrofishing sample downstream of SQN was dominated by Mississippi silversides (non-indigenous), while the electrofishing sample upstream of SQN was dominated by bluegill. Gill net samples at both sites were dominated by gizzard shad (Table 10).

Traditional Analyses

Summer 2011

One species richness parameter (number of insectivore species) was statistically ($P<0.05$) higher upstream than downstream of SQN. Although the differences were not significant, seven of the other nine species richness measures were also higher upstream of the plant (including non-indigenous species). Numbers of omnivore and tolerant species were higher downstream, but the differences were not significant. Of the parameters comparing CPUE, two, total CPUE and CPUE of intolerant individuals, were statistically higher at the site upstream of SQN than the downstream. Seven of the remaining eight parameters were higher upstream than downstream, but the differences were not significant. CPUE of top carnivores was slightly higher at the downstream site. Both diversity values showed no statistical difference between sites, although both were higher at the upstream site (Table 15).

Autumn 2011

All species richness parameters were similar (no statistical difference) upstream and downstream of SQN. Six of the ten species richness measures were higher at the downstream site (including numbers of omnivore and tolerant species), while three were higher at the upstream site; mean numbers of benthic invertivore species were the same at both sites. Two of the ten parameters comparing CPUE, total CPUE and CPUE of non-indigenous individuals, were statistically higher at the downstream site (Table 16). These significant differences were driven by the higher numbers (approximately nine times more) of the non-indigenous Mississippi silverside collected at the downstream site (Tables 13 and 14). All other CPUE parameters showed no statistical difference between sites. CPUEs of insectivores, omnivores, top carnivores, and thermally sensitive individuals were also higher at the downstream site, but differences were not statistically significant. The remaining four parameters (CPUE of benthic invertivores, indigenous, tolerant, and intolerant individuals) were higher at the upstream site. Both diversity values were slightly higher at the downstream site, but differences were not significant (Table 16).

Fish Community Summary

In conclusion, evaluation of the five characteristics of BIP and their respective metrics and traditional analyses indicated the downstream site was similar to the upstream site and that a balanced fish community existed at the site downstream of SQN in summer and autumn 2011.

Summer 2011

Seven of the 12 RFAI metrics received equal scores at both sites for the summer of 2011. The upstream site received a lower score for the metrics "Number of indigenous species," "Percent dominance by one species," "Percent top carnivores," and "Percent omnivores" (Table 9).

Twenty-nine indigenous species were collected at the upstream site and 28 were collected at the downstream site. No statistical difference existed in numbers of indigenous species and CPUE of indigenous individuals between sites (Table 15). Thirty-one resident important species (RIS) were collected at the upstream site compared to 29 at the downstream site (Tables 11 and 12). RIS are defined in EPA guidance as those species which are representative in terms of their biological requirements of a balanced, indigenous community of fish, shellfish, and wildlife in the body of water into which the discharge is made (EPA and NRC 1977). RIS often include non-indigenous species.

The same three aquatic nuisance (non-indigenous) species, common carp, yellow perch, and Mississippi silverside, were collected at both sites (Tables 11 and 12); CPUE of these three species was similar between sites (Table 15).

The same two thermally sensitive species (spotted sucker and logperch) were collected at both sites (Tables 11 and 12) and were collected in similar densities (Table 15). Water temperatures greater than 32.2°C (90°F) are known to be the avoidance level and/or lethal level to these species (Yoder et al. 2006).

Four commercially valuable species were collected at the downstream site and five were collected at the upstream site. Twenty-four recreationally valuable species were collected at the upstream site, while 25 were collected at the downstream site (Tables 11 and 12).

Autumn 2011

Nine of the 12 RFAI metrics received the same scores at both sites. The upstream site received a lower score for the electrofishing portion of the metric "Percent dominance by one species" and "Percent tolerant individuals", while the downstream site received a lower score for the metric "Percent top carnivores" (Table 10).

Twenty-eight indigenous species were collected at the upstream site, while 25 were collected at the downstream site. Numbers of indigenous species and indigenous CPUEs at the downstream site were similar to those at the upstream site (Table 16). Thirty resident important species were collected at the upstream site compared to 27 resident important species at the downstream stations (Tables 13 and 14). Representative important species are defined in EPA guidance as those species which are representative in terms of their biological requirements of a balanced, indigenous community of fish, shellfish, and wildlife in the body of water into which the discharge is made (EPA and NRC 1977).

Three aquatic nuisance species (common carp, yellow perch, and Mississippi silverside) were collected at the upstream site, while two aquatic nuisance species (common carp and Mississippi silverside) were collected at the downstream site (Tables 13 and 14). Although the numbers of non-indigenous species was similar between sites, CPUE of non-indigenous individuals was significantly higher at the downstream site (Table 16). This was due to a large number of Mississippi silversides collected at the downstream site (917, or 33.5% of total catch) compared to the upstream site (124, or 6.3 % of total catch) (Tables 13 and 14). This is a schooling fish species and is commonly collected in large numbers.

Two thermally sensitive species (spotted sucker and logperch) were collected upstream, while one (spotted sucker) was collected downstream (Tables 13 and 14). CPUE of these species was similar between sites (Table 16). Water temperatures greater than 32.2°C (90°F) are known to be the upper avoidance level or lethal to the aforementioned species (Yoder et al. 2006).

Thirteen commercially valuable species were collected at downstream site and 11 at the upstream site. Twenty-four recreationally valuable species were collected at the upstream site, while 19 were collected at the downstream site (Tables 13 and 14).

As discussed above, RFAI scores have an intrinsic variability of ±3 points. This variability comes from various sources, including annual variations in air temperature and stream flow; variations in pollutant loadings from nonpoint sources; changes in habitat, such as extent and density of aquatic vegetation; natural population cycles and movements of the species being sampled (TWRC, 2006). Another source of variability arises from the fact that nearly any practical measurement, lethal or non-lethal, of a biological community is a sample rather than a measurement of the entire population. As long as scores are within the 6-point range, there is no certainty that any real change at a site has occurred or difference between sites exists beyond method variability.

It should be noted that the upstream site is scored using transition criteria and the downstream site using forebay criteria (Table 4). More accurate comparisons can be made between sites that are located in the same reservoir zone (i.e., transition to transition). Due to the location of SQN, it is not possible to have an upstream and downstream site within the same reservoir zone. SQN is located at the downstream end of the transition zone on Chickamauga Reservoir; therefore, the downstream site is located in the upstream section of the forebay. The physical and chemical composition of a forebay is often different than that of a transition zone; consequently, inherent differences exist among the aquatic communities (e.g. species diversity is often higher in a transition zone than a forebay).

Through the years sampled, the upstream site averaged a score of 44 ("Good") while the downstream site averaged a score of 41 ("Good"), indicating the sites were similar annually and that the SQN heated effluent is not adversely affecting the fish community in the vicinity of the plant (Table 17). RFAI scores are presented for the Chickamauga Reservoir inflow site (TRM 529.0), the forebay site (TRM 472.3), and the Hiwassee River Embayment site (HiRM 8.5) to provide additional information on the health of the fish community throughout the reservoir; however, aquatic communities at these sites are not affected by SQN thermal discharges and are not used to determine BIP in relation to SQN. The average RFAI scores at these three sites among all years sampled have remained in the "Good" range (Table 17).

Individual metric scores, overall RFAI scores, species collected, and catch per effort from electrofishing and gill netting for the upstream and downstream sampling sites at SQN during 1999 through 2010 are included in Shaffer et al., 2010 and Simmons, 2011.

Benthic Macroinvertebrate Community

Summer 2011

During summer 2011, RBI scores at the downstream transects TRM 481.3 and TRM 483.4 were 27 ("Good") and 29 ("Good"), respectively, and were slightly higher than those at upstream transects TRM 488.0 and TRM 490.5 [27 ("Good") and 23 ("Fair"), respectively] (Table 18). A difference of 4 points or less between upstream and downstream stations is used to define "similar" conditions between the two sites. Because the average of the downstream sites (28) scored three points higher than that of the upstream sites (25) and rated "Good", it can be determined that BIP was maintained. For the discussion of each RBI metric, the downstream site was compared to the upstream control site.

Average number of taxa (> 5 required for highest score-forebay criteria; > 6.6 required for highest score-transition criteria)

The downstream sites (forebay) averaged 11.2 taxa, while the upstream sites (transition) averaged 7.1 taxa; all sites received the highest score for this metric (Table 18).

Proportion of samples with long-lived organisms (> 0.8 required for highest score-forebay criteria; > 0.9 required for highest score-transition criteria)

The observed values for the metric "Proportion of samples with long-lived organisms" (e.g., *Corbicula, Hexagenia,* mussels, and snails) were 0.8 at both downstream transects and both sites scored 3 (mid-range). Upstream of SQN, all samples at the transect at TRM 488.0 contained long-lived organisms (1.0) resulting in a score of 5, while TRM 409.5 received a score of 1 with only 40% of samples containing long-lived organisms (Table 18). Snail proportions, in particular, were higher downstream of SQN as compared to those upstream (Figure 19).

Average number of EPT taxa (> 0.9 required for highest score-forebay criteria; > 1.4 required for highest score-transition criteria)

The average number of EPT taxa present in each sample were 0.9 and 1.2 at the downstream transects, resulting in scores of 3 and 5, respectively. At the upstream transects TRM 488.0 and TRM 490.5, average number of EPT taxa was 0.8 (score: 3) and 0.2 (score: 1), respectively (Table 18). *Ephemeroptera* (mayflies) and *Trichoptera* (caddisflies) proportions were slightly higher at the downstream sites as compared to the upstream sites (Figure 17).

Average proportion of oligochaete individuals (< 21.0 required for highest score-forebay criteria; < 11.0 required for highest score-transition criteria)

The average proportion of oligochaete individuals at the downstream sites were 35.6% (score of 3) and 54.4% (score of 1). The upstream sites had smaller percentages of samples containing oligochaetes (15.5% at TRM 488.0 and 7.2% at TRM 490.5) and therefore, received higher scores of 3 and 5, respectively (Table 18).

Average proportion of total abundance comprised by the two most abundant species (< 81.7 required for highest score-forebay criteria; < 77.8 required for highest score-transition criteria)

Both downstream sites received scores of 5 with proportions of 73.7% (TRM 481.3) and 75.5% (TRM 483.4) of the samples comprising the two most abundant taxa (chironomids and oligochaetes). At the upstream sites TRM 488.0 and TRM 490.5, 82.8% and 86.4% of the total abundance, respectively, was comprised of the two most abundant taxa (chironomids and oligochaetes) resulting in mid-range scores for both sites (Tables 18 and 20).

Average density excluding chironomids and oligochaetes (> 249.9 required for highest score-forebay criteria; > 609.9 required for highest score-transition criteria)

At the downstream sites, average densities of organisms excluding chironomids and oligochaetes were 235/m^2 and 525/m^2, resulting in scores of 3 and 5, respectively. At the sites upstream of SQN, densities excluding chironomids and oligochaetes were 470/m^2 and 396.7/m^2 and both sites received scores of 3 (Table 18).

Proportion of samples containing no organisms (0 required for highest score)

There were no samples at any site upstream and downstream of SQN which were void of organisms. Therefore, all sites received the highest score for this RBI metric during summer 2011 (Table 18).

In conclusion, during the summer of 2011 downstream sites scored the same or higher than the upstream site on all metrics except "Average number of oligochaetes" indicating BIP was maintained downstream of SQN.

Autumn 2011

Autumn RBI scores for downstream were 29 ("Good"), 27 ("Good"), while the upstream site scored 19 ("Fair") (Table 18). A difference of 4 points or less between upstream and downstream stations is used to define "similar" conditions between the two sites. Because the downstream site scored 8 to 10 points higher and rated "Good," it can be determined that BIP was maintained. For the discussion of each RBI metric, the downstream site was compared to the upstream control site.

Average number of taxa (> 5 required for highest score-forebay criteria; > 6.6 required for highest score-transition criteria)

Averages of 7.8 and 13.6 taxa were observed for sites downstream of SQN. The site upstream of SQN averaged 6.6 taxa per sample. The downstream sites both received the highest score for this metric, while the upstream site received the mid-range score (Table 18).

Proportion of samples with long-lived organisms (> 0.8 required for highest score-forebay criteria; > 0.9 required for highest score-transition criteria)

The metric "proportion of samples with long-lived organisms" (*Corbicula*, *Hexagenia*, mussels, and snails) scored 3 at both downstream sites with proportions of 0.7 and 0.8. The proportion of samples with long-lived organisms (0.8) was similar at the upstream site and therefore, also a score of 3 (Table 18).

Average number of EPT taxa (> 0.9 required for highest score-forebay criteria; > 1.4 required for highest score-transition criteria)

The average numbers of EPT taxa present per sample at each of the downstream sites were 1.0 and 0.9, resulting in scores of 5 and 3, respectively. The site upstream of SQN received a score of 1 with 0.5 EPT taxa per sample (Table 18). *Ephemeroptera* (mayflies) and *Trichoptera* (caddisflies) proportions were higher at the downstream sites as compared to the upstream site (Figure 19).

Average proportion of oligochaete individuals (< 21.0 required for highest score-forebay criteria; < 11.0 required for highest score-transition criteria)

At the downstream sites, average proportion of oligochaete individuals in each sample was 29.4% at TRM 481.3 and 48.1% at TRM 483.4 resulting in scores of 3 and 1, respectively. The upstream site received a score of 3 with a proportion of 14.8% (Table 18).

Average proportion of total abundance comprised by the two most abundant species (< 81.7 required for highest score-forebay criteria; < 77.8 required for highest score-transition criteria)

During autumn 2011, 78.6% of the total abundance at TRM 481.3 was comprised of the two most abundant taxa (chironomids and oligochaetes). The two most abundant taxa at TRM 483.4 were oligochaetes and flatworms (Planariidae) and constituted 77% of the total abundance. Both downstream sites received the highest score of 5. At the upstream site TRM 490.5, 84.5% of the total abundance was comprised by the two most abundant taxa, chironomids and fingernail clams (Sphaeriidae), resulting in a mid-range score for this metric (Tables 18 and 20).

Average density excluding chironomids and oligochaetes (> 249.9 required for highest score-forebay criteria; > 609.9 required for highest score-transition criteria)

At the downstream sites, average densities excluding chironomids and oligochaetes were $181.7/m^2$ and $1{,}685/m^2$ resulting in scores of 3 and 5, respectively. Average density excluding chironomids and oligochaetes at the upstream site was $263.3/m^2$, resulting in the lowest score for this metric (Table 18).

Proportion of samples containing no organisms (0 required for highest score)

There were no samples at any site which were void of organisms. Therefore, all sites received the highest score for this RBI metric during autumn 2011 (Table 18).

In conclusion, during the autumn of 2011, downstream sites scored the same or higher on all the metrics indicating a BIP of benthic macroinvertebrates was maintained downstream of SQN (Table 18). The low score at the upstream site (19) was lower than expected based on historical scores; however, similarly low scores of 21 and 17 were observed in 2007 and 2008, respectively. A possible reason for the low score at the upstream site could be pollution impacts from the Hiwassee River, which enters the Tennessee River 9 miles upstream of TRM 490.5.

Individual RBI metric ratings and field scores from TRM 482.0 (downstream) and TRM 490.5 (upstream) are listed in Table 21 for comparison of results from 2000 to 2010. Although downstream sites sampled in 2011 were proximate to the transect sampled from 2000-2010

(TRM 482.0), 2011 RBI scores cannot be directly compared to those from 2000 to 2010 without inference.

RBI scores for the inflow, forebay, and Hiwassee River embayment sites are included in Table 19 to provide additional information on the overall health of the benthic macroinvertebrate community in Chickamauga Reservoir. RBI scores have averaged "Good" for the inflow and forebay sites and "Fair" for the Hiwassee River embayment over all sample years.

Plankton Community

Detailed results of taxa collected and estimates of sample density are provided in Table 26 (phytoplankton) and in Table 33 (zooplankton).

Phytoplankton

Summer 2011

Figure 18 indicates that average phytoplankton densities decreased progressively from TRM 490.7 (the most upstream site) to TRM 483.4 (immediately downstream of the diffusers). Phytoplankton density was lowest at TRM 483.4 and increased further downstream at TRM 481.1 to concentrations similar to the most upstream site.

Numerically, cyanophytes were the dominant taxa (96 to 99 percent; Table 22, Figure 18) at all sites, with a prevalence of *Cyanogranis* and several taxa in the family Chroococcaceae (Table 26). Considered as a percentage of total biovolume, bacillariophytes (diatoms) were more dominant (Figure 19). Total taxa richness for paired replicate samples ranged from 43 to 49, and the percentage of taxa shared between replicates samples ranged from 52.1 to 76.7 percent (Table 23). However, of the 67 taxa collected in August, seven cyanophyte taxa were common to all replicate samples and accounted for 86 to 95 percent of the total population (Tables 24, 26).

Percent Similarity coefficients (ranging from 75 to 87; Table 25) and Bray-Curtis similarity coefficients (BCe) were high (ranging from 0.78 to 0.81, Figure 25), indicating that the structure of the phytoplankton community was similar at all sites. The cluster analysis indicated that the communities at TRM 481.1 and TRM 487.9 were the most similar, followed by TRM 483.4 and 490.7. No upstream to downstream trend was evident.

Autumn 2011

Total population densities in October were much lower compared to those in August, and the spatial trend was reversed. That is, phytoplankton density increased progressively from the most upstream site (TRM 490.7) to a maximum density at the diffuser (TRM 483.4), then decreased again slightly at the site further downstream at TRM 481.1 (Figure 20).

Bacillariophytes (diatoms) were numerically dominant (36 to 63 percent; Table 22, Figure 20) at all sites and comprised approximately 74 to 91 percent of the total biovolume (Figure 21). Cryptophytes (*Cryptomonas*) were subdominant (21 to 36 percent) and the composition of chlorophytes and cyanophytes ranged from 6 to 16 percent. Total taxa richness for paired replicate samples ranged from 27 to 32 at the three lower sites, but only 19 taxa were collected at

TRM 490.7. The number of taxa shared between replicate samples ranged from 50.0 to 57.9 percent (Table 23). However, of the 38 taxa collected in October, nine were common to all samples and accounted for 74 to 97 percent of the total population. A mix of cyanophyte taxa often comprised more than 10 percent of the population in any given sample, but seldom was the same taxon present in both replicates, and no single taxon was represented in all samples (Tables 24, 26).

October PS coefficients among the three lower sites were relatively high (71 to 80), while the PS coefficients for TRM 490.7 were notably lower (63 for each site comparison) (Table 25). By this measure, the communities downstream (TRM 487.9, 483.4, and 481.1) were relatively similar, but the community at the most upstream site (TRM 490.7) showed the greatest dissimilarity to any other. The same taxa (*Aulacoseira, Fragilaria, and Cryptomonas*) were dominant at each site, but TRM 490.7 had lower taxa richness and the dominant taxa comprised a greater percentage of the overall population (Table 27).

The Bray-Curtis similarity coefficients (BCe) (0.64 to 0.73) indicate that phytoplankton community structure was slightly more dissimilar among sites in October than in August, which is supported by the PS coefficients. TRM 483.4 and TRM 487.9 formed the first cluster (BCe, 0.73), followed by a secondary cluster with TRM 481.1 (BCe, 0.68). TRM 490.7 clustered last, indicating this site was least similar in terms of taxa shared and taxa abundances (Figure 26). Overall, TRM 490.7 had higher composition of diatoms and lower composition of chlorophytes and cryptophytes compared to the three downstream locations (Table 22).

Chlorophyll

Chlorophyll a concentrations differed among the four sites in samples collected in both August and October (Table 28, Figure 22). Upstream to downstream differences in chlorophyll a concentrations closely paralleled phytoplankton density, but as expected, the chlorophyll a concentration was more closely associated with biovolume (Figures 19, 21).

August data show TRM 483.4 had the lowest concentrations (6.0 µg/l) followed by TRM 490.7 (9.5 µg/l). Chlorophyll a concentrations were similar for TRM 481.1 (12 µg/l) and TRM 487.9 (14 µg/l) (Table 28). Decreased concentrations at TRM 483.4 are supported by findings of reduced phytoplankton cell densities and biovolume at this location (Table 26, Figure 19).

October chlorophyll a concentrations increased progressively from TRM 490.7 to TRM 483.4, and then decreased at TRM 481.1 to a concentration similar to that of the uppermost site (TRM 490.7). Again, the spatial differences are supported by the phytoplankton density (Table 26) and biovolume data (Figure 21).

Zooplankton

Overall, 35 zooplankton taxa were represented in the samples collected. The number of taxa represented in each major group was 10 to 12, with the exception of the Bivalvia, for which only 2 taxa were represented (Table 31). Notably, taxa richness for individual samples ranged from 8 to 16, but the number of taxa shared between replicates ranged from only 3 to 8 (21.4 to 66.7 percent) due to substantial variability in the presence/absence of less abundant taxa (Tables 30, 33). In the samples collected during both August and October, four to five taxa comprised the majority (approximately 90 to 99 percent) of the populations at each of the four sites. The

dominant taxa were the cladocerans *Bosmina longirostris* and *Diaphanosoma birgei* (not present in October); copepods in the orders Calanoida and Cyclopoida; and the rotifer *Conochilus unicornis* (Table 33).

Summer 2011

Data from August samples showed that zooplankton densities were notably higher at sites downstream of the diffusers. Densities increased progressively from the most upstream site (TRM 490.7) to the highest density at TRM 483.4, just downstream of the diffusers, then decreased slightly at TRM 481.2. The lower overall density at TRM 481.2 was largely due to the collection of fewer rotifers. TRM 483.4 had higher rotifer group density than all other sites. TRM 481.1 had the highest density of cladocerans (Figure 23).

Cladocerans were numerically dominant (49 to 68 percent; Table 29, Figure 23) at all sites. The composition of copepods and rotifers was generally similar (15 to 26 percent) among all sites except TRM 481.1. Rotifers comprised only two percent of the population at TRM 481.1 and copepods comprised a slightly higher percentage (30 percent) compared to other sites. Total taxa richness for paired replicate samples was relatively low, ranging from 8 to 14. Taxa richness was highest (14) at TRM 481.1, with sites upstream having only 8 to 9 taxa represented (Table 30).

August PS coefficients (70 to 80) were relatively high among the three most upstream sites, indicating similar community structure. TRM 481.1 had somewhat low PS coefficients with TRM 483.4 and TRM 487.9 (63 and 69, respectively), due largely to lower composition of copepods in the order Calanoida and the rotifer *Conochilus unicornis* at TRM 481.1. The PS coefficient (75) for TRM 481.1 and TRM 490.7 was relatively high (Table 32).

Bray-Curtis Similarity yielded similar results. Coefficients ranged from 0.65 to 0.80. TRM 483.4 and TRM 490.7 were the most similar, with a high coefficient of 0.80. These sites formed a secondary cluster with TRM 487.9 (BCe, 0.72). TRM 481.1 clustered last (BCe, 0.65), indicating this site was least similar to the other sites in terms of taxa shared and taxa abundances (Figure 27).

Autumn 2011

In October, average zooplankton densities were highest at TRM 481.1, but variability between the replicate samples was high. TRM 490.7 had the second highest population density. Densities were similar at TRM 483.4 and TRM 487.5 (Figure 24).

Comparable to findings in August, cladocerans were numerically dominant (44 to 71 percent) at all sites and copepods were subdominant (23 to 40 percent). However, the composition of rotifers was higher at TRM 481.1 (16 percent) than at sites upstream (2 to 6 percent), which is the reverse of findings in August (Table 29). Total taxa richness ranged from 12 to 16 at the three most upstream sites, but only 9 taxa were collected at TRM 481.1 (Table 30).

October PS coefficients (72 to 93) were higher among sites than in August, but yielded similar findings, with the lowest PS coefficients (72 to 83) for TRM 481.1 (Table 32). However, the density and composition of copepods in the order Calanoida and the rotifer *Conochilus unicornis* were highest at TRM 481.1 in October and lowest in August (Table 33). These taxa contributed to the dissimilarity between TRM 481.1 and other sites exhibited during both sample dates.

Bray-Curtis Similarity yielded similar results. Coefficients ranged from 0.63 to 0.70. TRM 483.3 and TRM 487.9 formed the first cluster (BCe, 0.70), indicating the communities at these sites were the most similar of the four. These sites form a secondary cluster with TRM 490.7 (BCe, 0.68). TRM 481.1 clustered last, indicating greater dissimilarity with other sites (Figure 28).

Plankton Summary

The results of the Phytoplankton and Zooplankton studies at SQN during 2011 generally support findings from previous studies, which are presented in the section following this summary.

Phytoplankton

Phytoplankton data indicated that quantitative characteristics (total and group cell densities) differed among sites in both August and October, but there were few differences in community structure among the four sample sites on either date. Notably, the reduced phytoplankton densities, biovolume, and chlorophyll concentrations at TRM 483.4 in August could be interpreted as an effect from SQN diffuser discharge. Previous studies have indentified reduced phytoplankton densities and chlorophyll concentrations (biovolume was not measured) at TRM 483.4 due to the diffusers mixing water from the bottom – containing low phytoplankton densities – with water of the upper strata that typically contain greater densities. Previous studies have also documented that when phytoplankton reductions have occurred at TRM 483.4 in apparent relation to diffuser mixing, densities recovered within a few miles downstream of the diffusers. Likewise, in August, phytoplankton parameters (density, biovolume, and chlorophyll) showed lowest values at TRM 483.4, and then increased at TRM 481.1 to levels similar to those found upstream of the diffuser. Additionally, previous studies have documented that when differences have occurred in phytoplankton communities among locations, these differences typically have been either increases or decreases in organism densities, not compositional changes in the community. This was supported in the current study. In both August and October, the two independent measures of diversity indicated relatively high levels of similarity among sites upstream and downstream of the diffusers, even though population densities differed. Only TRM 490.7 exhibited lower similarity when compared with the other sites, and then only in October. However, we do not consider this dissimilarity related to the operation of SQN.

Zooplankton

Zooplankton data indicated that quantitative differences existed among sites in both August and October, but there were no upstream to downstream trends in population densities that provided definitive evidence of an effect from the operation of SQN. In August, zooplankton densities were highest at TRM 483.4, just downstream of the diffuser, and densities at both downstream sites were higher compared to those of the upstream sites. In October, zooplankton densities were highest at TRM 481.1, the most downstream site. Densities at TRM 483.4 and TRM 487.9 were very similar, but were lower than those at the most upstream and most downstream sites.

As with phytoplankton, compositions of the zooplankton communities were generally similar among sites, even though population densities differed. Overall, TRM 481.1 was more dissimilar to the other sites in both August and October. This was due in part to higher population densities at TRM 481.1, but interestingly, the taxa that contributed most to the

dissimilarity of this site were the same in both months. In August, TRM 481.1 had the lowest density and composition of calanoid copepods and of the rotifer *Conochilus unicornis*. In October, the same site had the highest density and composition of these taxa. Although the reduced densities of these taxa in August may have been due in part to operation of SQN, the greater abundance of organisms at TRM 481.1 – including the highest densities of copepods and cladocerans among all four sites – suggests that the majority of the reduction is more likely related to other variables. One such variable is the "patchy" nature of plankton distributions, as evidenced by the high variability in density of some taxa observed between replicate samples collected at each site. Such patchy distributions have been described in previous studies, and are discussed further in the review following this summary.

Review of Previous Plankton Studies

Previous plankton studies around SQN were conducted with the objective of evaluating the effects of SQN operations on plankton, but these were not controlled experiments (i.e. experiments designed to keep all variables constant except the test factor – in this case, the power plant). Instead, the program monitored a dynamic system: even without the influence of SQN, differences between the control locations (upstream of the plant) and the test locations (downstream of the plant) were expected due to other possible variables. One possible variable is the longitudinal point, or transition zone, where water velocities become sufficiently low for phytoplankton to remain in the photic zone long enough to sustain growth and reproduction. The location of this transition zone in the reservoir is dependent on flow conditions, and it might fluctuate upstream or downstream daily or even hourly, as inflows from the Hiwassee River and releases from Chickamauga and Watts Bar dams vary (Figures 29 and 30 – hourly average flows). Other variables may include but are not limited to: reservoir stratification; inflow from the overbanks and other highly productive areas; phase of population (and community) growth; the patchy nature of plankton distribution; differences in depth among sample locations; travel time between sample locations; and light penetration. Like the transition zone, many of the factors in this list are also directly or indirectly related to flow conditions. Each of the factors listed here has an important influence on plankton, and each contributes to the composition of the community sampled at each location.

Studies to date have documented that when differences in phytoplankton and zooplankton communities occurred among sample locations, these differences typically were either increases or decreases in organism densities, not community changes. Studies have shown that downstream increases were more commonly observed under relatively high reservoir flows (e.g., 30,000 cfs), while when reservoir flows were quite low (i.e., <10,000), decreases in downstream plankton densities were expected, particularly at the diffuser location (TRM 483.4). Greater variability in plankton densities was observed at intermediate flows.

The studies also indicated that reductions in phytoplankton densities were caused by different mechanisms than were reductions in zooplankton densities.

The mechanism most likely responsible for reductions of phytoplankton densities and of chlorophyll concentrations is mixing of the water column at the diffuser location. In-plant plankton studies conducted in 1987 (TVA, 1988) and in 1988 (TVA, 1989) indicated some reduction in cell densities may have occurred as water was entrained through the CCWS, but most of the reductions observed at TRM 483.4 were due to mixing caused by the diffusers. The cooling water that is withdrawn from the lower strata near the skimmer wall has naturally low

concentrations of phytoplankton compared to upper strata. This water is carried through the CCWS, heated, and discharged through the diffusers. The momentum from being discharged through the diffuser ports, plus the buoyancy from the added heat, cause this water to rise and mix with ambient water near the diffusers. The water withdrawn from and discharged at the bottom, already low in phytoplankton, and the mixing which redistributes the phytoplankton concentrated near the surface, are reflected as reduced phytoplankton concentrations for TRM 483.4 at most strata.

Previous studies have also documented that when phytoplankton reductions occurred at TRM 483.4 in apparent relation to diffuser mixing, recovery was realized by TRM 478.2 (previous study site). Furthermore, special biweekly surveys conducted from April to October, 1989, showed downstream phytoplankton concentrations recovered to levels similar to those above the diffuser within 1-2 river miles (TVA, 1990).

Reductions in zooplankton densities appear to be caused by a more complex set of factors, including passage through the SQN CCWS. In-plant studies have shown substantial reductions in zooplankton densities during passage through the CCWS, even without heat (TVA, 1988). Zooplankton densities were significantly lower in the diffuser pond samples compared to intake samples, and essentially all zooplankton examined from the diffuser pond were immobile and presumed dead (TVA, 1989). Discharge of the water with reduced number of zooplankters would result in some reduction in density at the diffuser location (TRM 483.4). However, these reductions alone were not sufficient to account for the magnitude of decreased density typically observed, particularly since many of the dead zooplankters would still be discharged and included in the enumeration from TRM 483.4.

These results indicate that some other factor or combination of factors, in addition to mixing at the diffuser, must be involved in reduced zooplankton densities at the diffuser site. One possible factor that became evident as more studies were conducted is the complex hydraulics in the vicinity of the diffuser discharge. The hydraulics of this area were likely complex even before SQN was constructed, due to the narrowing and deepening of the channel compared to upstream, and to the presence of an overbank (typically highly productive) with its point of inflow to the channel just upstream of where the channel narrows and deepens. Construction of SQN, including the addition of an underwater dam that occupies about half of the cross-sectional area of the river channel and the installation of the diffusers with buoyant discharge, further complicated the hydraulics in this area. Obviously, collection of representative samples from this area is difficult due to varying contributions of several factors, including reduced densities in the discharge water, increased densities in water entering the channel from the upstream overbank, and physical mixing of the zooplankton (which typically are not evenly distributed in the water column) in the ambient channel water. Although some of the reductions in zooplankton densities are due to operation of SQN, it has not been possible to specify the magnitude of that reduction separate from that due to other variables.

Visual Encounter Survey/Wildlife Observations

Summer 2011

Thirty-three individuals composing 11 bird species and 1 mammal species were observed along shoreline transects (RDB and LDB) upstream of SQN. Along shoreline transects downstream of SQN, 51 individuals constituting 10 bird and one mammal species were observed. Bird species

observed both upstream and downstream of SQN included unidentified species of swallow, belted kingfisher, osprey, and great blue heron. American crow, turkey vulture, red-winged blackbird, and an unidentified duck species were only observed at the transects upstream of SQN, while wood duck, double-crested cormorant, European starling, and green heron were only observed along transects downstream. White-tailed deer was the only mammal species observed during the survey and was observed in equal numbers (4 individuals) upstream and downstream of SQN (Table 35).

Autumn 2011

Four species of birds comprising 9 individuals were observed along transects upstream of SQN. Downstream of SQN, 1,024 birds composing 17 species and one species of mammal were observed. Three of the four bird species (great blue heron, belted kingfisher, and an unidentified songbird species) observed upstream were viewed downstream; an unidentified wren species was observed along transects upstream of SQN only. Fourteen bird species were only observed downstream of SQN and included blue jay, northern mockingbird, double-crested cormorant, American coot, American widgeon, pied-billed grebe, mallard, tufted titmouse, killdeer, wood duck, black-crowned night heron, gadwall, green-winged teal, and an unidentified sandpiper species. The only mammal species observed at the downstream transect was eastern gray squirrel (1 individual) (Table 35).

In summary, the wildlife community downstream of SQN was similar to that upstream during summer 2011. During the autumn 2011 survey, species richness and total numbers observed were significantly higher downstream of SQN.

Chickamauga Reservoir Flow and Temperature Near SQN

Total average daily flows from Watts Bar Dam, Ocoee No. 1 Dam, and Appalachia Dam from October 2010 to November 2011 and historical daily average flows from 1976 through 2010 are shown in Figure 31. Daily average flows from October 2010 to November 2011 were similar (total daily average flows averaged 6% higher) to historical daily average flows, but were below the historical averages during the summer and autumn sampling periods (Figure 31).

Daily average water temperatures recorded upstream of the SQN intake and downstream of SQN discharge, October 2010 through November 2011, are shown in Figure 20. Water temperatures remained within permitted limits (below 86.9°F) throughout the year (Figure 32).

Thermal Plume Characterization

Summer 2011

Temperature profiles collected on August 25, 2011 indicated the thermal plume extended from the SQN discharge point (TRM 483.6) downstream approximately 4.1 miles to TRM 479.5 (Table 36, Figure 4). The average ambient surface water temperature (0.3 m and 1 m depths) measured at TRM 486.7 on the date of the survey was 81.86°F; the maximum temperature recorded downstream of the discharge was 86.85°F. Once discharged from diffusers located on the river bottom, the thermal plume rose to the surface and remained in the upper 1 m (3.3 ft) of

the water column, as evidenced by temperatures measured at TRM 481.1 and TRM 480.0 (Table 36).

Autumn 2011

On August 14, 2011, the SQN thermal plume extended downstream approximately 2.6 miles to TRM 481 (Table 37, Figure 4). The average ambient surface water temperature (0.3 m and 1 m depths) measured at TRM 487.0 on the date of the survey was 77.16°F. Downstream of the discharge, the maximum water temperature measured was 81.91°F. The thermal plume remained in the upper 1 m (3.3 ft) of the water column, as evidenced by temperatures measured at TRM 483.4, TRM 482.2, and TRM 481 (Table 37).

In summary, the entire biomonitoring zone downstream of SQN was contained within the thermal plume during the summer and autumn 2011 survey periods (Figure 4). The thermal plume extended further downstream during the summer monitoring period than the autumn period. The difference was attributed to several factors including releases from Watts Bar Dam upstream and Chickamauga Dam downstream of the plant, power generation at SQN, and condenser cooling water discharge.

Water Quality Parameters at Fish Sampling Sites During RFAI Samples

Observed values of water temperature, conductivity, dissolved oxygen, and pH are listed for each profile (LDB, mid-channel, and RDB), transect (downstream, middle, and upstream), site (TRM 482 and 490.5), and season (summer and autumn 2011) in Table 38.

Summer 2011

Water temperatures at the sampling site upstream of SQN ranged from 80.44 to 83.73°F. Downstream of SQN, water temperatures ranged from 81.73 to 87.04°F. Dissolved oxygen concentrations ranged from 4.22 to 6.56 ppm at the sampling site upstream of SQN. Dissolved oxygen readings taken at the sampling site downstream of SQN ranged from 5.26 to 7.56 ppm. Conductivity values ranged from 190 to 227.5 µS at the downstream site and 193.2 to 201.3 at the upstream site. At the downstream site, pH values ranged from 7.55 to 8.5, while at the upstream site pH values ranged from 7.3 to 8.66 (Table 38).

Autumn 2011

Water temperatures at the sampling site upstream of SQN ranged from 69.85 to 70.47°F. Downstream of SQN, water temperatures ranged from 70.43 to 74.89°F. Dissolved oxygen concentrations ranged from 7.10 to 7.94 ppm at the sampling site upstream of SQN. Dissolved oxygen readings taken at the sampling site downstream of SQN ranged from 6.60 to 9.69 ppm. Conductivity values ranged from 182.7 to 185.3 µS at the downstream site and 179.4 to 191.6 µS at the upstream site. At the downstream site, pH values ranged from 7.23 to 8.50, while at the upstream site pH values ranged from 7.17 to 7.6 (Table 38).

Literature Cited

EPA (U.S. Environmental Protection Agency) and NRC (U.S. Nuclear Regulatory Commission). 1977 (draft). Interagency 316(a) Technical Guidance manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements. U.S. Environmental Protection Agency, Office of Water Enforcement, Permits Division, Industrial Permits Branch, Washington, DC.

Etnier, D.A. & Starnes, W.C. (1993) *The Fishes of Tennessee*. University of Tennessee Press, Knoxville, Tennessee, 681 pp.

Hickman, G. D. and T. A. McDonough. 1996. Assessing the Reservoir Fish Assemblage Index- A potential measure of reservoir quality. *In*: D. DeVries (Ed.) Reservoir symposium- Multidimensional approaches to reservoir fisheries management. Reservoir Committee, Southern Division, American Fisheries Society, Bethesda, MD. pp 85-97.

Hubert, W. A., 1996. Passive capture techniques, entanglement gears. Pages 160-165 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society Bethesda, Maryland, USA.

Jennings, M. J., L. S. Fore, and J. R. Karr. 1995. Biological monitoring of fish assemblages in the Tennessee Valley reservoirs. Regulated Rivers 11:263-274.

Levene, Howard. 1960. Robust tests for equality of variances. In Ingram Olkin, Harold Hotelling, et alia. Stanford University Press. pp. 278–292.

Mann, H. B.; Whitney, D. R. 1947. On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other. *Annals of Mathematical Statistics* 18 (1): 50–60.

McDonough, T.A. and G.D. Hickman. 1999. Reservoir Fish Assemblage Index development: A tool for assessing ecological health in Tennessee Valley Authority impoundments. *In*: Assessing the sustainability and biological integrity of water resources using fish communities. Simon, T. (Ed.) CRC Press, Boca Raton, pp 523-540.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M. (1989). Rapid assessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA/444/4-89-001, Washington DC, USA.

Reynolds, J. B., 1996. Electrofishing. Pages 221-251 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society Bethesda, Maryland, USA.

Shaffer, G.P., J.W. Simmons, and D.S. Baxter. 2010. Biological monitoring in the vicinity of the Sequoyah Nuclear Plant discharge, autumn 2009. Tennessee Valley Authority, Aquatic Monitoring and Management, Knoxville, TN. 76 pp.

Shapiro, S. S. and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52 (3-4): 591–611.

Simmons, J.W. 2011. Biological monitoring in the vicinity of the Sequoyah Nuclear Plant discharge, autumn 2010. Tennessee Valley Authority, Biological and Water Resources, Chattanooga, TN. 58 pp.

Tennessee Valley Authority. 1988. Results of plankton studies conducted in 1986 and 1987 as part of the Operational Aquatic Monitoring Program at Sequoyah Nuclear Plant, Chickamauga Reservoir. Office of Natural Resources and Economic Development, Division of Air and Water Resources, Knoxville, Tennessee.

Tennessee Valley Authority. 1989. Plankton studies at Sequoyah Nuclear Plant in 1988. River Basin Operations, Water Resources, Chattanooga, Tennessee, TVA/WR/AB—89/3.

Tennessee Valley Authority. 1990. Plankton studies at Sequoyah Nuclear Plant in 1989. River Basin Operations, Water Resources, Chattanooga, Tennessee, TVA/WR/AB—90/2.

TWRC. 2006. Strategic Plan, 2006-2012. Tennessee Wildlife Resources Commission, Nashville, TN. March 2006. pp 124-125. http://tennessee.gov/twra/pdfs/StratPlan06-12.pdf

Wilcoxon, F. 1945. Individual comparisons by ranking methods. *Biometrics Bulletin* 1 (6): 80–83

Yoder, C.O., B.J. Armitage, and E.T. Rankin. 2006. Re-evaluation of the Technical Justification for Existing Ohio River Mainstem Temperature Criteria. Midwest Biodiversity Institute, Columbus, Ohio.

Tables

Table 1. Shoreline Aquatic Habitat Index (SAHI) metrics and scoring criteria.

Metric	Scoring Criteria	Score
Cover	Stable cover (boulders, rootwads, brush, logs, aquatic vegetation, artificial structures) in 25 to 75 % of the drawdown zone	5
	Stable cover in 10 to 25 % or > 75 % of the drawdown zone	3
	Stable Cover in < 10 % of the drawdown zone	1
Substrate	Percent of drawdown zone with gravel substrate > 40	5
	Percent of drawdown zone with gravel substrate between 10 and 40	3
	Percent substrate gravel < 10	1
Erosion	Little or no evidence of erosion or bank failure. Most bank surfaces stabilized by woody vegetation.	5
	Areas of erosion small and infrequent. Potential for increased erosion due to less desirable vegetation cover (grasses) on > 25 % of bank surfaces.	3
	Areas of erosion extensive, exposed or collapsing banks occur along > 30% of shoreline.	1
Canopy Cover	Tree or shrub canopy > 60 % along adjacent bank	5
	Tree or shrub canopy 30 to 60 % along adjacent bank	3
	Tree or shrub canopy < 30 % along adjacent bank	1
Riparian Zone	Width buffered > 18 meters	5
	Width buffered between 6 and 18 meters	3
	Width buffered < 6 meters	1
Habitat	Habitat diversity optimum. All major habitats (logs, brush, native vegetation, boulders, gravel) present in proportions characteristic of high quality, sufficient to support all life history aspects of target species. Ready access to deeper sanctuary areas present.	5
	Habitat diversity less than optimum. Most major habitats present, but proportion of one is less than desirable, reducing species diversity. No ready access to deeper sanctuary areas.	3
	Habitat diversity is nearly lacking. One habitat dominates, leading to lower species diversity. No ready access to deeper sanctuary areas.	1
Gradient	Drawdown zone gradient abrupt (> 1 meter per 10 meters). Less than 10 percent of shoreline with abrupt gradient due to dredging.	5
	Drawdown zone gradient abrupt. (> 1 meter per 10 meters) in 10 to 40 % of the shoreline resulting from dredging. Rip-rap used to stabilize bank along > 10 % of the shoreline.	3
	Drawdown zone gradient abrupt in > 40 % of the shoreline resulting from dredging. Seawalls used to stabilize bank along > 10 % of the shoreline.	1

Table 2. Expected values for upper mainstem Tennessee River reservoir transition and forebay zones.

	Upper Mainstem Tennessee River Transition						Upper Mainstem Tennessee River Forebay					
	Proportion			Number of species			Proportion			Number of species		
Trophic Guild	-	Avg	+	-	Avg	+	-	Avg	+	-	Avg	+
Benthic Invertivore	< 2.4	2.4 to 4.8	> 4.8	< 2	2 to 4	> 4	< 2.2	2.2 to 4.2	> 4.2	< 2	2 to 4	> 4
Insectivore	< 24.2	24.2 to 48.4	> 48.4	< 4	4 to 8	> 8	< 34.2	34.2 to 62.6	> 62.6	< 4	4 to 8	> 8
Top Carnivore	< 18.9	18.9 to 37.7	> 37.7	< 4	4 to 8	> 8	< 18.8	18.8 to 33.4	> 33.4	< 4	4 to 8	> 8
Omnivore	> 40.2	20.2 to 40.2	< 20.2	> 6	3 to 6	< 3	> 40.1	21.4 to 40.1	< 21.4	> 6	3 to 6	< 3
Planktivore	> 41.2	20.6 to 41.2	< 20.6	0	1	> 1	> 10.4	5.2 to 10.4	< 5.2	0	1	> 1
Parasitic	< 0.4	0.4 to 0.9	> 0.9	0	1	> 1	< 0.4	0.4 to 0.8	> 0.8	0	1	> 1
Herbivore	---	---	---	---	---	---	---	---	---	---	---	---

***Values calculated from data collected from 1993 to 2010 from 750 electrofishing runs and 500 overnight experimental gill net sets in upper mainstem Tennessee River reservoir transition areas and from 900 electrofishing runs and 600 overnight experimental gill net sets in forebay areas of upper mainstem Tennessee River reservoirs. This trisection is intended to show less than expected (-), expected or average (Avg), and above expected or average (+) values for trophic level proportions and species occurring within each reservoir zone in upper mainstem Tennessee River reservoirs..**

Table 3. Average trophic guild proportions and average number of fish species, bound by confidence intervals (95%), expected in upper mainstem Tennessee River reservoir transition and forebay zones and proportions and numbers of species observed during summer and autumn 2011.

	Transition Zones		Summer 2011 (Upstream)		Autumn 2011 (Upstream)		Forebay Zones		Summer 2011 (Downstream)		Autumn 2011 (Downstream)	
Trophic Guild	Average Proportion (%)	Average Number of Species	Proportion (%)	Number of Species	Proportion (%)	Number of Species	Average Proportion (%)	Average Number of Species	Proportion (%)	Number of Species	Proportion (%)	Number of Species
Benthic Invertivore	3.1 ± 0.2	3.7 ± 0.2	2.6	4	1.3	3	2.3 ± 0.4	3.3 ± 0.3	1.7	3	0.8	3
Insectivore	44.5 ± 2.2	9.2 ± 0.5	52.2	10	45.6	8	50.4 ± 5.7	8.7 ± 0.5	52.0	10	48.3	8
Top Carnivore	18.2 ± 0.9	10.2 ± 0.5	8.8	10	8.2	11	19.0 ± 2.7	9.9 ± 0.3	11.0	10	5.2	9
Omnivore	29.5 ± 1.5	6.4 ± 0.3	36.3	7	33.3	6	22.4 ± 3.5	6.1 ± 0.3	35.2	7	29.7	6
Planktivore	5.6 ± 0.3	1.1 ± 0.1	0.1	1	1.1	1	1.8 ± 0.9	1.0 ± 0.1	0.1	1	16.1	1
Parasitic	0.04 ± 0.02	1.0 ± 0.1	----	----	----	----	0.05 ± 0.05	0.1 ± 0.08	----	----	----	----
Herbivore	0.01 ± 0.004	1.0 ± 0.1	----	----	0.1	1	----	----	----	----	----	----

***Expected values were calculated using data collected from 1993 to 2010 from 750 electrofishing runs and 500 overnight experimental gill net sets in upper mainstem Tennessee River reservoir transition areas and from 900 electrofishing runs and 600 overnight experimental gill net sets in forebay areas of upper mainstem Tennessee River reservoirs.**

Table 4. RFAI scoring criteria (2002) for fish community samples in forebay, transition, and inflow sections of upper mainstream Tennessee River reservoirs. Upper mainstream reservoirs include Nickajack, Chickamauga, Watts Bar, Fort Loudoun, Melton Hill, and Tellico.

		Scoring Criteria								
		Forebay			Transition			Inflow		
Metric	Gear	1	3	5	1	3	5	1	3	5
1. Total species	Combined	<14	14-27	>27	<15	15-29	>29	<14	14-27	>27
2. Total Centrarchid species	Combined	<2	2-4	>4	<2	2-4	>4	<3	3-4	>4
3. Total benthic invertivores	Combined	<4	4-7	>7	<4	4-7	>7	<3	3-6	>6
4. Total intolerant species	Combined	<2	2-4	>4	<2	2-4	>4	<2	2-4	>4
5. Percent tolerant individuals	Electrofishing	>62%	31-62%	<31%	>62%	31-62%	<31%	>58%	29-58%	<29%
	Gill netting	>28%	14-28%	<14%	>32%	16-32%	<16%			
6. Percent dominance by 1 species	Electrofishing	>50%	25-50%	<25%	>40%	20-40%	<20%	>46%	23-46%	<23%
	Gill netting	>29%	15-29%	<15%	>28%	14-28%	<14%			
7. Percent non-indigenous species	Electrofishing	>4%	2-4%	<2%	>6%	3-6%	<3%	>17%	8-17%	<8%
	Gill netting	>16%	8-16%	<8%	>9%	5-9%	<5%			
8. Total top carnivore species	Combined	<4	4-7	>7	<4	4-7	>7	<3	3-6	>6
9. Percent top carnivores	Electrofishing	<5%	5-10%	>10%	<6%	6-11%	>11%	<11%	11-22%	>22%
	Gill netting	<25%	25-50%	>50%	<26%	26-52%	>52%			
10. Percent omnivores	Electrofishing	>49%	24-49%	<24%	>44%	22-44%	<22%	>55%	27-55%	<27%
	Gill netting	>34%	17-34%	<17%	>46%	23-46%	<23%			
11. Average number per run	Electrofishing	<121	121-241	>241	<105	105-210	>210	<51	51-102	>102
	Gill netting	<12	12-24	>24	<12	12-24	>24			
12. Percent anomalies	Electrofishing	>5%	2-5%	<2%	>5%	2-5%	<2%	>5%	2-5%	<2%
	Gill netting	>5%	2-5%	<2%	>5%	2-5%	<2%			

Table 5. Scoring criteria for benthic macroinvertebrate community samples (lab-processed) for forebay, transition, and inflow sections of mainstream Tennessee River reservoirs. (TRM 481.3 and TRM 483.4-Forbay, TRM 488.0 and TRM 490.5-Transition) scoring criteria were used for sites upstream and downstream of SQN.

Benthic Community Metrics	**Forebay** 1	3	5	**Transition** 1	3	5	**Inflow** 1	3	5
Average number of taxa	< 2.8	2.8-5.5	> 5.5	< 3.3	3.3-6.6	> 6.6	< 4.2	4.2-8.3	> 8.3
Proportion of samples with long-lived organisms	< 0.6	0.6-0.8	> 0.8	< 0.6	0.6-0.9	> 0.9	< 0.6	0.6-0.8	> 0.8
Average number of EPT (Ephemeroptera, Plecoptera, Trichoptera)	< 0.6	0.6-0.9	> 0.9	< 0.6	0.6-1.4	> 1.4	< 0.9	0.9-1.9	> 1.9
Average proportion of oligochaete individuals	> 41.9	41.9-21.0	< 21.0	> 21.9	21.9-11.0	< 11.0	> 23.9	23.9-12.0	< 12.0
Average proportion of total abundance comprised by the two most abundant taxa	> 90.3	90.3-81.7	< 81.7	> 87.9	87.9-77.8	< 77.8	> 86.2	86.2-73.1	< 73.1
Average density excluding chironomids and oligochaetes	< 125.0	125.0-249.9	> 249.9	< 305.0	305.0-609.9	> 609.9	< 400.0	400.0-799.9	> 799.9
Zero-samples - proportion of samples containing no organisms	> 0	---	0	> 0	---	0	> 0	---	0

Table 6. SAHI scores for 16 shoreline habitat assessments conducted within the Upstream RFAI sampling area of SQN on Chickamauga Reservoir, autumn 2009.

	1(LD)	2(LD)	3(LD)	4(LD)	5(LD)	6(LD)	7(LD)	8(LD)	Avg.
Latitude	35.26755	35.27312	35.27784	35.28179	35.28669	35.29674	35.20021	35.3037	
Longitude	-85.09749	-85.09602	-85.09093	-85.08571	-85.0741	-85.06678	-85.06367	-85.06049	
Aquatic Macrophytes	0%	0%	0%	0%	0%	0%	0%	0%	0%
SAHI Variables									
Cover	1	1	5	1	5	1	1	3	2
Substrate	5	1	1	1	3	5	3	5	3
Erosion	1	5	1	5	5	3	1	3	3
Canopy Cover	5	5	5	5	1	5	5	5	5
Riparian Zone	5	5	5	5	1	5	5	5	5
Habitat	1	1	3	1	3	1	1	3	2
Slope	1	1	1	1	3	3	3	3	2
Total	19	19	21	19	21	23	19	27	22
Rating	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Good	Fair

	1(RD)	2(RD)	3(RD)	4(RD)	5(RD)	6(RD)	7(RD)	8(RD)	Avg.
Latitude	35.26823	35.27665	35.28347	35.28747	35.29329	35.30095	35.30458	35.3092	
Longitude	-85.108	-85.10484	-85.09809	-85.09035	-85.08268	-85.07718	-85.07455	-85.07194	
Aquatic Macrophytes	0%	0%	0%	0%	0%	0%	0%	0%	0%
SAHI Variables									
Cover	3	1	5	5	3	3	5	1	3
Substrate	5	5	5	5	1	5	1	1	4
Erosion	1	1	5	5	5	5	5	3	4
Canopy Cover	5	5	1	3	5	3	3	1	3
Riparian Zone	5	5	1	1	5	1	1	1	3
Habitat	1	3	3	3	1	3	3	1	2
Slope	1	1	1	1	1	3	1	3	2
Total	21	21	21	23	21	23	19	11	21
Rating	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Poor	Fair

***Scores are shown for eight shoreline sections on the left descending bank (LD) and eight shoreline sections along the right descending bank (RD). Scoring criteria: poor (7-16); fair (17-26); and good (27-35).**

Table 7. SAHI Scores for 16 Shoreline Habitat Assessments Conducted within the Downstream RFAI Sampling Area of SQN on Chickamauga Reservoir, Autumn 2009.

	1(LD)	2(LD)	3(LD)	4(LD)	5(LD)	6(LD)	7(LD)	8(LD)	Avg.
Latitude	35.19455	35.20021	35.20443	35.20584	35.20617	35.2061	35.20865	35.21104	
Longitude	-85.11967	-85.11858	-85.11671	-85.11346	-85.10754	-85.10212	-85.09711	-85.09188	
Aquatic Macrophytes	0%	0%	15%	0%	0%	10%	0%	0%	2%
SAHI Variables									
Cover	5	5	5	5	3	1	1	3	4
Substrate	1	1	1	3	1	1	1	1	1
Erosion	3	5	3	3	3	1	3	5	3
Canopy Cover	5	3	5	5	5	5	1	1	4
Riparian Zone	5	3	5	5	5	5	1	3	4
Habitat	3	3	3	3	1	1	3	1	2
Slope	3	5	5	3	5	5	1	1	4
Total	25	25	27	27	23	19	11	15	22
Rating	Fair	Fair	Good	Good	Fair	Fair	Poor	Poor	Fair

	1(RD)	2(RD)	3(RD)	4(RD)	5(RD)	6(RD)	7(RD)	8(RD)	Avg.
Latitude	35.19718	35.20069	35.20722	35.20967	35.21449	35.21521	35.21565	35.2159	
Longitude	-85.12923	-85.12331	-85.12156	-85.11884	-85.1115	-85.10953	-85.10047	-85.09368	
Aquatic Macrophytes	0%	0%	0%	0%	10%	5%	25%	0%	5%
SAHI Variables									
Cover	3	5	5	3	1	3	5	3	4
Substrate	3	1	3	3	1	1	1	1	2
Erosion	5	5	5	5	3	3	1	5	4
Canopy Cover	5	5	5	1	1	1	5	1	3
Riparian Zone	5	5	5	1	1	1	3	5	3
Habitat	1	3	3	3	1	1	3	1	2
Slope	3	1	3	1	5	5	5	5	4
Total	25	25	29	17	13	15	23	21	22
Rating	Fair	Fair	Good	Fair	Poor	Poor	Fair	Fair	Fair

***Scores are Shown for Eight Shoreline Sections on the Left Descending Bank (LD) and Eight Shoreline Sections Along the Right Descending Bank (RD). Scoring Criteria: Poor (7-16); Fair (17-26); and good (27-35).**

Table 8. Substrate percentages and average water depth (ft) per transect upstream (8 transects) and downstream (8 transects) of SQN.

	% Substrate per transect downstream of SQN								
	1	2	3	4	5	6	7	8	**AVG**
Mollusk shell	15.5	32.0	20.5	26.0	24.5	22.5	26.5	52.9	**27.6**
Silt	37.5	12.0	11.0	13.0	23.5	36.0	19.5	7.0	**19.9**
Clay	14.0	16.0	9.0	30.0	8.0	29.5	6.0	17.0	**16.4**
Sand	19.5	14.0	22.0	6.0	12.0	3.5	28.5	2.5	**13.5**
Bedrock	10.0	9.0	18.0	20.	20.0	0	10.0	15.0	**12.8**
Detritus	2.5	4.5	3.5	3.5	3.0	5.0	3.0	4.6	**3.7**
Gravel	0	3.0	7.0	1.0	8.0	3.5	3.5	0.5	**3.0**
Cobble	1.0	9.5	9.0	0.5	1.0	0	3.0	0.5	**3.1**
Avg. depth (ft)	27.1	39.7	32.6	33.2	27	29.8	35.1	44.7	33.7
Actual depth range: 7.4 to 78.5 ft									

	% Substrate per transect upstream of SQN								
	1	2	3	4	5	6	7	8	**AVG**
Silt	30.5	43.0	56.5	22.0	45.5	71.0	63.5	77.5	**51.2**
Mollusk shell	25.0	19.5	15.5	33.5	20.0	10.0	15.5	8.0	**18.4**
Bedrock	10.0	20.0	0	20.0	20.0	0	0	0	**8.8**
Detritus	7.0	7.0	8.5	7.5	2.5	10.5	9.0	8.0	**7.5**
Clay	14.0	0	0	5	7.0	8.5	8.0	6.5	**6.1**
Cobble	4.0	5.0	10.0	0	2.5	0	4.0	0	**3.2**
Sand	7.5	5.5	7.5	4.5	0.5	0	0	0	**3.1**
Gravel	2.0	0	2.0	7.5	2.0	0	0	0	**1.7**
Avg. depth (ft)	33	30.1	34.9	33.6	26.2	31.8	32.2	26.1	31.0
Actual depth range: 6.4 to 55.2 ft									

Table 9. Individual Metric Scores and the Overall RFAI Scores Downstream (TRM 482) and Upstream (TRM 490.5) of Sequoyah Nuclear Plant Summer 2011.

Summer 2011	Gear	TRM 482		TRM 490.5	
Metric	**(Electrofishing/Gill Net)**	**Obs**	**Score**	**Obs**	**Score**
A. Species richness and composition					
1. Number of indigenous species (Tables 11 and 12)	Combined	**28**	**5**	**29**	**3**
2. Number of centrarchid species (less *Micropterus*)	Combined	**8** Black crappie Bluegill Green sunfish Longear sunfish Redbreast sunfish Redear sunfish Warmouth White crappie	**5**	**8** Black crappie Bluegill Green sunfish Longear sunfish Redbreast sunfish Redear sunfish Warmouth White crappie	**5**
3. Number of benthic invertivore species	Combined	**3** Freshwater drum Logperch Spotted sucker	**1**	**4** Freshwater drum Logperch River redhorse Spotted sucker	**3**
4. Number of intolerant species	Combined	**5** Brook silverside Longear sunfish Skipjack herring Smallmouth bass Spotted sucker	**5**	**6** Brook silverside Longear sunfish River redhorse Skipjack herring Smallmouth bass Spotted sucker	**5**

Table 9. (Continued)

Summer 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs		TRM 482 Score	TRM 490.5 Obs		TRM 490.5 Score
5. Percent tolerant individuals	Electrofishing	**85.7%**		**0.5**	**79.8%**		**0.5**
		Bluegill	49.1%		Bluegill	40.7%	
		Bluntnose minnow	1.6%		Bluntnose minnow	5.3%	
		Common carp	0.2%		Common carp	0.2%	
		Gizzard shad	26.9%		Gizzard shad	28.2%	
		Golden shiner	1.6%		Golden shiner	1.1%	
		Green sunfish	0.1%		Green sunfish	0.3%	
		Largemouth bass	3.8%		Largemouth bass	1.7%	
		Redbreast sunfish	1.6%		Redbreast sunfish	1.4%	
		Spotfin shiner	0.7%		Spotfin shiner	1.0%	
	Gill Netting	**55.1%**		**0.5**	**43.9%**		**0.5**
		Bluegill	0.7%		Bluegill	0.8%	
		Common carp	0.7%		Gizzard shad	37.9%	
		Gizzard shad	52.2%		Golden shiner	3.8%	
		White crappie	1.4%		Largemouth bass	0.8%	
					White crappie	0.8%	
6. Percent dominance by one species	Electrofishing	**49.1%** Bluegill		**1.5**	**40.7%** Bluegill		**0.5**
	Gill Netting	**52.2%** Gizzard shad		**0.5**	**37.9%** Gizzard shad		**0.5**
7. Percent non-indigenous species	Electrofishing	**2.9%**		**1.5**	**5.2%**		**1.5**
		Common carp	0.3%		Common carp	0.1%	
		Mississippi silverside	2.5%		Mississippi silverside	4.8%	
		Yellow perch	0.1%		Yellow perch	0.3%	
	Gill Netting	**0.7%** Common carp		**2.5**	**0%**		**2.5**

Table 9. (Continued)

Summer 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs		Score	TRM 490.5 Obs		Score
8. Number of top carnivore species	Combined	**10**		5	**10**		5
		Black crappie			Black crappie		
		Flathead catfish			Flathead catfish		
		Largemouth bass			Largemouth bass		
		Skipjack herring			Sauger		
		Smallmouth bass			Skipjack herring		
		Spotted bass			Smallmouth bass		
		Spotted gar			Spotted bass		
		White bass			Spotted gar		
		White crappie			White crappie		
		Yellow bass			Yellow bass		
B. Trophic composition							
9. Percent top carnivores	Electrofishing	**8.2%**		**1.5**	**5.3%**		**0.5**
		Black crappie	1.0%		Flathead catfish	0.8%	
		Largemouth bass	3.0%		Largemouth bass	1.7%	
		Smallmouth bass	0.1%		Smallmouth bass	0.2%	
		Spotted bass	0.8%		Spotted bass	1.1%	
		Spotted gar	2.2%		Spotted gar	1.5%	
		White bass	0.1%				
		Yellow bass	0.2%				
	Gill Netting	**29.0%**		**1.5**	**42.4%**		**1.5**
		Black crappie	10.1%		Black crappie	16.7%	
		Flathead catfish	1.4%		Flathead catfish	1.5%	
		Skipjack herring	1.4%		Largemouth bass	0.8%	
		Spotted bass	7.2%		Sauger	0.8%	
		Spotted gar	1.4%		Skipjack herring	15.2%	
		White bass	0.7%		Spotted bass	2.3%	
		White crappie	1.4%		White crappie	0.8%	
		Yellow bass	5.1%		Yellow bass	4.5%	

Table 9. (Continued)

Summer 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs		Score	TRM 490.5 Obs		Score
10. Percent omnivores	Electrofishing	**31.2%**		**2.5**	**35.1%**		**1.5**
		Bluntnose minnow	1.6%		Bluntnose minnow	5.3%	
		Channel catfish	0.7%		Channel catfish	0.2%	
		Common carp	0.2%		Common carp	0.2%	
		Gizzard shad	26.9%		Gizzard shad	28.2%	
		Golden shiner	1.6%		Golden shiner	1.1%	
		Smallmouth buffalo	0.1%		Smallmouth buffalo	0.2%	
	Gill Netting	**61.6%**		**0.5**	**47.7%**		**0.5**
		Blue catfish	5.8%		Blue catfish	4.5%	
		Channel catfish	1.4%		Channel catfish	1.5%	
		Common carp	0.7%		Gizzard shad	37.9%	
		Gizzard shad	52.2%		Golden shiner	3.8%	
		Smallmouth buffalo	1.4%				
C. Fish abundance and health							
11. Average number per run	Electrofishing	**60.7**		**0.5**	**82.4**		**0.5**
	Gill Netting	**13.8**		**1.5**	**13.2**		**1.5**
12. Percent anomalies	Electrofishing	**1.2%**		**2.5**	**0.6%**		**2.5**
	Gill Netting	**0%**		**2.5**	**0%**		**2.5**
Overall RFAI Score				**41** **Good**			**38** **Fair**

Table 10. Individual Metric Scores and the Overall RFAI Scores Downstream (TRM 482) and Upstream (TRM 490.5) of (Sequoyah nuclear) Autumn 2011.

Autumn 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs	Score	TRM 490.5 Obs	Score
A. Species richness and composition					
1. Number of indigenous species (Tables 13 and 14)	Combined	**25**	**3**	**27**	**3**
2. Number of centrarchid species (less *Micropterus*)	Combined	**7** Black crappie Bluegill Green sunfish Longear sunfish Redbreast sunfish Redear sunfish Warmouth	**5**	**7** Black crappie Bluegill Green sunfish Redbreast sunfish Redear sunfish Warmouth White crappie	**5**
3. Number of benthic invertivore species	Combined	**3** Freshwater drum Golden redhorse Spotted sucker	**1**	**3** Freshwater drum Logperch Spotted sucker	**1**
4. Number of intolerant species	Combined	**4** Longear sunfish Skipjack herring Smallmouth bass Spotted sucker	**3**	**3** Skipjack herring Smallmouth bass Spotted sucker	**3**
5. Percent tolerant individuals	Electrofishing	**42.6%** Bluegill 12.3% Bluntnose minnow 0.5% Common carp 0.% Gizzard shad 26.1% Golden shiner 0.3% Green sunfish 0.1% Largemouth bass 1.6% Redbreast sunfish 0.9% Spotfin shiner 0.5%	**1.5**	**80.8%** Bluegill 43.0% Bluntnose minnow 0.1% Common carp 0.1% Gizzard shad 30.8% Golden shiner 0.2% Green sunfish 0.1% Largemouth bass 1.7% Redbreast sunfish 4.7% Spotfin shiner 0.2%	**0.5**

Table 10 (continued).

Autumn 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs	Score	TRM 490.5 Obs	Score
		64.8%		**42.4%**	
	Gill Netting	Bluegill 0.8% Gizzard shad 63.1% Largemouth bass 0.8%	**0.5**	Bluegill 0.7% Gizzard shad 39.6% Golden shiner 0.7% White crappie 1.4%	**0.5**
6. Percent dominance by one species	Electrofishing	**35.1%** Mississippi silverside	**1.5**	**43.0%** Bluegill	**0.5**
	Gill Netting	**63.1%** Gizzard shad	**0.5**	**39.6%** Gizzard shad	**0.5**
7. Percent non-indigenous species	Electrofishing	**33.8%** Common carp 0.3% Mississippi silverside 33.5%	**0.5**	**6.9%** Common carp 0.1% Mississippi silverside 6.3% Yellow perch 0.1%	**0.5**
	Gill Netting	**0%**	**2.5**	**0%**	**2.5**

Table 10. (Continued)

Autumn 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs		Score	TRM 490.5 Obs		Score
8. Number of top carnivore species	Combined	**9** Black crappie Flathead catfish Largemouth bass Skipjack herring Smallmouth bass Spotted bass Spotted gar White bass Yellow bass		**5**	**11** Black crappie Flathead catfish Largemouth bass Skipjack herring Smallmouth bass Spotted bass Spotted gar Walleye White bass White crappie Yellow bass		**5**
B. Trophic composition							
9. Percent top carnivores	Electrofishing	**4.5%** Black crappie Flathead catfish Largemouth bass Smallmouth bass Spotted bass Spotted gar	 1.9% 0.01% 1.6% 0.01% 0.4% 0.6%	**0.5**	**6.2%** Black crappie Flathead catfish Largemouth bass Smallmouth bass Spotted bass Spotted gar White bass Yellow bass	 1.4% 0.5% 1.7% 0.9% 1.4% 0.1% 0.1% 0.2%	**1.5**
	Gill Netting	**19.7%** Black crappie Flathead catfish Largemouth bass Skipjack herring Smallmouth bass Spotted bass White bass Yellow bass Black crappie	 7.4% 2.5% 0.8% 1.6% 0.8% 4.1% 0.8% 1.6% 7.4%	**0.5**	**34.5%** Black crappie Flathead catfish Skipjack herring Spotted bass Walleye White bass White crappie Yellow bass	 12.2% 0.7% 8.6% 6.5% 0.7% 1.4% 1.4% 2.9%	**1.5**

Table 10. (Continued)

Autumn 2011 Metric	Gear (Electrofishing/Gill Net)	TRM 482 Obs		Score	TRM 490.5 Obs		Score
10. Percent omnivores	Electrofishing	**27.5%**		1.5	**31.9%**		1.5
		Blue catfish	0.01%		Blue catfish	0.1%	
		Bluntnose minnow	0.5%		Bluntnose minnow	0.1%	
		Channel catfish	0.2%		Channel catfish	0.7%	
		Common carp	0.3%		Common carp	0.1%	
		Gizzard shad	26.1%		Gizzard shad	30.8%	
		Golden shiner	0.3%		Golden shiner	0.2%	
					Blue catfish	0.1%	
	Gill Netting	**76.2%**		0.5	**51.1%**		0.5
		Blue catfish	9.8%		Blue catfish	5.8%	
		Channel catfish	3.3%		Channel catfish	5.0%	
		Gizzard shad	63.1%		Gizzard shad	39.6%	
					Golden shiner	0.7%	
C. Fish abundance and health							
11. Average number per run	Electrofishing	**174.2**		**1.5**	**122.4**		**1.5**
	Gill Netting	**12.2**		**1.5**	**13.9**		**1.5**
12. Percent anomalies	Electrofishing	**0.6**		**2.5**	**0.3**		**2.5**
	Gill Netting	**0**		**2.5**	**0**		**2.5**
Overall RFAI Score				**35** **Fair**			**35** **Fair**

Table 11. Summer 2011 Species Collected, Trophic level, Indigenous and Tolerance Classification, Catch Per Effort During Electrofishing and Gill Netting at Areas Downstream (TRM 482.0) of Sequoyah Nuclear Plant Discharge, Summer 2011.

Common Name	Scientific name	Trophic level	Indigenous species	Tolerance	Thermally Sensitive Species	Commercially Valuable Species	Recreationally Valuable Species	EF Catch Rate Per Run	EF Catch Rate Per Hour	Total fish EF	Gill Netting Catch Rate Per Net Night	Total Gill net fish	Total fish Combined	Percent Composition
Gizzard shad	*Dorosoma cepedianum*	OM	X	TOL	.	X	X	16.33	57.38	245	7.20	72	317	30.2%
Common carp	*Cyprinus carpio*	OM	.	TOL	.	X	.	0.13	0.47	2	0.10	1	3	0.3%
Golden shiner	*Notemigonus crysoleucas*	OM	X	TOL	.	X	.	1.00	3.51	15	.	.	15	1.4%
Spotfin shiner	*Cyprinella spiloptera*	IN	X	TOL	.	.	.	0.40	1.41	6	.	.	6	0.6%
Bluntnose minnow	*Pimephales notatus*	OM	X	TOL	.	.	X	1.00	3.51	15	.	.	15	1.4%
Redbreast sunfish	*Lepomis auritus*	IN	X	TOL	.	.	X	1.00	3.51	15	.	.	15	1.4%
Green sunfish	*Lepomis cyanellus*	IN	X	TOL	.	.	X	0.07	0.23	1	.	.	1	0.1%
Bluegill	*Lepomis macrochirus*	IN	X	TOL	.	.	X	29.80	104.68	447	0.10	1	448	42.7%
Largemouth bass	*Micropterus salmoides*	TC	X	TOL	.	.	X	2.33	8.20	35	.	.	35	3.3%
White crappie	*Pomoxis annularis*	TC	X	TOL	.	.	X	.	.	.	0.20	2	2	0.2%
Skipjack herring	*Alosa chrysochloris*	TC	X	INT	.	X	X	.	.	.	0.20	2	2	0.2%
Spotted sucker	*Minytrema melanops*	BI	X	INT	X	X	.	0.47	1.64	7	0.20	2	9	0.9%
Longear sunfish	*Lepomis megalotis*	IN	X	INT	.	.	X	0.13	0.47	2	0.10	1	3	0.3%
Smallmouth bass	*Micropterus dolomieu*	TC	X	INT	.	.	X	0.07	0.23	1	.	.	1	0.1%
Brook silverside	*Labidesthes sicculus*	IN	X	INT	.	X	X	0.07	0.23	1	.	.	1	0.1%
Spotted gar	*Lepisosteus oculatus*	TC	X	.	.	X	.	1.33	4.68	20	0.20	2	22	2.1%
Threadfin shad	*Dorosoma petenense*	PK	X	.	.	X	X	0.13	0.47	2	.	.	2	0.2%
Smallmouth buffalo	*Ictiobus bubalus*	OM	X	.	.	X	X	0.07	0.23	1	0.20	2	3	0.3%
Blue catfish	*Ictalurus furcatus*	OM	X	.	.	X	X	.	.	.	0.80	8	8	0.8%
Channel catfish	*Ictalurus punctatus*	OM	X	.	.	X	X	0.40	1.41	6	0.20	2	8	0.8%
Flathead catfish	*Pylodictis olivaris*	TC	X	.	.	X	X	.	.	.	0.20	2	2	0.2%
White bass	*Morone chrysops*	TC	X	.	.	.	X	0.07	0.23	1	0.10	1	2	0.2%
Yellow bass	*Morone mississippiensis*	TC	X	.	.	.	X	0.13	0.47	2	0.70	7	9	0.9%
Warmouth	*Lepomis gulosus*	IN	X	.	.	.	X	0.07	0.23	1	.	.	1	0.1%
Redear sunfish	*Lepomis microlophus*	IN	X	.	.	.	X	2.53	8.90	38	0.50	5	43	4.1%
Spotted bass	*Micropterus punctulatus*	TC	X	.	.	.	X	0.47	1.64	7	1.00	10	17	1.6%
Black crappie	*Pomoxis nigromaculatus*	TC	X	.	.	.	X	0.60	2.11	9	1.40	14	23	2.2%
Yellow perch	*Perca flavescens*	IN	.	.	.	.	X	0.07	0.23	1	.	.	1	0.1%
Logperch	*Percina caprodes*	BI	X	.	X	.	X	0.33	1.17	5	.	.	5	0.5%
Freshwater drum	*Aplodinotus grunniens*	BI	X	.	.	X	X	.	.	.	0.40	4	4	0.4%
Mississippi silverside	*Menidia audens*	IN	.	.	.	X	.	1.73	6.09	26	.	.	26	2.5%
Total			**28**		**2**	**14**	**25**	**60.73**	**213.33**	**911**	**13.80**	**138**	**1,049**	**100%**
Number Samples								**15**			**10**			
Species Collected								**26**			**18**			

***All species listed are Resident Important Species (RIS). No federally threatened or endangered species were collected. Trophic: benthic invertivore (BI), insectivore (IN), omnivore (OM), planktivore (PK), top carnivore (TC). Tolerance: tolerant (TOL), intolerant (INT).**

Table 12. Summer 2011 Species Collected, Trophic level, Indigenous and Tolerance Classification, Catch Per Effort During Electrofishing and Gill Netting at Areas Upstream (TRM 490.5) of Sequoyah Nuclear Plant Discharge, Summer 2011.

Common Name	Scientific name	Trophic level	Indigenous species	Tolerance	Thermally Sensitive Species	Commer-cially Valuable Species	Recrea-tionally Valuable Species	EF Catch Rate Per Run	EF Catch Rate Per Hour	Total fish EF	Gill Netting Catch Rate Per Net Night	Total Gill net fish	Total fish Combined	Percent Composition
Gizzard shad	*Dorosoma cepedianum*	OM	X	TOL	.	X	X	23.27	81.54	349	5.00	50	399	29.2%
Common carp	*Cyprinus carpio*	OM	.	TOL	.	X	.	0.13	0.47	2	.	.	2	0.1%
Golden shiner	*Notemigonus crysoleucas*	OM	X	TOL	.	X	.	0.87	3.04	13	0.50	5	18	1.3%
Spotfin shiner	*Cyprinella spiloptera*	IN	X	TOL	.	.	.	0.80	2.80	12	.	.	12	0.9%
Bluntnose minnow	*Pimephales notatus*	OM	X	TOL	.	.	X	4.33	15.19	65	.	.	65	4.8%
Redbreast sunfish	*Lepomis auritus*	IN	X	TOL	.	.	X	1.13	3.97	17	.	.	17	1.2%
Green sunfish	*Lepomis cyanellus*	IN	X	TOL	.	.	X	0.27	0.93	4	.	.	4	0.3%
Bluegill	*Lepomis macrochirus*	IN	X	TOL	.	.	X	33.53	117.52	503	0.10	1	504	36.8%
Largemouth bass	*Micropterus salmoides*	TC	X	TOL	.	.	X	1.40	4.91	21	0.10	1	22	1.6%
White crappie	*Pomoxis annularis*	TC	X	TOL	.	.	X	.	.	.	0.10	1	1	0.1%
Skipjack herring	*Alosa chrysochloris*	TC	X	INT	.	X	X	.	.	.	2.00	20	20	1.5%
Spotted sucker	*Minytrema melanops*	BI	X	INT	X	X	.	0.53	1.87	8	0.10	1	9	0.7%
River redhorse	*Moxostoma carinatum*	BI	X	INT	.	.	.	0.07	0.23	1	.	.	1	0.1%
Longear sunfish	*Lepomis megalotis*	IN	X	INT	.	.	X	0.53	1.87	8	.	.	8	0.6%
Smallmouth bass	*Micropterus dolomieu*	TC	X	INT	.	.	X	0.13	0.47	2	.	.	2	0.1%
Brook silverside	*Labidesthes sicculus*	IN	X	INT	.	X	.	0.13	0.47	2	.	.	2	0.1%
Spotted gar	*Lepisosteus oculatus*	TC	X	.	.	X	.	1.27	4.44	19	.	.	19	1.4%
Threadfin shad	*Dorosoma petenense*	PK	X	.	.	X	X	0.07	0.23	1	.	.	1	0.1%
Smallmouth buffalo	*Ictiobus bubalus*	OM	X	.	.	X	X	0.13	0.47	2	.	.	2	0.1%
Blue catfish	*Ictalurus furcatus*	OM	X	.	.	X	X	.	.	.	0.60	6	6	0.4%
Channel catfish	*Ictalurus punctatus*	OM	X	.	.	X	X	0.20	0.70	3	0.20	2	5	0.4%
Flathead catfish	*Pylodictis olivaris*	TC	X	.	.	X	X	0.67	2.34	10	0.20	2	12	0.9%
Yellow bass	*Morone mississippiensis*	TC	X	.	.	.	X	.	.	.	0.60	6	6	0.4%
Warmouth	*Lepomis gulosus*	IN	X	.	.	.	X	0.13	0.47	2	.	.	2	0.1%
Redear sunfish	*Lepomis microlophus*	IN	X	.	.	.	X	5.93	20.79	89	0.70	7	96	7.0%
Spotted bass	*Micropterus punctulatus*	TC	X	.	.	.	X	0.87	3.04	13	0.30	3	16	1.2%
Black crappie	*Pomoxis nigromaculatus*	TC	X	.	.	.	X	.	.	.	2.20	22	22	1.6%
Yellow perch	*Perca flavescens*	IN	.	.	.	.	X	0.27	0.93	4	.	.	4	0.3%
Logperch	*Percina caprodes*	BI	X	.	X	.	X	1.27	4.44	19	.	.	19	1.4%
Sauger	*Sander canadense*	TC	X	.	.	.	X	.	.	.	0.10	1	1	0.1%
Freshwater drum	*Aplodinotus grunniens*	BI	X	.	.	X	X	0.13	0.47	2	0.40	4	6	0.4%
Mississippi silverside	*Menidia audens*	IN	.	.	.	X	.	4.33	15.19	65	.	.	65	4.8%
Total			**29**		**2**	**14**	**24**	**82.39**	**288.79**	**1,236**	**13.20**	**132**	**1,368**	**100%**
Number Samples								**15**			**10**			
Species Collected								**26**			**16**			

***All species listed are Resident Important Species (RIS). No federally threatened or endangered species were collected. Trophic: benthic invertivore (BI), insectivore (IN), omnivore (OM), planktivore (PK), top carnivore (TC). Tolerance: tolerant (TOL), intolerant (INT).**

Table 13. Autumn 2011 Species Collected, Trophic level, Indigenous and Tolerance Classification, Catch Per Effort During Electrofishing and Gill Netting at Areas Downstream (TRM 482.0) of Sequoyah Nuclear Plant Discharge, Autumn 2011.

Common Name	Scientific name	Trophic level	Indigenous species	Tolerance	Thermally Sensitive Species	Commer-cially Valuable Species	Recrea-tionally Valuable Species	EF Catch Rate Per Run	EF Catch Rate Per Hour	Total fish EF	Gill Netting Catch Rate Per Net Night	Total Gill net fish	Total fish Combined	Percent Composition
Gizzard shad	*Dorosoma cepedianum*	OM	X	TOL	.	X	X	45.53	212.11	683	7.70	77	760	27.8%
Common carp	*Cyprinus carpio*	OM	.	TOL	.	X	.	0.47	2.17	7	.	.	7	0.3%
Golden shiner	*Notemigonus crysoleucas*	OM	X	TOL	.	X	.	0.60	2.80	9	.	.	9	0.3%
Spotfin shiner	*Cyprinella spiloptera*	IN	X	TOL	.	.	.	0.80	3.73	12	.	.	12	0.4%
Bluntnose minnow	*Pimephales notatus*	OM	X	TOL	.	.	X	0.93	4.35	14	.	.	14	0.5%
Redbreast sunfish	*Lepomis auritus*	IN	X	TOL	.	.	X	1.60	7.45	24	.	.	24	0.9%
Green sunfish	*Lepomis cyanellus*	IN	X	TOL	.	.	X	0.07	0.31	1	.	.	1	0.0%
Bluegill	*Lepomis macrochirus*	IN	X	TOL	.	.	X	21.47	100.00	322	0.10	1	323	11.8%
Largemouth bass	*Micropterus salmoides*	TC	X	TOL	.	.	X	2.73	12.73	41	0.10	1	42	1.5%
Skipjack herring	*Alosa chrysochloris*	TC	X	INT	.	X	X	.	.	.	0.20	2	2	0.1%
Spotted sucker	*Minytrema melanops*	BI	X	INT	X	X	.	0.73	3.42	11	0.10	1	12	0.4%
Longear sunfish	*Lepomis megalotis*	IN	X	INT	.	.	X	0.13	0.62	2	.	.	2	0.1%
Smallmouth bass	*Micropterus dolomieu*	TC	X	INT	.	.	X	0.07	0.31	1	0.10	1	2	0.1%
Spotted gar	*Lepisosteus oculatus*	TC	X	.	.	X	.	1.00	4.66	15	.	.	15	0.5%
Threadfin shad	*Dorosoma petenense*	PK	X	.	.	X	.	29.27	136.34	439	.	.	439	16.1%
Golden redhorse	*Moxostoma erythrurum*	BI	X	.	.	X	.	.	.	.	0.10	1	1	0.0%
Blue catfish	*Ictalurus furcatus*	OM	X	.	.	X	X	0.07	0.31	1	1.20	12	13	0.5%
Channel catfish	*Ictalurus punctatus*	OM	X	.	.	X	X	0.33	1.55	5	0.40	4	9	0.3%
Flathead catfish	*Pylodictis olivaris*	TC	X	.	.	X	X	0.07	0.31	1	0.30	3	4	0.1%
White bass	*Morone chrysops*	TC	X	.	.	.	X	.	.	.	0.10	1	1	0.0%
Yellow bass	*Morone mississippiensis*	TC	X	.	.	.	X	.	.	.	0.20	2	2	0.1%
Warmouth	*Lepomis gulosus*	IN	X	.	.	.	X	0.47	2.17	7	.	.	7	0.3%
Redear sunfish	*Lepomis microlophus*	IN	X	.	.	.	X	2.27	10.56	34	0.10	1	35	1.3%
Spotted bass	*Micropterus punctulatus*	TC	X	.	.	.	X	0.73	3.42	11	0.50	5	16	0.6%
Black crappie	*Pomoxis nigromaculatus*	TC	X	.	.	.	X	3.27	15.22	49	0.90	9	58	2.1%
Freshwater drum	*Aplodinotus grunniens*	BI	X	.	.	X	X	0.47	2.17	7	0.10	1	8	0.3%
Mississippi silverside	*Menidia audens*	IN	.	.	.	X	.	61.13	284.78	917	.	.	917	33.5%
Total			**25**		**1**	**13**	**19**	**174.21**	**811.49**	**2,613**	**12.20**	**122**	**2,735**	**100%**
Number Samples								**15**			**10**			
Species Collected								**23**			**16**			

***All species listed are Resident Important Species (RIS). No federally threatened or endangered species were collected. Trophic: benthic invertivore (BI), insectivore (IN), omnivore (OM), planktivore (PK), top carnivore (TC). Tolerance: tolerant (TOL), intolerant (INT).**

Table 14. Autumn 2011 Species Collected, Trophic level, Indigenous and Tolerance Classification, Catch Per Effort During Electrofishing and Gill Netting at Areas Upstream (TRM 490.5) of Sequoyah Nuclear Plant Discharge, Autumn 2011.

Common Name	Scientific name	Trophic level	Indigenous species	Tolerance	Thermally Sensitive Species	Commer-cially Valuable Species	Recrea-tionally Valuable Species	EF Catch Rate Per Run	EF Catch Rate Per Hour	Total fish EF	Gill Netting Catch Rate Per Net Night	Total Gill net fish	Total fish Combined	Percent Composition
Gizzard shad	*Dorosoma cepedianum*	OM	X	TOL	.	X	X	37.73	164.53	566	5.50	55	621	31.4%
Common carp	*Cyprinus carpio*	OM	.	TOL	.	X	.	0.07	0.29	1	.	.	1	0.1%
Golden shiner	*Notemigonus crysoleucas*	OM	X	TOL	.	X	.	0.27	1.16	4	0.10	1	5	0.3%
Spotfin shiner	*Cyprinella spiloptera*	IN	X	TOL	.	.	.	0.27	1.16	4	.	.	4	0.2%
Bluntnose minnow	*Pimephales notatus*	OM	X	TOL	.	.	X	0.13	0.58	2	.	.	2	0.1%
Redbreast sunfish	*Lepomis auritus*	IN	X	TOL	.	.	X	5.73	25.00	86	.	.	86	4.4%
Green sunfish	*Lepomis cyanellus*	IN	X	TOL	.	.	X	0.07	0.29	1	.	.	1	0.1%
Bluegill	*Lepomis macrochirus*	IN	X	TOL	.	.	X	52.60	229.36	789	0.10	1	790	40.0%
Largemouth bass	*Micropterus salmoides*	TC	X	TOL	.	.	X	2.07	9.01	31	.	.	31	1.6%
White crappie	*Pomoxis annularis*	TC	X	TOL	.	.	X	.	.	.	0.20	2	2	0.1%
Skipjack herring	*Alosa chrysochloris*	TC	X	INT	.	X	X	.	.	.	1.20	12	12	0.6%
Smallmouth bass	*Micropterus dolomieu*	TC	X	INT	.	.	X	1.07	4.65	16	.	.	16	0.8%
Spotted sucker	*Minytrema melanops*	BI	X	INT	X	.	.	0.40	1.74	6	0.40	4	10	0.5%
Spotted gar	*Lepisosteus oculatus*	TC	X	.	.	X	X	0.13	0.58	2	.	.	2	0.1%
Threadfin shad	*Dorosoma petenense*	PK	X	.	.	X	.	1.47	6.40	22	.	.	22	1.1%
Largescale stoneroller	*Campostoma oligolepis*	HB	X	.	.	.	X	0.93	4.07	14	.	.	14	0.7%
Blue catfish	*Ictalurus furcatus*	OM	X	.	.	X	X	0.07	0.29	1	0.80	8	9	0.5%
Channel catfish	*Ictalurus punctatus*	OM	X	.	.	X	X	0.80	3.49	12	0.70	7	19	1.0%
Flathead catfish	*Pylodictis olivaris*	TC	X	.	.	X	X	0.60	2.62	9	0.10	1	10	0.5%
White bass	*Morone chrysops*	TC	X	.	.	.	X	0.07	0.29	1	0.20	2	3	0.2%
Yellow bass	*Morone mississippiensis*	TC	X	.	.	.	X	0.20	0.87	3	0.40	4	7	0.4%
Warmouth	*Lepomis gulosus*	IN	X	.	.	.	X	0.67	2.91	10	.	.	10	0.5%
Redear sunfish	*Lepomis microlophus*	IN	X	.	.	.	X	4.27	18.60	64	1.50	15	79	4.0%
Spotted bass	*Micropterus punctulatus*	TC	X	.	.	.	X	1.67	7.27	25	0.90	9	34	1.7%
Black crappie	*Pomoxis nigromaculatus*	TC	X	.	.	.	X	1.73	7.56	26	1.70	17	43	2.2%
Yellow perch	*Perca flavescens*	IN	.	.	.	.	X	0.13	0.58	2	.	.	2	0.1%
Logperch	*Percina caprodes*	BI	X	.	X	.	X	0.07	0.29	1	.	.	1	0.1%
Walleye	*Sander vitreum*	TC	X	.	.	.	X	.	.	.	0.10	1	1	0.1%
Freshwater drum	*Aplodinotus grunniens*	BI	X	.	.	X	X	0.93	4.07	14	.	.	14	0.7%
Mississippi silverside	*Menidia audens*	IN	.	.	.	X	.	8.27	36.05	124	.	.	124	6.3%
Total			**27**		**2**	**11**	**24**	**122.42**	**533.71**	**1,836**	**13.90**	**139**	**1,975**	**100%**
Number Samples								**15**			**10**			
Species Collected								**27**			**15**			

***All species listed are Resident Important Species (RIS). No federally threatened or endangered species were collected. Trophic: benthic invertivore (BI), insectivore (IN), omnivore (OM), planktivore (PK), top carnivore (TC). Tolerance: tolerant (TOL), intolerant (INT).**

Table 15. Spatial statistical comparisons of numbers of species, mean electrofishing catch per unit effort values (number/run), tolerance designations, trophic levels, and non-indigenous individuals, along with species richness and Simpson and Shannon diversity values, collected near Sequoyah Nuclear Plant, summer 2011.

	Mean (Standard Deviation)				
Parameter	**Downstream (TRM 482)**	**Upstream (TRM 490.5)**	**Significant Difference**	**Test Statistic[(a)]**	**P Value**
Number of species (per run)					
Total (Species richness)	10.7 (2.3)	12.1 (3.5)	No	t= -1.23	0.23
Benthic invertivores	0.5 (0.7)	0.8 (0.8)	No	Z= -1.28	0.20
Insectivores	3.4 (1.5)	4.5 (1.1)	Yes	Z= -2.08	0.04
Omnivores	2.2. (1.1)	1.8 (0.9)	No	Z= 1.44	0.15
Top carnivores	2.3 (0.7)	2.5 (1.4)	No	Z= 0.09	0.93
Non-indigenous	0.5 (0.5)	0.9 (0.7)	No	Z= -1.57	0.11
Indigenous	7.9 (2.1)	8.7 (1.9)	No	t= -1.79	0.28
Tolerant	4.5 (0.8)	4.4 (1.2)	No	Z= 0.39	0.69
Intolerant	0.5 (1.0)	1.0 (0.8)	No	Z= -1.90	0.06
Thermally sensitive	0.5 (0.7)	0.6 (0.8)	No	Z= -0.41	0.68
CPUE (per run)					
Total	4.05 (1.63)	5.49 (2.10)	Yes	t= -2.11	0.04
Benthic invertivores	0.05 (0.10)	0.13 (0.21)	No	Z= -1.50	0.13
Insectivores	2.35 (1.36)	3.13 (1.29)	No	t= -1.59	0.12
Omnivores	1.26 (1.47)	1.92 (1.68)	No	Z= -1.14	0.25
Top Carnivores[(b)]	0.33(0.14)	0.29 (0.22)	No	t= 0.98	0.33
Non-indigenous	0.13 (0.27)	0.32 (0.39)	No	Z= -1.65	0.10
Indigenous	4.83 (1.72)	6.06 (2.02)	No	t= -1.79	0.08
Tolerant	3.47 (1.52)	4.38 (1.92)	No	t= -1.44	0.16
Intolerant	0.05 (0.09)	0.09 (0.09)	Yes	Z= -1.99	0.05
Thermally sensitive	0.07 (0.10)	0.13 (0.22)	No	Z= -0.47	0.64
Diversity indices (per run)					
Simpson	0.64 (0.14)	0.70 (0.11)	No	Z= -1.37	0.17
Shannon[(b)]	5.02 (2.18)	7.02 (4.10)	No	t= -1.79	0.13

(a) *t*-Value indicates results of independent two-sample *t*-test (α=0.05). *Z*-Value indicates results of Mann-Whitney-Wilcoxon *Z*-test (α=0.05) used when raw data could not be normalized using transformation.

(b) Square root or ln(x+1) transformed data used for statistical analyses because raw data were not normally distributed and/or did not have equal variances.

Table 16. Spatial statistical comparisons of numbers of species, mean electrofishing catch per unit effort values (number/run), tolerance designations, trophic levels, and non-indigenous individuals, along with species richness and Simpson and Shannon diversity values, collected near Sequoyah Nuclear Plant, autumn 2011.

	Mean (Standard Deviation)				
Parameter	**Downstream (TRM 482)**	**Upstream (TRM 490.5)**	**Significant Difference**	**Test Statistic[a]**	**P Value**
Number of species (per run)					
Total (Species richness)	13.5 (3.0)	12.9 (2.4)	No	t= 0.6	0.55
Benthic invertivores	0.5 (0.3)	0.5 (0.5)	No	Z= 0.94	0.35
Insectivores	3.9 (1.8)	4.1 (1.0)	No	Z= -0.45	0.65
Omnivores	2.3 (1.0)	1.9 (0.6)	No	Z= 1.16	0.25
Top carnivores	3.1 (1.0)	3.2 (1.7)	No	Z= 0.04	0.97
Non-indigenous	1.2 (0.4)	1.1 (0.5)	No	Z= 0.78	0.44
Indigenous[b]	10.1 (3.5)	9.4 (2.2)	No	t= 0.48	0.63
Tolerant	4.7 (1.7)	3.9 (0.9)	No	t= 1.62	0.12
Intolerant	0.7 (0.9)	0.8 (0.6)	No	Z= -0.67	0.50
Thermally sensitive	0.6 (0.5)	0.4 (0.6)	No	Z= 1.18	0.24
CPUE (per run)					
Total[b]	3.34 (0.71)	2.81 (0.50)	Yes	t= 2.34	0.03
Benthic invertivores	0.08 (0.06)	0.09 (0.07)	No	Z= -0.22	0.83
Insectivores	5.86 (2.98)	4.80 (3.25)	No	t= 0.93	0.36
Omnivores	3.19 (1.36)	2.60 (1.54)	No	t= 1.16	0.25
Top Carnivores	0.52 (0.27)	0.50 (0.47)	No	Z= 0.94	0.35
Non-indigenous	4.11 (3.41)	0.56 (0.50)	Yes	Z= 3.43	0.0006
Indigenous[b]	7.51 (4.37)	7.60 (2.86)	No	t= -0.30	0.76
Tolerant	4.95 (2.66)	6.60 (2.74)	No	t= -1.67	0.11
Intolerant	0.05 (0.07)	0.10 (0.11)	No	Z= -1.53	0.13
Thermally sensitive	0.05 (0.05)	0.03 (0.05)	No	Z= 1.18	0.24
Diversity indices (per run)					
Simpson	0.84 (0.06)	0.83 (0.12)	No	Z= -0.33	0.74
Shannon	9.1 (2.1)	8.9 (2.6)	No	t= 0.16	0.87

(a) *t*-Value indicates results of independent two-sample *t*-test (α=0.05). *Z*-Value indicates results of Wilcoxon Rank-Sum *Z*-test (α=0.05) used when raw data could not be normalized using transformation.
(b) Square root or ln(x+1) transformed data used for statistical analyses because raw data were not normally distributed and/or did not have equal variances.

Table 17. Summary of RFAI scores from sites located directly upstream and downstream of Sequoyah Nuclear Plant as well as scores from sampling conducted during autumn 1993-2011 as part of the Vital Signs Monitoring Program in Chickamauga Reservoir.

Station	Location	1993	1994	1995	1996	1997	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
Inflow	TRM 529.0	52	52	48	42	44	42	44	46	48	48	42	42	42	42	44	44	44	50	**45**
Transition SQN Upstream	TRM 490.5	51	40	48	44	39	45	46	45	51	42	49	46	47	44	34	41	39	35	**44**
Forebay SQN Downstream	TRM 482.0	---	---	---	47	---	41	48	46	43	45	41	39	35	38	38	37	39	35	**41**
Forebay	TRM 472.3	43	44	47	---	40	45	45	48	46	43	43	46	43	41	41	42	40	34	**43**
Hiwassee River Embayment	HiRM 8.5	46	39	39	---	40	43	43	47	---	36	42	45	---	41	---	42	---	37	**42**

***TRM 482 scored with forebay criteria, TRM 490.5 scored with transition criteria (Refer to Table 4).**
****RFAI Scores: 12-21 ("Very Poor"), 22-31 ("Poor"), 32-40 ("Fair"), 41-50 ("Good"), or 51-60 ("Excellent")**

Table 18. Comparison of mean density per square meter of benthic taxa collected at upstream and downstream sites near SQN during August and October 2011.

	DOWNSTREAM								UPSTREAM							
	TRM 481.3				TRM 483.4				TRM 488.0		TRM 490.5					
	Summer		Autumn		Summer		Autumn		Summer		Summer		Autumn			
Metric	Obs	Rating	Obs	Rating	Obs	Rating	Obs	Rating	Obs	Rating	Obs	Rating	Obs	Rating		
1. Average number of taxa	9.0	5	7.8	5	13.6	5	13.6	5	7.0	5	7.2	5	6.6	3		
2. Proportion of samples with long-lived organisms	0.8	3	0.7	3	0.8	3	0.8	3	1.0	5	0.4	1	0.8	3		
3. Average number of EPT taxa	0.9	3	1.0	5	1.2	5	0.9	3	0.8	3	0.2	1	0.5	1		
4. Average proportion of oligochaete individuals	35.6	3	29.4	3	54.4	1	48.1	1	15.5	3	7.2	5	14.8	3		
5. Average proportion of total abundance comprised by the two most abundant taxa	73.7	5	78.6	5	75.5	5	77.0	5	82.8	3	86.4	3	84.5	3		
6. Average density excluding chironomids and oligochaetes	235.0	3	181.7	3	525.0	5	1685.0	5	470.0	3	396.7	3	263.3	1		
7. Zero-samples – proportion of samples containing no organisms	0	5	0	5	0	5	0	5	0	5	0	5	0	5		
Benthic Index Score		**27 Good**		**29 Good**		**29 Good**		**27 Good**		**27 Good**		**23 Fair**		**19 Fair**		

***TRM 481.3 and 483.4 scored with forebay criteria, TRM 488.9 and 490.5 scored with transition criteria (Refer to Table 5).**
Reservoir Benthic Index Scores: 7-12 ("Very Poor"), 13-18 ("Poor"), 19-23 ("Fair"), 24-29 ("Good"), 30-35 ("Excellent")

Table 19. Summary of RBI Scores from Sites Located Directly Upstream and Downstream of Sequoyah Nuclear Plant as Well as Scores from Sampling Conducted as Part of the Vital Signs Monitoring Program in Chickamauga Reservoir.

Station	Location	1994	1995	1997	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
Inflow	TRM 527.4	---	---	---	---	---	29	27	33	35	31	---	23	23	23	21	*	**27**
Inflow	TRM 518.0	19	31	25	21	23	29	23	27	35	29	33	25	---	31	---	27	**27**
Transition SQN Upstream	TRM 490.5	33	29	31	31	23	25	25	31	31	31	27	21	17	27	23	19	**27**
Forebay SQN Downstream	TRM 482.0	---	---	---	---	23	31	29	29	33	31	31	25	25	23	29	---	**28**
Forebay	TRM 472.3	31	27	29	25	27	27	21	27	29	27	29	19	25	23	---	21	**26**
Hiwassee River Embayment	HiRM 8.5	17	27	25	21	---	21	---	31	---	25	---	13	---	19	---	19	**22**

*** - Sampling was conducted, but data was not available at the time this report was issued.**
Reservoir Benthic Index Scores: 7-12 ("Very Poor"), 13-18 ("Poor"), 19-23 ("Fair"), 24-29 ("Good"), 30-35 ("Excellent")

Table 20. Comparison of mean density per Square Meter of Benthic Taxa collected with a Ponar Dredge along Transects Upstream and Downstream of Sequoyah Nuclear Plant, Chickamauga Reservoir, Summer and Autumn 2011.

Taxa	Summer Downstream TRM 481.3	Autumn Downstream TRM 481.3	Summer Downstream TRM 483.4	Autumn Downstream TRM 483.4	Summer Upstream TRM 488.0	Summer Upstream TRM 490.5	Autumn Upstream TRM 490.5
Insecta							
Diptera							
Chironomidae							
Ablabesmyia annulata	5	8	2	2	13	7	7
Ablabesmyia mallochi	2	-----	3	-----	-----	-----	-----
Ablabesmyia rhamphe gp.	7	-----	10	13	-----	-----	-----
Ablabesmyia sp.	-----	-----	-----	------	-----	3	-----
Chironomidae	3	2	-----	------	-----	-----	-----
Chironomus crassicaudatus	10	2	10	------	7	73	22
Chironomus decorus gp.	2	2	------	------	-----	------	-----
Chironomus major	15	2	------	------	-----	27	2
Chironomus sp.	5	------	------	------	------	------	------
Cladopelma sp.	------	------	------	------	------	------	2
Cladotanytarsus sp.	------	------	5	2	------	------	15
Coelotanypus sp.	135	23	35	12	217	410	------
Coelotanypus tricolor	------	205	-------	103	------	------	292
Clinotanypus sp.	------	------	-------	2	------	------	------
Cryptochironomus sp.	7	7	2	7	3	------	3
Cricotopus sp.	------	------	-------	2	------	------	-------
Cricotopus reverses gp.	------	2	-------	--------	------	------	-------
Dicrotendipes lucifer	------	-------	58	45	------	------	-------
Dicrotendipes modestus	------	-------	12	53	------	------	-------
Dicrotendipes neomodestus	2	2	28	5	------	------	-------
Dicrotendipes simpsoni	------	-------	3	3	------	------	-------
Dicrotendipes sp.	------	-------	2	2	------	------	-------
Glyptotendipes sp.	------	2	27	3	------	------	-------
Hydrobaenus sp.	2	-------	-------	-------	------	------	-------
Microtendipes pedellus gp.	2	-------	-------	-------	------	------	-------
Nanocladius alternantherae	------	-------	-------	2	------	------	-------
Nanocladius distinctus	------	-------	3	5	------	------	-------
Orthocladius sp.	------	-------	2	-------	------	-------	-------
Parachironomus carinatus	-------	-------	7	3	------	-------	-------
Parachironomus frequens	-------	--------	-------	7	-------	-------	-------
Parachironomus sp.	-------	-------	-------	2	-------	-------	-------
Polypedilum halterale gp.	-------	2	3	-------	-------	-------	-------
Procladius sp.	5	2	2	2	7	-------	5
Pseudochironomus sp.	-------	-------	-------	2	-------	-------	-------

Table 20 (continued).

Taxa	Summer Downstream TRM 481.3	Autumn Downstream TRM 481.3	Summer Downstream TRM 483.4	Autumn Downstream TRM 483.4	Summer Upstream TRM 488.0	Summer Upstream TRM 490.5	Autumn Upstream TRM 490.5
Chironomidae (Cont.)							
Tanytarsus sp.	2	3	-------	5	-------	-------	-------
Thienemanniella lobapodema	-------	-------	-------	-------	10	-------	-------
Ceratopogonidae	3	-------	-------	-------	-------	-------	2
Argia sp.	-------	-------	2	-------	-------	-------	-------
Palpomyia sp.	-------	-------	-------	-------	-------	7	-------
Chaoboridae	-------	-------	-------	-------	-------	-------	-------
Chaoborus punctipennis	115	67	22	2	63	260	10
Ephemeroptera							
Ephemeridae							
Hexagenia limbata	28	23	3	13	20	3	7
Hexagenia sp.	2	-------	-------	2	-------	-------	2
Heptageniidae							
Stenacron interpunctatum	2	3	-------	-------	-------	-------	-------
Caenidae							
Caenis sp.	-------	-------	-------	-------	-------	-------	2
Trichoptera							
Leptoceridae							
Oecetis sp.	7	8	20	12	7	-------	3
Polycentropodidae							
Cyrnellus fraternus	3	-------	17	18	-------	-------	-------
Polycentropus sp.	-------	-------	-------	-------	-------	-------	2
Hydroptilidae							
Orthotrichia sp.	-------	2	3	-------	-------	-------	-------
Ostracoda							
Podocopa							
Candoniidae							
Candona sp.	3	70	-------	58	-------	7	22
Ostracoda	5	2	3	-------	-------	-------	-------
Brachiopoda							
Cladocera							
Daphnidae							
Ceriodaphnia	2	-------	-------	-------	-------	-------	-------
Sididae							
Sida crystallina	2	2	32	5	-------	-------	3

Table 20 (continued).

Taxa	Summer Downstream TRM 481.3	Autumn Downstream TRM 481.3	Summer Downstream TRM 483.4	Autumn Downstream TRM 483.4	Summer Upstream TRM 488.0	Summer Upstream TRM 490.5	Autumn Upstream TRM 490.5
Oligocheata							
Haplotaxida							
Tubificidae							
Aulodrilus piqueti	392	33	27	77	7	3	2
Branchiura sowerbyi	3	2	10	3	-----	-----	-----
Limnodrilus hoffmeisteri	10	13	7	93	20	-----	10
Limnodrilus cervix	-----	2	-----	-----	-----	-----	-----
Tubificidae	168	75	52	542	60	70	120
Naididae							
Dero sp.	60	18	855	822	7	-----	-----
Naididae	3	3	137	167	-----	-----	12
Nais cf. pardalis	-----	-----	30	2	-----	-----	-----
Nais sp.	-----	-----	22	40	-----	-----	5
Prisitina breviseta	-----	2	-----	-----	-----	-----	5
Pristina leidyi	-----	-----	2	-----	-----	-----	-----
Pristina sp.	-----	2	-----	25	-----	-----	-----
Slavina appendiculata	-----	-----	15	18	-----	-----	-----
Stylaria lacustris	-----	-----	-----	410	-----	-----	-----
Branchiobdellida							
Branchiodellida	-----	-----	-----	2	-----	-----	-----
Bivalvia							
Veneroida							
Corbiculidae							
Corbicula fluminea	42	38	98	212	223	67	67
Dreissenidae							
Dreissena polymorpha	-------	-------	77	198	-------	-------	-------
Sphaeriidae							
Eupera cubensis	-------	-------	2	-------	-------	-------	-------
Musculium transversum	100	62	27	138	187	283	165
Pisidium sp.	20	12	12	5	20	27	3
Sphaeriidae	-------	-------	-------	2	-------	-------	-------
Unionoida							
Unoinidae							
Utterbackia imbecillis	2	-------	-------	5	-------	-------	-------
Truncilla truncata	-------	-------	-------	-------	-------	-------	2
Gastropoda							
Mesogastropoda							
Viviparidae							
Viviparus sp.	7	-------	13	55	3	-------	-------

Table 20 (continued).

Taxa	Summer Downstream TRM 481.3	Autumn Downstream TRM 481.3	Summer Downstream TRM 483.4	Autumn Downstream TRM 483.4	Summer Upstream TRM 488.0	Summer Upstream TRM 490.5	Autumn Upstream TRM 490.5
Gastropoda (cont.)							
Campeloma decisum	-------	-------	2	7	-------	-------	2
Hydrobiidae							
Amnicola limosa	-------	-------	3	2	-------	-------	-------
Pleuroceridae							
Pleurocera canaliculata	-------	-------	3	10	-------	-------	3
Basommatophora							
Planorbidae							
Menetus dilatatus	-------	-------	2	-------	-------	-------	-------
Malacostraca							
Amphipoda							
Crangonyctidae							
Crangonyx sp.	2	-------	-------	8	-------	-------	-------
Gammaridae							
Gammarus sp.	-------	-------	7	3	-------	-------	-------
Talitrida							
Hyalella azteca	-------	3	-------	-------	-------	-------	-------
Maxillopoda							
Copepoda							
Cyclopoida	5	-------	3	5	3	7	2
Harpacticoida	-------	-------	2	-------	-------	-------	-------
Turbellaria							
Tricladida							
Planariidae							
Dugesia tigrina	2	2	185	625	-------	-------	-------
Cura foremanii	-------	2	-------	-------	-------	-------	-------
Hirudinea							
Rhynchobdellida							
Glossiphoniidae							
Glossiphoniidae sp.	-------	-------	12	88	-------	3	-------
Helobdella stagnalis	15	22	17	165	10	3	3
Helobdella sp.	-------	2	2	73	-------	-------	-------
Helobdella triserialis	-------	-------	8	13	-------	-------	-------
Placobdella montifera	-------	3	-------	-------	-------	-------	-------
Pharyngobdellida							
Erpobdellidae							
Erpobdellidae	-------	-------	3	28	-------	-------	-------

Table 20 (continued).

Taxa	Summer Downstream TRM 481.3	Autumn Downstream TRM 481.3	Summer Downstream TRM 483.4	Autumn Downstream TRM 483.4	Summer Upstream TRM 488.0	Summer Upstream TRM 490.5	Autumn Upstream TRM 490.5
Nematoda							
Nematoda							
Nematoda	2	-------	2	-------	-------	3	2
Arachnoidea							
Unoinicolidae							
Unionicola sp.	-------	2	-------	-------	-------	-------	8
Acariformes							
Hygrobatidae							
Atractides sp.	-------	-------	2	-------	-------	-------	2
Hydrozoa							
Hydroida							
Hydridae							
Number of samples	**10**	**10**	**10**	**10**	**5**	**5**	**10**
Mean Density per meter²	**1,205**	**735**	**1,883**	**4,283**	**887**	**1,263**	**810**
Taxa Richness	**42**	**40**	**54**	**58**	**20**	**18**	**36**
Sum of area sampled (meters²)	**0.60**	**0.60**	**0.60**	**0.60**	**0.30**	**0.30**	**0.60**

Table 21. Individual Metric Ratings and the Overall RBI Field Scores for Downstream and Upstream Sampling Sites Near SQN, Chickamauga Reservoir, Autumn 2000-2010. Reservoir Benthic Index Scores: 7-12 ("Very Poor"), 13-18 ("Poor"), 19-23 ("Fair"), 24-29 ("Good"), 30-35 ("Excellent").

Downstream (TRM 482.0)	**2000**		**2001**		**2002**		**2003**		**2004**		**2005**		**2006**		**2007**		**2008**		**2009**		**2010**	
Metric	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**
Avg. Number of Taxa	3.7	3	6.2	5	5.4	5	5.7	5	6.3	5	6.6	5	4.9	5	4.1	3	5.8	5	4.2	3	5	5
% Long-Lived Organisms	0.9	5	0.8	5	1	5	0.6	3	1	5	0.9	5	0.9	5	0.6	3	0.6	3	0.7	3	0.9	5
Avg. Number of EPT Taxa	0.3	1	0.6	3	0.4	1	0.3	1	0.5	3	0.7	3	0.7	3	0.5	3	0.6	3	0.5	3	0.5	3
% as Oligochaetes	27.9	3	27.1	3	19.4	3	9.4	5	8.8	5	15	3	17.3	3	6.3	5	21.7	3	4.4	5	11.7	5
% as Dominant Taxa	87.6	3	80.8	5	78.6	5	79.8	5	68.4	5	79	5	78.1	5	90.6	3	83.9	3	83.9	3	81.3	5
Density excluding chironomids and oligochaetes	230	3	348.3	5	365	5	580	5	563.3	5	573.3	5	265	5	125	3	166.7	3	104.4	1	98.3	1
Number of Samples with Zero Organisms	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5
Overall Score		**23**		**31**		**29**		**29**		**33**		**31**		**31**		**25**		**25**		**23**		**29**

Upstream (TRM 490.5)	**2000**		**2001**		**2002**		**2003**		**2004**		**2005**		**2006**		**2007**		**2008**		**2009**		**2010**	
Metric	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**	**Obs**	**Score**
Avg. Number of Taxa	4.7	5	6	5	6.4	5	7.4	5	7.2	5	6.8	5	5.4	5	4.7	5	5.4	5	5	5	4.4	5
% Long-Lived Organisms	0.9	5	0.9	5	1	5	0.9	5	0.9	5	0.9	5	0.8	5	0.5	3	0.3	1	0.8	5	0.7	3
Avg. Number of EPT Taxa	0.3	1	0.4	3	0.2	1	0.7	3	0.7	3	0.9	5	0.5	3	0.3	1	0.1	1	0.6	3	0.7	3
% as Oligochaetes	7.7	5	14.8	3	8.4	5	10.7	5	6.4	5	4.4	5	2.5	5	5.2	5	16.7	3	7.2	5	1.1	5
% as Dominant Taxa	88.4	1	79.4	3	85	3	71	5	78	5	79.8	3	83.1	3	93.4	1	95	1	81.2	3	91.8	1
Density excluding chironomids and oligochaetes	218.3	1	230	1	168.6	1	341.7	3	571.7	3	479.2	3	223.3	1	56.7	1	31.7	1	81.7	1	181.7	1
Number of Samples with Zero Organisms	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5
Overall Score		**23**		**25**		**25**		**31**		**31**		**31**		**27**		**21**		**17**		**27**		**23**

Table 22. Mean percent composition of major phytoplankton groups at sites sampled upstream and downstream of SQN in August and October, 2011.

	August 25, 2011				October 10, 2011			
Division	TRM 481.1	TRM 483.4	TRM 487.9	TRM 490.7	TRM 481.1	TRM 483.4	TRM 487.9	TRM 490.7
Bacillariophyta	0	0	1	0	36	38	39	63
Chlorophyta	1	1	2	1	16	16	13	11
Chrysophyta	0	0	0	0	---	---	---	---
Cryptophyta	0	0	0	0	30	34	36	21
Cyanophyta	99	98	96	98	16	12	12	11
Euglenophyta	0	0	0	0	1	0	---	0
Pyrrophyta	0	0	0	0	1	0	0	---

**To enhance pattern recognition, percentages are rounded to whole numbers, and values may not add to 100. "0" values indicate percentages less than 0.5%. Blank values indicate no individuals of the taxa collected.*

Table 23. Comparison of the similarity of phytoplankton taxa within paired replicate samples.

	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Replicate Taxa Richness	37	39	36	40	36	43	33	40	23	25	21	24	19	22	15	15
Combined Taxa Richness	43		46		49		48		32		30		27		19	
Species Shared	33		30		30		25		16		15		14		11	
Percent Shared	76.7%		65.2%		61.2%		52.1%		50.0%		50.0%		51.9%		57.9%	

Table 24. Taxa richness of the main phytoplankton groups.

	Total Number of Taxa		
Group	August	October	Combined
Bacillariophyta	9	12	16
Chlorophyta	31	14	37
Chrysophyta	7	---	7
Cryptophyta	2	1	2
Cyanophyta	14	7	18
Euglenophyta	1	2	2
Pyrrophyta	3	2	4
Total Taxa Richness	**67**	**38**	**86**

Table 25. Percent Similarity Index for comparison of phytoplankton communities among sites.

Station Comparison		Phytoplankton - Percent Similarity[a] August 25, 2011	October 10, 2011
TRM 481.1	– TRM 483.4	83	76
	– TRM 487.9	85	71
	– TRM 490.7	75	63
TRM 483.4	– TRM 487.9	87	80
	– TRM 490.7	81	63
TRM 487.9	– TRM 490.7	84	63

a. Percent Similarity comparison of two communities

Table 26. Phytoplankton taxa and density (cells/ml) data for samples collected at four stations within Chickamauga Reservoir on the Tennessee River – August 25 and October 10, 2011. Abbreviations "R1" and R2" designate replicate samples.

		TRM 481.1				TRM 483.4				TRM 487.9				TRM 490.7			
		August		October		August		October		August		October		August		October	
Division	**Taxon**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
Bacillariophyta	Achnanthes					30.3					34.1				28.4		
	Anomoeneis						56.8										
	Aulacoseira	151.5	151.5	74.9	66.1	60.6	56.8	90.4	74.9	170.4	166.5	51.0	68.3		56.8	69.1	76.5
	Cyclotella	568.0	814.1	17.6	22.0	333.2	312.4	20.9	16.5	2044.7	1908.4	23.1	20.9	710.0	1164.4	2.2	6.6
	Nitzschia	68.2	265.1	3.3	2.2	121.2	113.6	3.3		702.9	306.7	4.4	3.3	56.8	170.4	0.5	1.0
	Skeletonema	45.4	75.7							397.6	357.8			454.4	227.2		
	Stephanodiscus		18.9			60.6		2.2									
	Surirella						28.4										
	Synedra	22.7	113.6	12.1	9.9	30.3	56.8	16.5	9.9	68.2	5.5	6.6	8.8		28.4	5.9	5.6
	Achnanthidium				1.1			3.3	1.1			0.7	0.1			2.9	1.5
	Cocconeis			2.2	1.1				0.1			0.7					
	Cymbella			0.1	0.7			0.1					0.7			0.5	
	Fragilaria			50.7	63.9			86.0	50.7			72.7	52.9			83.7	54.4
	Gyrosigma																0.5
	Melosira											0.2	0.4				
	Navicula			0.1	0.7				0.1			3.3	2.2				
Bacillariophyta Total		**856**	**1,439**	**161**	**168**	**636**	**625**	**223**	**153**	**3,384**	**2,779**	**163**	**158**	**1,221**	**1,676**	**165**	**146**
Chlorophyta	Carteria	22.7	18.9				28.4										
	Chlamydomonas	386.2	302.9	5.5	6.6	121.2	198.8	49.6	20.9	681.6	511.2	23.1	16.5	198.8	142.0	9.6	6.6
	Chlorococcaceae	22.7	56.8			121.2	113.6			136.3	408.9			170.4	142.0		
	Chlorogonium										34.1						
	Coelastrum		75.7							272.6	408.9						
	Cosmarium						28.4										
	Crucigenia					121.2		5.7	0.6				0:8		894.6	0.3	7.6
	Diacanthos										34.1						
	Dictyosphaerium	249.9				121.2	227.2				136.3			113.6	312.4		
	Euastrum	22.7															
	Eudorina					484.7											
	Golenkinia						28.4			34.1	34.1				28.4		
	Kirchneriella									136.3							
	Lagerheimia					30.3	28.4				34.1			85.2			
	Micractinium		113.6			121.2	113.6			170.4				113.6			
	Monomastix						28.4										
	Monoraphidium	249.9	151.5	4.4		151.5	426.0		4.4	443.0	920.1		0.1	397.6	227.2		

Table 26 (continued).

		TRM 481.1				TRM 483.4				TRM 487.9				TRM 490.7			
		August		October		August		October		August		October		August		October	
Division	**Taxon**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
Chlorophyta (continued)	Mougeotia	22.7															
	Oocystis		18.9			60.6	142.0			545.3	272.6			113.6	113.6		
	Pandorina	363.5	87.8											87.8			
	Pediastrum	76.8	208.3	22.8		242.3	87.8	22.8	1.8		1056.4	0.8			113.6	2.1	
	Pyramichlamys	22.7	56.8												28.4		
	Quadrigula													28.4			
	Scenedesmus	284.0	1022.4	0.4	10.5	1272.3	426.0	3.1	13.2	1363.1	1158.7	16.1	17.6	1703.9	1168.4	15.6	6.1
	Schroederia	22.7	75.7			30.3	28.4				34.1				28.4		
	Sphaerocystis										272.6						
	Staurastrum						28.4		0.7	34.1		0.1					0.0
	Teilingia														21.9		
	Tetraedron	45.4			0.7	30.3	113.6			34.1	34.1		0.7	113.6	85.2		
	Tetrastrum		75.7	5.7			113.6	0.4		136.3	136.3	2.9					
	Treubaria					30.3	28.4				34.1						
	Actinastrum			17.6	11.4			8.8	0.8			0.4	17.6			3.8	0.4
	Ankistrodesmus			8.8	5.7								0.2				
	Chlorella			23.1	16.5			13.2	7.7			3.3	3.3				0.1
	Closterium				0.7												
	Elakatothrix			0.6												1.0	
	Selenastrum			9.4				0.2					1.4				
Chlorophyta Total		**1,792**	**2,265**	**98**	**52**	**2,938**	**2,189**	**104**	**50**	**3,987**	**5,521**	**47**	**58**	**3,126**	**3,306**	**32**	**21**
Chrysophyta	Chrysococcus													28.4			
	Conradiella		132.5			242.3	198.8			408.9	204.5			170.4	340.8		
	Erkenia	272.6	208.3			121.2	113.6			408.9	937.2			568.0	198.8		
	Goniochloris									34.1				28.4			
	Gonyostomum										5.5			5.5	5.5		
	Kephyrion														28.4		
	Mallomonas									68.2	68.2						
Chrysophyta Total		**273**	**341**			**364**	**312**			**920**	**1,215**			**801**	**573**		
Cryptophyta	Cryptomonas	318.1	397.6	146.6	123.4	30.3	56.8	188.4	139.9	306.7	681.6	157.6	137.7	426.0	284.0	53.6	49.2
	Rhodomonas	454.4	284.0			121.2	113.6			238.6	1465.4			568.0	312.4		
Cryptophyta Total		**772**	**682**	**147**	**123**	**151**	**170**	**188**	**140**	**545**	**2,147**	**158**	**138**	**994**	**596**	**54**	**49**

Table 26 (continued).

		TRM 481.1				TRM 483.4				TRM 487.9				TRM 490.7			
		August		*October*		*August*		*October*		*August*		*October*		*August*		*October*	
Division	**Taxon**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
Cyanophyta	Anabaena	43.9	738.4	0.9			76.8	1.5		886.1	477.1	1.9	74.4				
	Anabaenopsis														153.6		
	Aphanocapsa	6179.6	17561.7			3513.9	2186.7			5316.3	477.1			10947.7	6957.8		
	Chroococcaceae	98554.4	65702.9			78022.2	70835.9			100607.6	104714.0			151938.0	170416.9		
	Chroococcus	795.2	75.7	22.0	0.2	363.5	340.8		11.4	681.6	477.1		2.9		227.2		
	Cyanocatena					21900.9	10266.1								14783.2		
	Cyanogranis	59789.6	158097.6			65702.9	94447.9			68988.0	98760.2			123192.9	68988.0		
	Cylindrospermopsis	2805.8	2515.9			1206.5	1318.4			1243.9	1756.2			666.0	467.4		
	Dactylococcopsis	22.7	56.8								136.3			142.0	142.0		
	Leptolyngbya			32.8													
	Limnothrix				25.7				2.3								
	Lyngbya	3358.7	1416.2			1269.2	1817.5			963.3	1613.1			1363.2	3908.7		
	Merismopedia	8497.0	5566.2		11.4		1931.1	2.4	59.3	272.6	2453.7			454.4	681.6		
	Oscillatoria	6410.1	3691.9			4543.8	4158.1			4089.5	6043.3			8503.5	7403.6		
	Planktothrix				48.5												27.9
	Pseudanabaena				0.9				34.3			19.8					
	Synechococcus	61664.6	110873.7			30113.8	34989.9			40203.9	62789.2			22585.4	35415.9		
	Synechocystis	5339.0	4998.2			4453.0	3635.1			7497.3	6986.2			5963.8	5310.6		
Cyanophyta Total		**253,461**	**371,295**	**56**	**87**	**211,090**	**226,004**	**4**	**107**	**230,750**	**286,683**	**22**	**77**	**325,757**	**314,856**	**0**	**28**
Euglenophyta	Euglena	45	11	6	7	15		0	1	5				5		1	
	Trachelomonas								1								
Euglenophyta Total		**45**	**11**	**6**	**7**	**15**		**0**	**3**	**5**				**5**		**1**	
Pyrrophyta	Glenodinium	23	5								11			28			
	Gymnodinium	45	38			30					34				28		
	Peridinium	45	5		2			0	0	11			1		28		
	Ceratium				0				0								
Pyrrophyta Total		**114**	**49**		**2**	**30**		**0**	**0**	**11**	**45**		**1**	**28**	**57**		
Total Phytoplankton Cell Count		**257,313**	**376,081**	**467**	**439**	**215,224**	**229,301**	**519**	**453**	**239,603**	**298,391**	**389**	**432**	**331,933**	**321,065**	**251**	**244**

Table 27. Percentage Composition of phytoplankton for samples collected at four stations within Chickamauga Reservoir on the Tennessee River – August 25 and October 10, 2011.

	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
Taxon	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
Bacillariophyta																
Achnanthes	---	---	0	---	---	0	---	0	---	---	---	---	---	---	---	---
Anomoeneis	---	---	---	0	---	---	---	---	---	---	---	---	---	---	---	---
Aulacoseira	0	0	0	0	0	0	---	0	16	15	17	17	13	16	27	31
Cyclotella	0	0	0	0	1	1	0	0	4	5	4	4	6	5	1	3
Nitzschia	0	0	0	0	0	0	0	0	1	1	1	---	1	1	0	0
Skeletonema	0	0	---	---	0	0	0	0	---	---	---	---	---	---	---	---
Stephanodiscus	---	0	0	---	---	---	---	---	---	---	0	---	---	---	---	---
Surirella	---	---	---	0	---	---	---	---	---	---	---	---	---	---	---	---
Synedra	0	0	0	0	0	0	---	0	3	2	3	2	2	2	2	2
Achnanthidium	---	---	---	---	---	---	---	---	---	0	1	0	0	0	1	1
Cocconeis	---	---	---	---	---	---	---	---	0	0	---	0	0	---	---	---
Cymbella	---	---	---	---	---	---	---	---	0	0	0	---	---	0	0	---
Fragilaria	---	---	---	---	---	---	---	---	11	15	17	11	19	12	33	22
Gyrosigma	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0
Melosira	---	---	---	---	---	---	---	---	---	---	---	---	0	0	---	---
Navicula	---	---	---	---	---	---	---	---	0	0	---	0	1	1	---	---
Bacillariophyta Total	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**34**	**38**	**43**	**34**	**42**	**36**	**66**	**60**
Chlorophyta																
Carteria	0	0	---	0	---	---	---	---	---	---	---	---	---	---	---	---
Chlamydomonas	0	0	0	0	0	0	0	0	1	2	10	5	6	4	4	3
Chlorococcaceae	0	0	0	0	0	0	0	0	---	---	---	---	---	---	---	---
Chlorogonium	---	---	---	---	---	0	---	---	---	---	---	---	---	---	---	---
Coelastrum	---	0	---	---	0	0	---	---	---	---	---	---	---	---	---	---
Cosmarium	---	---	---	0	---	---	---	---	---	---	---	---	---	---	---	---
Crucigenia	---	---	0	---	---	---	---	0	---	---	1	0	---	0	0	3
Diacanthos	---	---	---	---	---	0	---	---	---	---	---	---	---	---	---	---
Dictyosphaerium	0	---	0	0	---	0	0	0	---	---	---	---	---	---	---	---
Euastrum	0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Eudorina	---	---	0	---	---	---	---	---	---	---	---	---	---	---	---	---
Golenkinia	---	---	---	0	0	0	---	0	---	---	---	---	---	---	---	---
Kirchneriella	---	---	---	---	0	---	---	---	---	---	---	---	---	---	---	---
Lagerheimia	---	---	0	0	---	0	0	---	---	---	---	---	---	---	---	---
Micractinium	---	0	0	0	0	---	0	---	---	---	---	---	---	---	---	---
Monomastix	---	---	---	0	---	---	---	---	---	---	---	---	---	---	---	---
Monoraphidium	0	0	0	0	0	0	0	0	1	---	---	1	---	0	---	---
Mougeotia	0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Oocystis	---	0	0	0	0	0	0	0	---	---	---	---	---	---	---	---
Pandorina	0	0	---	---	---	---	0	---	---	---	---	---	---	---	---	---
Pediastrum	0	0	0	0	---	0	---	0	5	---	4	0	0	---	1	---
Pyramichlamys	0	0	---	---	---	---	---	0	---	---	---	---	---	---	---	---
Quadrigula	---	---	---	---	---	---	0	---	---	---	---	---	---	---	---	---
Scenedesmus	0	0	1	0	1	0	1	0	0	2	1	3	4	4	6	3

Table 27. (Continued)

	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
Taxon	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
(Chlorophyta)																
Schroederia	0	0	0	0	---	0	---	0	---	---	---	---	---	---	---	---
Sphaerocystis	---	---	---	---	---	0	---	---	---	---	---	---	---	---	---	---
Staurastrum	---	---	---	0	0	---	---	---	---	---	---	0	0	---	---	0
Teilingia	---	---	---	---	---	---	---	0	---	---	---	---	---	---	---	---
Tetraedron	0	---	0	0	0	0	0	0	---	0	---	---	---	0	---	---
Tetrastrum	---	0	---	0	0	0	---	---	1	---	0	---	1	---	---	---
Treubaria	---	---	0	0	---	0	---	---	---	---	---	---	---	---	---	---
Actinastrum	---	---	---	---	---	---	---	---	4	3	2	0	0	4	2	0
Ankistrodesmus	---	---	---	---	---	---	---	---	2	1	---	---	---	0	---	---
Chlorella	---	---	---	---	---	---	---	---	5	4	3	2	1	1	---	0
Closterium	---	---	---	---	---	---	---	---	---	0	---	---	---	---	---	---
Elakatothrix	---	---	---	---	---	---	---	---	0	---	---	---	---	---	0	---
Selenastrum	---	---	---	---	---	---	---	---	2	---	0	---	---	0	---	---
Chlorophyta Total	**1**	**1**	**1**	**1**	**2**	**2**	**1**	**1**	**21**	**12**	**20**	**11**	**12**	**14**	**13**	**9**
Chrysophyta																
Chrysococcus	---	---	---	---	---	---	0	---	---	---	---	---	---	---	---	---
Conradiella	---	0	0	0	0	0	0	0	---	---	---	---	---	---	---	---
Erkenia	0	0	0	0	0	0	0	0	---	---	---	---	---	---	---	---
Goniochloris	---	---	---	---	0	---	0	---	---	---	---	---	---	---	---	---
Gonyostomum	---	---	---	---	---	0	0	0	---	---	---	---	---	---	---	---
Kephyrion	---	---	---	---	---	---	---	0	---	---	---	---	---	---	---	---
Mallomonas	---	---	---	---	0	0	---	---	---	---	---	---	---	---	---	---
Chrysophyta Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**—**
Cryptophyta																
Cryptomonas	0	0	0	0	0	0	0	0	31	28	36	31	41	32	21	20
Rhodomonas	0	0	0	0	0	0	0	0	---	---	---	---	---	---	---	---
Cryptophyta Total	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**31**	**28**	**36**	**31**	**41**	**32**	**21**	**20**
Cyanophyta																
Anabaena	0	0	---	0	0	0	---	---	0	---	0	---	0	17	---	---
Anabaenopsis	---	---	---	---	---	---	---	0	---	---	---	---	---	---	---	---
Aphanocapsa	2	5	2	1	2	0	3	2	---	---	---	---	---	---	---	---
Chroococcaceae	38	17	36	31	42	35	46	53	---	---	---	---	---	---	---	---
Chroococcus	0	0	0	0	0	0	---	0	5	0	---	3	---	1	---	---
Cyanocatena	---	---	10	4	---	---	---	5	---	---	---	---	---	---	---	---
Cyanogranis	23	42	31	41	29	33	37	21	---	---	---	---	---	---	---	---
Cylindrospermopsis	1	1	1	1	1	1	0	0	---	---	---	---	---	---	---	---
Dactylococcopsis	0	0	---	---	---	0	0	0	---	---	---	---	---	---	---	---
Leptolyngbya	---	---	---	---	---	---	---	---	7	---	---	---	---	---	---	---
Limnothrix	---	---	---	---	---	---	---	---	---	6	---	1	---	---	---	---
Lyngbya	1	0	1	1	0	1	0	1	---	---	---	---	---	---	---	---
Merismopedia	3	1	---	1	0	1	0	0	---	3	0	13	---	---	---	---
Oscillatoria	2	1	2	2	2	2	3	2	---	---	---	---	---	---	---	---
Planktothrix	---	---	---	---	---	---	---	---	---	11	---	---	---	---	---	11
Pseudanabaena	---	---	---	---	---	---	---	---	---	0	---	8	5	---	---	---
Synechococcus	24	29	14	15	17	21	7	11	---	---	---	---	---	---	---	---
Synechocystis	2	1	2	2	3	2	2	2	---	---	---	---	---	---	---	---
Cyanophyta Total	**99**	**99**	**98**	**99**	**96**	**96**	**98**	**98**	**12**	**20**	**1**	**24**	**6**	**18**	**—**	**11**

Table 27. (Continued)

Taxon	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Euglenophyta																
Euglena	0	0	0	---	0	---	0	---	1	2	0	0	---	---	0	---
Trachelomonas	---	---	---	---	---	---	---	---	---	---	---	0	---	---	---	---
Euglenophyta Total	**0**	**0**	**0**	**—**	**0**	**—**	**0**	**—**	**1**	**2**	**0**	**1**	**—**	**—**	**0**	**—**
Pyrrophyta																
Glenodinium	0	0	---	---	---	0	0	---	---	---	---	---	---	---	---	---
Gymnodinium	0	0	0	---	---	0	---	0	---	---	---	---	---	---	---	---
Peridinium	0	0	---	---	0	---	---	0	---	1	0	0	---	0	---	---
Ceratium	---	---	---	---	---	---	---	---	---	0	---	0	---	---	---	---
Pyrrophyta Total	**0**	**0**	**0**	**—**	**0**	**0**	**0**	**0**	**—**	**1**	**0**	**0**	**—**	**0**	**—**	**—**

Table 28. Concentrations of chlorophyll a (apparent and corrected), phaeophytin a and the chlorophyll/phaeophytin index values for samples collected upstream and downstream of SQN during 2011.

Collection Date	Sample Site	Replicate	Chlorophyll a (µg/L) Apparent	Chlorophyll a (µg/L) Corrected	Phaeophytin a (µg/L)	Chlorophyll/Phaeophytin Index
08/25/2011	TRM 481.2	R1	13	11	2.2	1.6
		R2	14	13	1.5	1.6
	TRM 483.4	R1	8	6	2.5	1.5
		R2	8	6	2.6	1.5
	TRM 487.9	R1	13	13	< 1.0	1.7
		R2	15	15	< 1.0	1.7
	TRM 490.7	R1	11	10	1.0	1.6
		R2	11	9	1.5	1.6
10/10/2011	TRM 481.1	R1	6	5	1.0	1.6
		R2	8	7	1.7	1.6
	TRM 483.4	R1	10	9	1.4	1.6
		R2	13	11	1.6	1.6
	TRM 487.9	R1	7	6	1.7	1.5
		R2	9	8	1.4	1.6
	TRM 490.8	R1	7	5	2.0	1.5
		R2	6	6	1.1	1.6

Table 29. Mean percent composition of major zooplankton groups at sites sampled upstream and downstream of SQN in August and October, 2011.

	August 25, 2011				October 10, 2011			
Group	TRM 481.1	TRM 483.4	TRM 487.9	TRM 490.7	TRM 481.1	TRM 483.4	TRM 487.9	TRM 490.7
Bivalvia (veliger)	---	---	---	---	---	0	0	---
Cladocera	66	51	65	62	44	59	71	69
Copepoda	32	27	20	23	40	37	23	29
Rotifera	2	22	15	16	16	4	6	2

** Percentages are rounded to whole numbers, and values may not add to 100.*
"0" values indicate percentages less than 0.5%. Blank values indicate no individuals of the taxa collected.

Table 30. Comparison of the similarity of zooplankton taxa within paired replicate samples.

	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Replicate Taxa Richness	8	9	6	7	7	8	7	7	7	7	11	11	8	9	12	9
Combined Taxa Richness	14		8		9		9		9		16		12		13	
Species Shared	3		5		6		5		5		6		5		8	
Percent Shared	21.4%		62.5%		66.7%		55.6%		55.6%		37.5%		41.7%		61.5%	

Table 31. Taxa richness of the main zooplankton groups.

Group	Total Number of Taxa		
	August	October	Combined
Bivalvia	---	2	2
Cladocera	7	8	11
Copepoda	3	9	10
Rotifera	8	7	12
Total Taxa Richness	**18**	**26**	**35**

Table 32. Percent Similarity Index for comparison of zooplankton communities among sites.

Station Comparison		Zooplankton - Percent Similarity[a]	
		August 25, 2011	October 10, 2011
TRM 481.1	– TRM 483.4	63	83
	– TRM 487.9	69	72
	– TRM 490.7	75	74
TRM 483.4	– TRM 487.9	70	86
	– TRM 490.7	72	89
TRM 487.9	– TRM 490.7	80	93

a. Percent Similarity comparison of two communities

Table 33. Zooplankton taxa and density (organisms/m3) data for samples collected at four stations within Chickamauga Reservoir on the Tennessee River – August 25 and October 10, 2011. Abbreviations "R1" and R2" designate replicate samples.

	TRM 481.1				TRM 483.4				TRM 487.9				TRM 490.7			
	August		October		August		October		August		October		August		October	
Taxon	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Bivalvia																
Corbiculidae																
Corbicula fluminea (veliger)								9								
Dreissenidae																
Dreissena polymorpha (veliger)							9	9			15					
Cladocera																
Cladocera (immature)											15					
Diplostraca																
Bosminidae																
Bosmina longirostris	1175	2385	5017	18182	1421	784	2461	3614	596	1083	2895	3762	627	796	5511	5863
Bosminidae (immature)																40
Eubosmina tubicen							18					34			41	
Daphiniidae																
Ceriodaphnia		147				41			79	120			37		14	
Daphnia galeatá	76				31											
Daphnia lumholtzi		73						9		160	30	17				40
Daphnia retrocurva														89		
Leptodoridae																
Leptodora kindtii	38		38					18								
Sididae																
Diaphanosoma birgei	417	1027			958	1238			397	321			111	265		
Diaphanosoma brachyurum															14	
Sididae (immature)				112											14	40
Ilyocryptidae																
Ilyocryptus spinifer							9									
Macrothricidae																
Macrothrix sp.								9								
Copepoda																
Calanoida																
Calanoida		37	3961	12907	247	372	1558	1276	357	80	1006	872	111	44	2020	2193
Temoridae																
Epischura fluviatilis												34				
Eurytemora affinis			377				186	120			15	77			82	120
Eurytemora sp.				673												

Table 33 (continued).

	TRM 481.1				TRM 483.4				TRM 487.9				TRM 490.7			
	August		October		August		October				August		October		August	
Taxon	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
(Copepoda)																
Cyclopoida																
Cyclopoida	1023	1284	453	2918	1019	661	230	370	119	241	137	94	221	265	220	179
Cyclopidae																
Cyclops sp.	38					41							37			
Eucyclops agilis							9									
Mesocyclops edax							27									
Tropocyclops prasinus															41	20
Harpacticoida																
Harpacticoida				112												
Poecilostomatoida																
Ergasilidae																
Ergasilus sp.								18							41	40
Rotifera																
Flosculariaceae																
Conochilidae																
Conochilus unicornis	38		1773	6846	31	2312	416		278	281	503		184	265	96	199
Ploima																
Brachionidae																
Brachionus angularis															14	
Brachionus calyciflorus		37	38				9	9								
Brachionus patulus												9				
Brachionus quadridentatus												17				
Brachionus quadridentatus f. brevispinus											15					
Kellicottia longispina										40						
Keratella cochlearis									40						14	
Platyias patulus		37														
Gastropidae																
Ascomorpha sp.														44		
Lecanidae																
Lecane sp.	38															
Trichocercidae																
Trichocerca sp.		37														
Total Zooplankton Abundance	**2842**	**5064**	**11657**	**41751**	**3707**	**5449**	**4930**	**5462**	**1866**	**2326**	**4632**	**4917**	**1327**	**1769**	**8122**	**8734**

Table 34. Percentage composition of zooplankton taxa for samples collected at four stations within Chickamauga Reservoir on the Tennessee River – August 25 and October 10, 2011.

	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Bivalvia																
Corbiculidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Corbicula fluminea (veliger)	---	---	---	---	---	---	---	---	---	---	---	0	---	---	---	---
Dreissenidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Dreissena polymorpha (veliger)	---	---	---	---	---	---	---	---	---	---	0	0	0	---	---	---
Bivalvia Total	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**0**	**0**	**0**	**---**	**---**	**---**
Cladocera																
Cladocera (immature)	---	---	---	---	---	---	---	---	---	---	---	---	0	---	---	---
Diplostraca	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Bosminidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Bosmina longirostris	41	47	38	14	32	47	47	45	43	44	50	66	63	77	68	67
Bosminidae (immature)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0
Eubosmina tubicen	---	---	---	---	---	---	---	---	---	---	0	---	---	1	1	---
Daphiniidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ceriodaphnia	---	3	---	1	4	5	3	---	---	---	---	---	---	---	0	---
Daphnia galeata	3	---	1	---	---	---	---	---	---	---	---	---	---	---	---	---
Daphnia lumholtzi	---	1	---	---	---	7	---	---	---	---	---	0	1	0	---	0
Daphnia retrocurva	---	---	---	---	---	---	---	5	---	---	---	---	---	---	---	---
Leptodoridae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Leptodora kindtii	1	---	---	---	---	---	---	---	0	---	---	0	---	---	---	---
Sididae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Diaphanosoma birgei	15	20	26	23	21	14	8	15	---	---	---	---	---	---	---	---
Diaphanosoma brachyurum	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0	---
Sididae (immature)	---	---	---	---	---	---	---	---	---	0	---	---	---	---	0	0
Ilyocryptidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ilyocryptus spinifer	---	---	---	---	---	---	---	---	---	---	0	---	---	---	---	---
Macrothricidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Macrothrix sp.	---	---	---	---	---	---	---	---	---	---	---	0	---	---	---	---
Cladocera Total	**60**	**72**	**65**	**38**	**57**	**72**	**58**	**65**	**43**	**44**	**50**	**67**	**63**	**78**	**69**	**68**
Copepoda																
Calanoida	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Calanoida	---	1	7	7	19	3	8	2	34	31	32	23	22	18	25	25
Temoridae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Epischura fluviatilis	---	---	---	---	---	---	---	---	---	---	---	---	---	1	---	---
Eurytemora affinis	---	---	---	---	---	---	---	---	3	---	4	2	0	2	1	1
Eurytemora sp.	---	---	---	---	---	---	---	---	---	2	---	---	---	---	---	---
Cyclopoida	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cyclopoida	36	25	27	12	6	10	17	15	4	7	5	7	3	2	3	2

Table 34. (Continued)

	August 25, 2011								October 10, 2011							
	TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7		TRM 481.1		TRM 483.4		TRM 487.9		TRM 490.7	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
(Cyclopoida)																
Cyclops sp.	1	---	---	1	---	---	3	---	---	---	---	---	---	---	---	---
Eucyclops agilis	---	---	---	---	---	---	---	---	---	---	0	---	---	---	---	---
Mesocyclops edax	---	---	---	---	---	---	---	---	---	---	1	---	---	---	---	---
Tropocyclops prasinus	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1	0
Harpacticoida	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Harpacticoida	---	---	---	---	---	---	---	---	---	0	---	---	---	---	---	---
Poecilostomatoida	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ergasilidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ergasilus sp.	---	---	---	---	---	---	---	---	---	---	---	0	---	---	1	0
Copepoda Total	**37**	**26**	**34**	**20**	**26**	**14**	**28**	**17**	**41**	**40**	**41**	**33**	**25**	**22**	**30**	**29**
Rotifera																
Flosculariaceae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Conochilidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Conochilus unicornis	1	---	1	42	15	12	14	15	15	16	8	---	11	---	1	2
Ploima	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Brachionidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Brachionus angularis	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0	---
Brachionus calyciflorus	---	1	---	---	---	---	---	---	0	---	0	0	---	---	---	---
Brachionus patulus	---	---	---	---	---	---	---	---	---	---	---	---	---	0	---	---
Brachionus quadridentatus	---	---	---	---	---	---	---	---	---	---	---	---	---	0	---	---
Brachionus quadridentatus f. brevispinus	---	---	---	---	---	---	---	---	---	---	---	---	0	---	---	---
Kellicottia longispina	---	---	---	---	---	2	---	---	---	---	---	---	---	---	---	---
Keratella cochlearis	---	---	---	---	2	---	---	---	---	---	---	---	---	---	0	---
Platyias patulus	---	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Gastropidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ascomorpha sp.	---	---	---	---	---	---	---	2	---	---	---	---	---	---	---	---
Lecanidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Lecane sp.	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Trichocercidae	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Trichocerca sp.	---	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Rotifera Total	**3**	**2**	**1**	**42**	**17**	**14**	**14**	**17**	**16**	**16**	**9**	**0**	**11**	**1**	**2**	**2**

** Percentages are rounded to whole numbers, and values may not add to 100.*

"0" values indicate percentages less than 0.5%. Blank values indicate no individuals of the taxa collected.

Table 35. Wildlife Visual Encounter Survey Results of Shoreline Upstream and Downstream of Sequoyah Nuclear Plant during August (Summer) and October (Autumn) 2011. (RDB = right descending bank, LDB = Left Descending Bank)

Season	Site	Transect	Birds	Obs.	Mammals	Obs.
August 2011	Upstream	RDB	Swallow sp.	1		
			Belted Kingfisher	1		
			American Crow	4		
			Turkey Vulture	2		
			Osprey	1		
			Great Blue Heron	5		
			Unidentified Duck	2		
	Upstream	LDB	Swallow sp.	2	White-tailed Deer	4
			Red-winged Blackbird	5		
			American Crow	1		
			Great Blue Heron	5		
	Downstream	RDB	Swallow Sp.	3	White-tailed Deer	4
			Osprey	2		
			Wood Duck	1		
			Great Blue Heron	4		
			Double-crested Cormorant	2		
	Downstream	LDB	Belted Kingfisher	1		
			Swallow sp.	5		
			European Starling	30		
			Green Heron	1		
			Great Blue Heron	2		
October 2011	Upstream	RDB	Songbird sp.	2		
			Great Blue Heron	4		
	Upstream	LDB	Wren sp.	1		
			Belted Kingfisher	1		
			Great Blue Heron	1		
	Downstream	RDB	Songbird sp.	6	Eastern Gray Squirrel	1
			Belted Kingfisher	3		
			Blue Jay	1		
			Northern Mockingbird	1		
			Double-crested Cormorant	1		
			Great Blue Heron	5		
			American Coot	335		
			American Widgeon	2		
			Pied-billed Grebe	2		
			Mallard	5		
	Downstream	LDB	Belted Kingfisher	2		
			Tufted Titmouse	3		
			Killdeer	2		
			Sandpiper sp.	2		
			Songbird sp.	3		
			Great Blue Heron	7		
			Wood Duck	15		
			American Coot	603		
			Black-crowned Night Heron	1		
			Gadwall	3		
			Mallard	13		
			Green-winged Teal	2		
			Pied-billed Grebe	2		
			Double-crested Cormorant	5		

Table 36. Water temperature (°F) profiles measured at five locations (10%, 30%, 50%, 70%, 90%) from right descending bank along transects located at TRM 486.7 (ambient), TRM 483.4 (discharge), TRM 481.1 (middle of plume), TRM 480.0 (downstream limit of plume), and TRM 478.3 (below plume) on August 25, 2011 (Summer). Green numbers represent ambient temperatures used to characterize the thermal plume. Red numbers represent temperatures 3.6˚F (2°C) or greater above ambient temperature.

Depth (m)	Ambient TRM 486.7					SQN Discharge TRM 483.4					Middle of Plume TRM 481.1					At Plume Limit TRM 480.0					Below Plume TRM 478.3				
	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%
0.3	82.35	82.63	81.63	81.55	81.59	85.42	85.15	84.92	85.30	84.69	85.28	85.69	86.63	86.22	86.85	85.95	85.51	85.89	86.72	86.77	84.18	84.74	85.19	85.46	85.86
1	81.93	82.38	81.52	81.43	81.54	85.08	85.06	83.52	84.85	84.87	85.03	84.87	85.03	86.04	86.72	85.77	85.08	85.69	84.97	86.16	84.11	84.63	85.03	85.30	85.37
2	81.63	81.50	81.32	81.23	81.41	84.72	84.58	82.58	84.96	84.43	84.69	84.51	84.65	85.32		84.51	84.18	85.21		84.88	83.52	83.98	84.74	84.31	85.33
3	81.36	81.32	81.21	81.68	81.37	82.60	82.96	81.73	84.51	83.32	84.02	84.16	84.40	84.27		84.40	83.93	84.31			83.55	83.95	84.51	84.13	85.32
4	81.25	81.09	81.10	81.05	81.27	82.13	82.40		84.31	84.45	83.75	83.97	84.29	84.24		84.34	83.82	83.84				83.93	84.11	84.11	85.26
5	81.12		81.09	81.03	81.05		82.18		84.22	83.80		83.86	84.25	84.20		84.18		83.59				83.89	83.93	84.06	84.97
6			81.03	81.01	80.73				84.33	83.82		83.66	84.16			84.11		82.96				83.82	83.86	83.84	84.16
7			80.98	80.94	80.65				84.20	83.75		83.75	84.07			83.98		82.58				83.46	83.79	83.82	83.84
8			80.85	80.89	80.65				84.20	82.76		83.12	83.84			83.61		82.36				83.43	83.75	83.80	83.77
9			80.80	80.85	80.65				83.70	82.11		82.94	83.53			83.39		82.17				83.17	83.66	83.75	83.68
10			80.80	80.85	80.65				83.55	82.09		82.85	83.16			83.28		82.11				83.26	83.17	83.71	83.66
11			80.80	80.83	80.64				83.10	81.68		82.49	82.72			83.19		82.11				83.25	82.99	83.66	83.64
12				80.83	80.64				83.14	81.70		82.54	82.47			83.14		82.09				83.10	82.90	82.92	
13					80.64				82.67	81.63		82.47	82.20					82.11				83.10	82.80	82.87	
14					80.64				82.17	81.59		82.38	82.08					82.11				83.05	82.54	82.63	
15									82.18			82.26	82.08									83.01	82.53	82.58	
16									82.13			82.26	82.08										82.51	82.58	
17									82.06			82.27	82.08										82.51	82.56	
18									82.04			82.15	82.08										82.45	82.56	

Table 37. Water temperature (°F) profiles measured at five locations (10%, 30%, 50%, 70%, 90%) from right descending bank along transects located at TRM 487 (ambient), TRM 483.4 (discharge), TRM 482.2 (below discharge), TRM 481.0 (downstream limit of plume), and TRM 478.3 (below plume) on September 14, 2011 (Autumn). Green numbers represent ambient temperatures used to characterize the thermal plume. Red numbers represent temperatures 3.6˚F (2°C) or greater above ambient temperature.

Depth (m)	Ambient TRM 487					SQN Discharge TRM 483.4					Below Discharge TRM 482.2					At Plume Limit TRM 481					Below Plume TRM 480.5				
	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%
0.3	77.18	77.18	77.54	77.36	77.54	81.25	80.42	80.55	80.01	81.68	81.45	81.21	81.14	81.48	81.91	80.15	81.03	81.32	80.53	80.65	80.08	80.04	80.42	79.25	79.45
1	77.00	76.82	77.18	76.64	77.18	80.71	80.29	80.10	79.88	81.09	81.09	80.28	79.79	80.06	80.71	79.61	79.74	79.75	79.66	79.59	78.18	79.14	79.00	78.62	78.76
2	76.64	76.46	76.46	76.46	76.28	82.35	80.08	80.06	79.70	80.58		79.83	79.29	79.20	80.24	78.60	78.60	79.00	79.30	78.80	78.82	78.49	78.48	78.44	77.58
3	76.64	76.46	76.10	76.10	76.10	78.40	79.61	80.06	79.54	80.69		79.74	78.93	79.00	79.39	78.40	78.21	78.04	78.84	78.51	78.71	78.19	78.21		77.52
4	76.46	76.46	75.92	75.20	75.38		78.06	79.97	79.47	80.80		79.47		78.84	78.87		77.83	77.49	78.75	77.61	78.58	78.04	77.94		77.49
5	76.46		75.56	75.20				80.20	79.34	80.64		78.24		78.53	78.71		77.68	77.34	78.69	77.49	78.13	77.81	77.56		
6			75.20	75.02				79.02	79.25	80.55				78.37	78.58		77.38	77.32	78.51	77.43		77.74	77.50		
7			75.20	75.02					78.49	80.28				78.28			77.32	77.20				77.70	77.45		
8			75.02	74.48					77.58	78.49				78.06			77.20	76.93				77.67	77.36		
9			75.02	74.48					77.22	77.54				77.67			77.04	76.84				77.58	77.34		
10			74.48	74.30					76.15	77.43				77.59			76.96	76.80				77.52	77.09		
11			73.58	74.30					76.12	77.36				77.58			76.66	76.69				77.49	76.96		
12			73.22						75.97	76.82				77.56			76.28	76.41				77.47	76.23		
13									75.94	76.82				77.23			76.21	76.24				77.05	76.19		
14									75.87	76.05				76.14			76.08	76.19							
15									75.76					75.83			76.08	76.06							
16									75.76					75.78				76.03							
17									75.74					75.78											
18									75.72																

Table 38. Seasonal water quality parameters collected along vertical depth profiles downstream (TRM 482) and upstream (TRM 490.5) of the Sequoyah Nuclear Plant in Chickamauga Reservoir on the Tennessee River. Abbreviations: °C – Temperature in degrees Celsius, °F – Temperature in degrees Fahrenheit, Cond – Conductivity, DO – Dissolved Oxygen

Summer - TRM 482																		
	LDB						Mid-channel						RDB					
	Depth	°C	°F	Cond	DO	pH	Depth	°C	°F	Cond	DO	pH	Depth	°C	°F	Cond	DO	pH
Downstream Transect	0.3	29.33	84.79	192.8	7.46	7.91	0.3	29.50	85.10	192.2	8.05	8.11	0.3	29.73	85.51	192.6	6.73	7.74
	1.5	29.09	84.36	193.1	7.18	7.83	1.5	29.15	84.47	192.3	7.55	7.98	1.5	29.30	84.74	192.8	7.22	7.86
	3	28.67	83.61	193.0	6.51	7.67	3	29.10	84.38	192.4	7.49	7.95	3	29.07	84.33	193.8	7.59	7.98
	5	28.62	83.52	193.1	6.39	7.64	4	29.07	84.33	192.5	7.45	7.93	5	28.74	83.73	192.4	8.22	8.18
							6	28.85	83.93	192.4	7.17	7.85						
							8	28.69	83.64	192.0	7.02	7.80						
							12	28.40	83.12	191.4	6.55	7.70						
							15	28.19	82.74	192.2	6.38	7.64						
							19	28.07	82.53	227.5	6.24	7.63						
Middle Transect	0.3	29.60	85.28	192.8	6.89	7.78	0.3	29.35	84.83	191.6	7.35		0.3	30.58	87.04	191.8	9.12	8.37
	1.5	29.14	84.45	191.6	7.03	7.81	1.5	29.03	84.25	191.3	7.35	7.92	1.5	29.19	84.54	191.0	8.58	8.21
	3	28.59	83.46	192.3	8.05	8.07	3	28.79	83.82	191.2	7.16	7.86	3	28.69	85.44	190.4	7.94	8.02
	4.5	28.30	82.94	190.2	8.35	8.23	4	28.65	83.57	191.0	7.23	7.87						
							8	28.35	83.03	191.7	6.94	7.79						
							12	27.93	82.27	191.8	6.60	7.71						
							14.5	27.87	82.17	191.2	6.53	7.67						
Upstream Transect	0.3	28.75	83.75	190.9	9.00	8.21	0.3	29.20	84.56	192.0	7.61	7.81	0.3	29.31	84.76	190.0	9.66	8.50
	1.5	27.84	82.11	190.0	7.12	7.72	1.5	29.07	84.33	191.7	7.44	7.79	1.5	29.25	84.65	191.5	9.58	8.45
	3	27.78	82.00	190.5	7.14	7.63	3	29.09	84.36	191.9	6.78	7.68	3	29.15	84.47	190.7	9.48	8.42
	3.5	27.77	81.99	190.0	6.96	7.55	4	28.75	83.75	191.2	6.73	7.67	4	29.18	84.52	190.7	9.69	8.46
							6	28.44	83.19	191.8	6.84	7.70	6	29.12	84.42	191.0	9.55	8.44
							8	28.50	83.30	191.5	6.88	7.72	8	28.83	83.89	190.8	8.36	8.19
							12	27.86	82.15	190.6	6.86	7.73	12	27.63	81.73	191.9	6.60	7.64
							16	27.80	82.04	190.4	6.85	7.75						

Table 38 (continued).

	Summer - TRM 490.5																	
	LDB						Mid-channel						RDB					
	Depth	**˚C**	**°F**	**Cond**	**DO**	**pH**	**Depth**	**˚C**	**°F**	**Cond**	**DO**	**pH**	**Depth**	**˚C**	**°F**	**Cond**	**DO**	**pH**
Downstream Transect	0.3	28.19	82.74	198.5	9.58	8.52	0.3	27.90	82.22	198.7	8.88	8.33	0.3	28.32	82.98	194.5	9.50	8.51
	1.5	28.15	82.67	199.0	9.54	8.49	1.5	27.72	81.90	200.1	7.07	8.16	1.5	28.29	82.92	194.9	9.40	8.42
	3	27.51	81.52	197.7	6.60	7.62	3	27.68	81.82	200.2	7.74	8.03	3	27.43	81.37	196.6	6.13	7.55
	5	26.91	80.44	200.6	4.23	7.33	4	27.30	81.14	200.5	5.75	7.62	4.5	27.19	80.94	198.1	5.17	7.42
	7	26.91	80.44	199.5	4.31	7.36	6	27.19	80.94	200.0	5.50	7.53						
							8	27.15	80.87	201.1	5.21	7.48						
							10	27.09	80.76	200.7	5.04	7.45						
							13	27.11	80.80	200.3	5.17	7.46						
							17	27.14	80.85	200.1	5.37	7.47						
Middle Transect	0.3	28.70	83.66	196.0	10.9	n/a	0.3	28.38	83.08	198.8	9.84	8.57	0.3	28.74	83.73	193.2	9.83	8.64
	1.5	28.28	82.90	196.2	10.0	n/a	1.5	27.90	82.22	200.6	8.48	8.20	1.5	27.44	81.39	199.4	6.58	7.75
	3	27.16	80.89	198.2	4.68	n/a	3	27.25	81.05	201.3	5.61	7.54	3	27.27	81.09	200.4	5.88	7.55
	5	27.09	80.76	197.3	4.37	n/a	5	27.13	80.83	200.9	4.97	7.45	4	27.34	81.21	200.4	6.15	7.59
							7	27.02	80.64	200.3	4.71	7.40	6	27.17	80.91	200.8	5.50	7.44
							9	27.00	80.60	200.7	4.62	7.38	7	27.19	80.94	201.1	5.57	7.37
							11	26.98	80.56	200.5	4.56	7.40						
Upstream Transect	0.3	28.71	83.68	197.8	10.4	8.66	0.3	28.15	82.67	200.6	8.30	8.15	0.3	28.07	82.53	200.0	6.15	8.12
	1.5	28.49	83.28	197.9	9.92	8.55	1.5	27.87	82.17	200.0	7.77	7.97	1.5	27.80	82.04	200.1	6.24	7.89
	3	27.70	81.86	197.0	6.00	7.79	3	27.36	81.25	200.3	5.78	7.51	3	27.46	81.43	199.6	7.93	7.49
							4	27.24	81.03	200.5	5.21	7.42	4	27.37	81.27	199.3	8.58	7.43
							6	27.18	80.92	200.7	4.94	7.36						
							8	27.08	80.74	200.5	4.73	7.30						
							9.5	27.07	80.73	200.2	4.68	7.30						

Table 38 (continued).

Autumn - TRM 482																		
	LDB						Mid-channel						RDB					
	Depth	°C	°F	Cond	DO	pH	Depth	°C	°F	Cond	DO	pH	Depth	°C	°F	Cond	DO	pH
Downstream Transect	0.3	22.43	72.37	184.5	7.45	7.49	0.3	22.92	73.26	183.7	7.57	7.48	0.3	22.43	72.37	184.4	7.49	7.54
	1.5	22.42	72.36	184.3	7.41	7.47	1.5	22.89	73.20	183.7	7.48	7.47	1.5	22.19	71.94	184.7	7.48	7.49
	2	22.38	72.28	184.0	7.42	7.44	3	22.63	72.73	184.2	7.41	7.44	3	22.14	71.85	185.1	7.37	7.47
							5	22.51	72.52	184.6	7.38	7.43	5	22.12	71.82	185.3	7.32	7.44
							7	22.35	72.23	185.0	7.34	7.40						
							9	22.18	71.92	184.4	7.29	7.36						
							11	21.75	71.15	184.8	7.29	7.33						
							13	21.70	71.06	184.2	7.33	7.29						
							15	21.63	70.93	183.7	7.29	7.25						
Middle Transect	0.3	23.49	74.28	183.7	7.72	7.57	0.3	23.46	74.23	183.4	7.59	7.50	0.3	22.97	73.35	183.8	7.62	7.52
	1.5	23.21	73.78	183.6	7.66	7.53	1.5	23.89	75.00	183.8	7.47	7.49	1.5	22.71	72.88	183.8	7.57	7.52
	3	23.21	73.78	183.4	7.66	7.49	3	22.96	73.33	183.8	7.45	7.47	3	22.65	72.77	184.1	7.45	7.51
							4	22.92	73.26	183.4	7.40	7.45	4	22.59	72.66	183.9	7.74	7.46
							6	22.81	73.06	183.9	7.33	7.44						
							8	22.45	72.41	183.5	7.34	7.39						
							10	21.99	71.58	183.3	7.32	7.37						
							12	21.74	71.13	182.9	7.31	7.33						
							14	21.41	70.54	183.0	7.23	7.29						
							16	21.39	70.50	183.1	7.15	7.23						
Upstream Transect	0.3	23.75	74.75	183.8	7.49	7.49	0.3	23.83	74.89	183.7	7.42	7.49	0.3	23.42	74.16	183.5	9.66	8.50
	1.5	23.46	74.23	183.5	7.39	7.51	1.5	23.57	74.43	183.3	7.37	7.48	1.5	23.28	73.90	183.4	9.58	8.45
	3	22.97	73.35	183.9	7.33	7.48	3	23.03	73.45	183.9	7.34	7.84	3	23.08	73.54	183.6	9.48	8.42
	4	22.69	72.84	184.0	7.30	7.47	4	22.71	72.88	183.3	7.33	7.47					9.69	8.46
	6	22.61	72.70	183.6	7.24	7.46	6	22.48	72.46	183.3	7.31	7.46					9.55	8.44
	8	22.38	72.28	184.2	7.12	7.44	8	22.44	72.39	183.1	7.32	7.45					8.36	8.19
	10	22.15	71.87	184.4	7.06	7.42	10	22.32	72.18	183.9	7.27	7.43					6.60	7.64
	12	22.17	71.91	184.1	7.06	7.39	12	21.89	71.40	182.7	7.29	7.41						
							14	21.54	70.77	182.8	7.24	7.38						
							16	21.35	70.43	183.0	7.26	7.39						

Table 38 (continued).

	Autumn - TRM 490.5																	
	LDB						Mid-channel						RDB					
	Depth	°C	°F	Cond	DO	pH	Depth	°C	°F	Cond	DO	pH	Depth	°C	°F	Cond	DO	pH
Downstream Transect	0.3	21.23	70.21	182.7	7.68	7.54	0.3	21.26	70.27	182.9	7.67	7.55	0.3	21.21	70.18	182.6	7.82	7.58
	1.5	21.23	70.21	182.7	7.66	7.52	1.5	21.26	70.27	183.0	7.62	7.56	1.5	21.21	70.18	182.8	7.82	7.56
	2	21.22	70.20	182.6	7.66	7.54	3	21.26	70.27	183.0	7.59	7.54	3	21.20	70.16	186.7	7.84	7.55
							4	21.26	70.27	183.0	7.55	7.53	4	21.19	70.14	183.5	7.94	7.55
							6	21.25	70.25	183.0	7.50	7.56						
							8	21.24	70.23	183.0	7.48	7.51						
							10	21.24	70.23	182.6	7.46	7.59						
							12	21.23	70.21	183.0	7.44	7.47						
							14	21.24	70.23	183.0	7.37	7.44						
							16	21.03	69.85	183.0	7.39	7.42						
Middle Transect	0.3	21.09	69.96	191.6	7.81	7.57	0.3	21.33	70.39	187.0	7.68	7.54	0.3	21.34	70.41	182.7	7.67	7.52
	1.5	21.09	69.96	182.7	7.79	7.57	1.5	21.33	70.39	182.0	7.65	7.50	1.5	21.34	70.41	182.8	7.66	7.57
	3	21.10	69.98	180.7	7.75	7.55	3	21.32	70.38	182.2	7.60	7.51	3	21.34	70.41	187.7	7.65	7.51
	5	21.20	70.16	181.7	7.75	7.48	5	21.37	70.47	182.4	7.54	7.17	4	21.34	70.41	182.7	7.59	7.54
							7	21.29	70.32	181.1	7.50	7.45	6	21.33	70.39	182.8	7.55	7.53
							9	21.27	70.29	181.3	7.47	7.40	8	21.32	70.38	182.8	7.44	7.50
													10	21.31	70.36	182.8	7.45	7.48
Upstream Transect	0.3	21.06	69.91	179.4	7.81	7.56	0.3	21.20	70.16	179.5	7.40	7.49	0.3	21.29	70.32	180.7	7.72	7.55
	1.5	21.06	69.91	179.5	7.81	7.52	1.5	21.20	70.16	179.5	7.46	7.50	1.5	21.28	70.30	180.2	7.83	7.56
	3	21.03	69.85	179.9	7.77	7.55	3	21.20	70.16	180.0	7.45	7.50	2	21.22	70.20	181.1	7.86	7.60
							5	21.19	70.14	179.4	7.44	7.48						
							7	21.19	70.14	179.4	7.39	7.46						
							9	21.25	70.25	179.5	7.10	7.41						

Figures

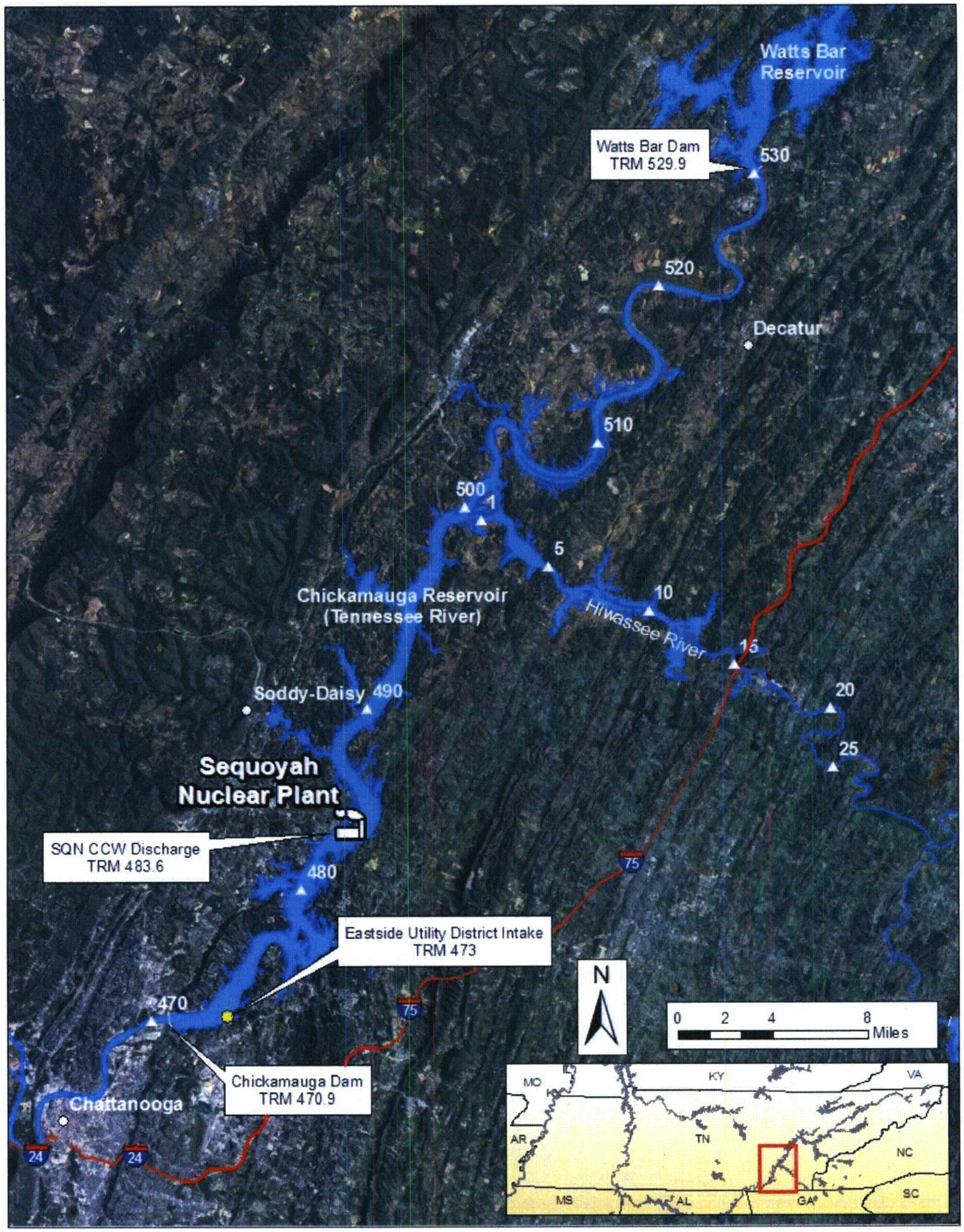


Figure 1. Vicinity map for Sequoyah Nuclear plant depicting Chickamauga and Watts Bar Dam locations and water supply intakes downstream of the plant thermal discharge

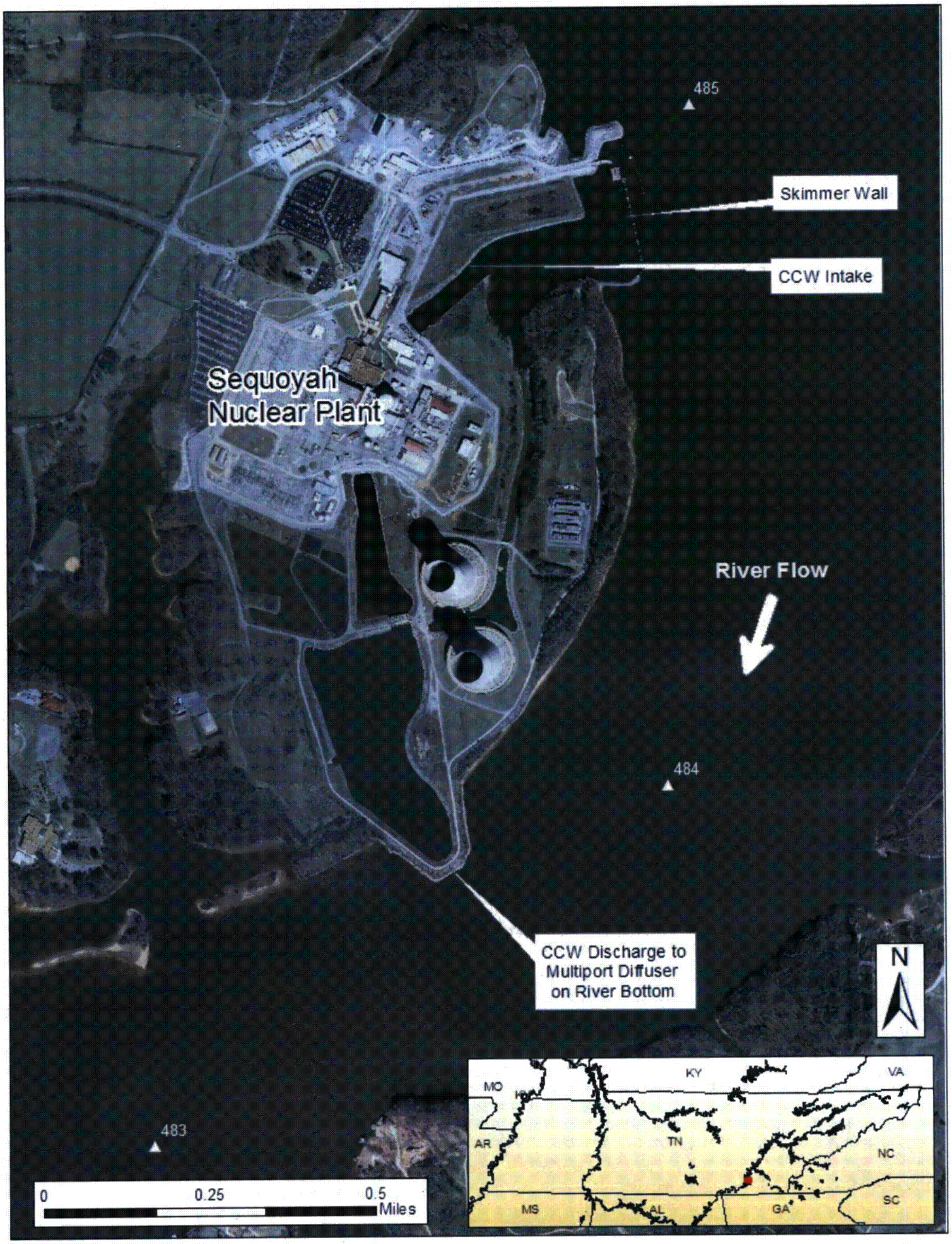


Figure 2. Site map for Sequoyah Nuclear plant showing condenser cooling water intake structure, skimmer wall, and NPDES-permitted discharge Outfall No. 101

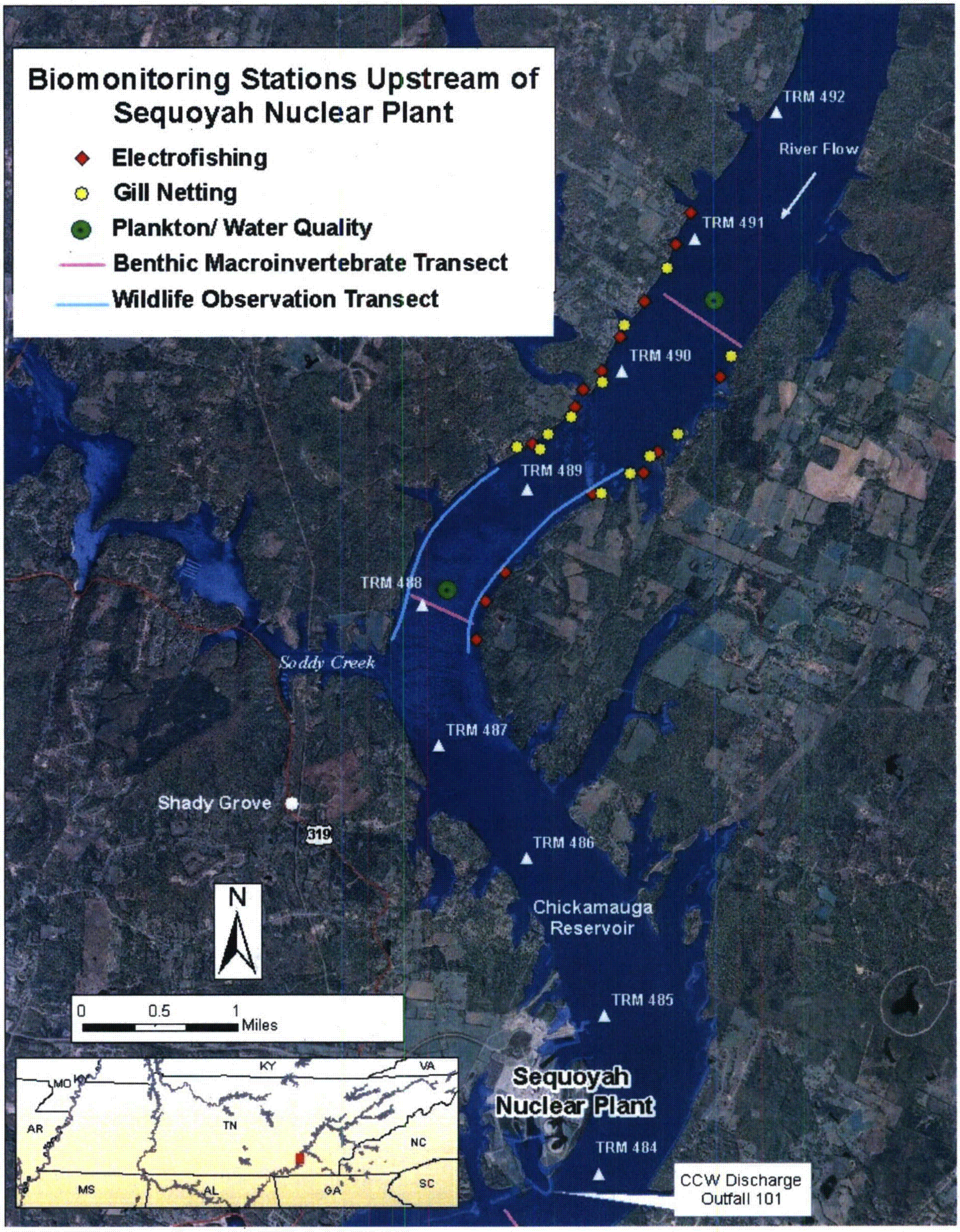


Figure 3. Biological monitoring stations upstream of Sequoyah Nuclear Plant.

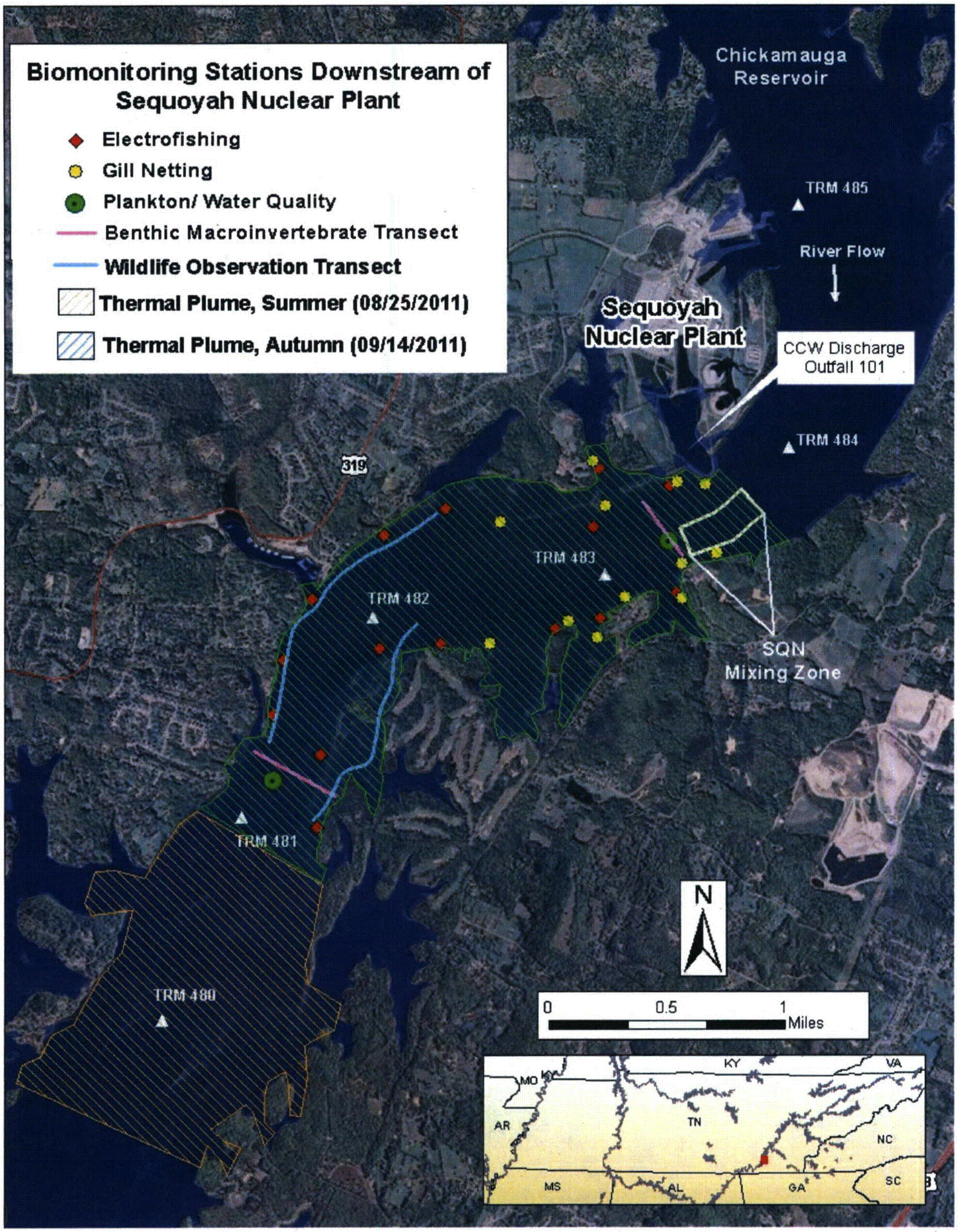


Figure 4. Biological monitoring stations downstream of Sequoyah Nuclear Plant, including mixing zone and thermal plume from SQN CCW discharge.

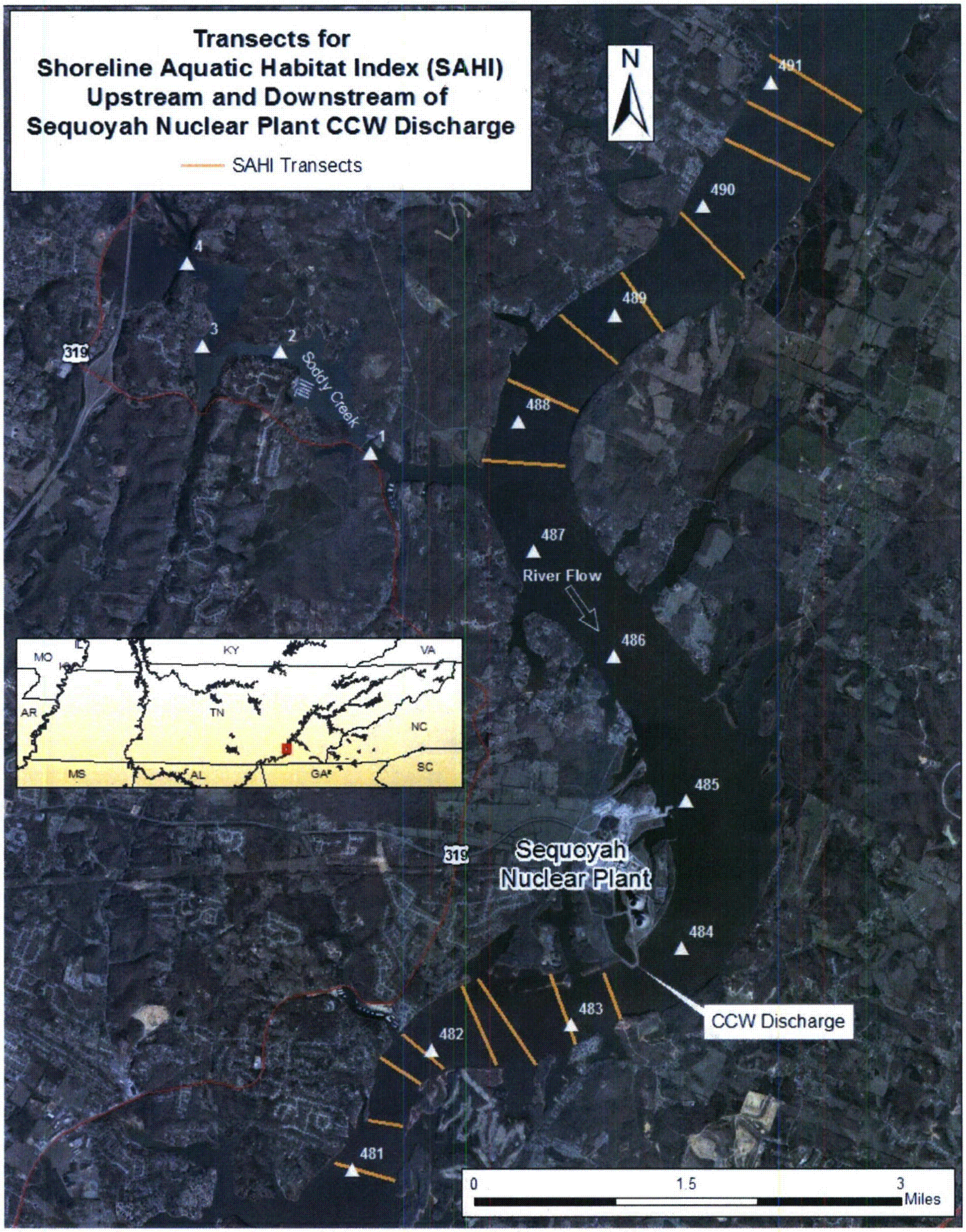


Figure 5. Benthic and shoreline habitat transects within the fish community sampling area upstream and downstream of SQN. SAHI data were collected on the left and right descending banks at endpoints of each transect.

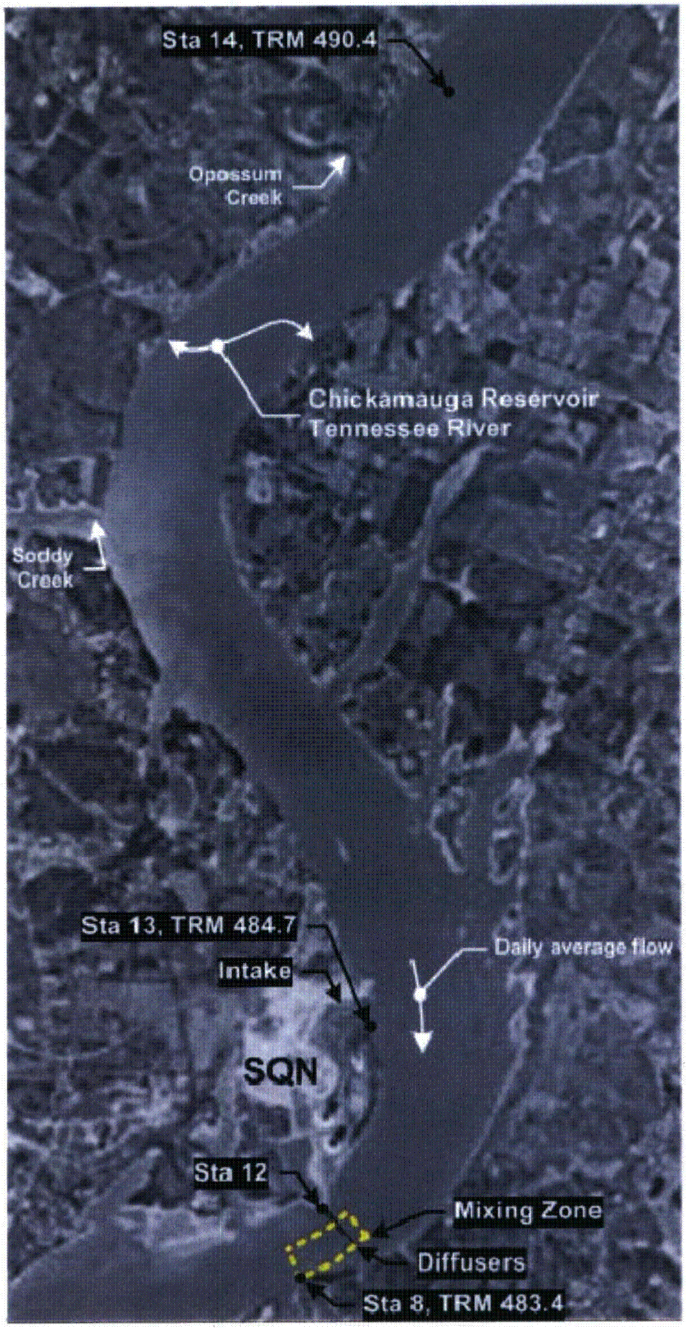


Figure 6. Locations of water temperature monitoring stations used to compare water temperatures upstream of SQN intake and downstream of SQN discharge during October 2010 through November 2011. Station 14 was used for upstream ambient temperatures of the SQN intake and was located at TRM 490.4. Station 8 was used for temperatures downstream of SQN discharge and was located at TRM 483.4.

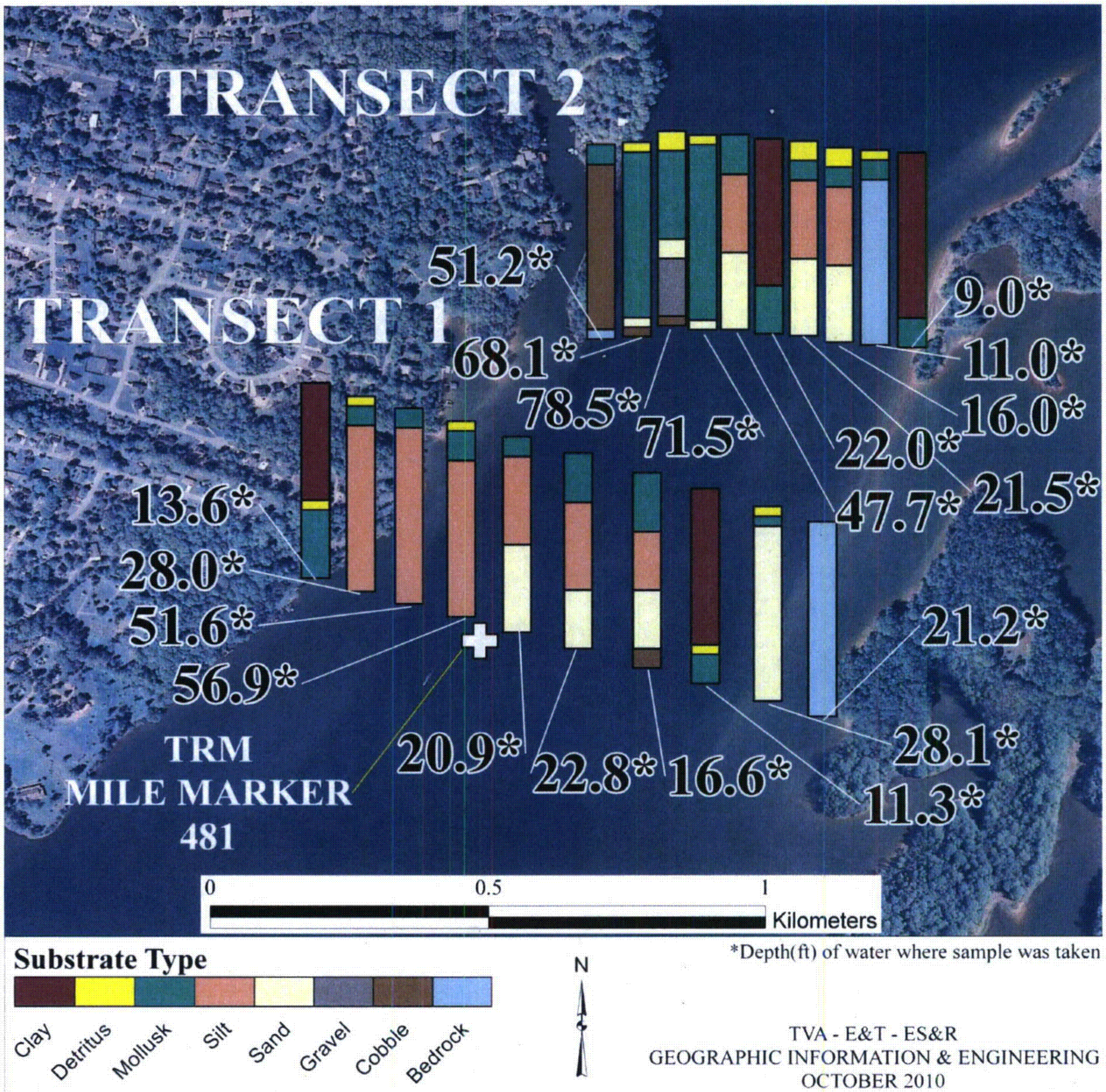


Figure 7. Substrate composition at ten equally spaced points per transect (1 and 2) across the Tennessee River downstream of SQN. *Water depth (ft) at each point is denoted. Transects 1 and 2 are the most downstream of the eight transects downstream of the SQN discharge.

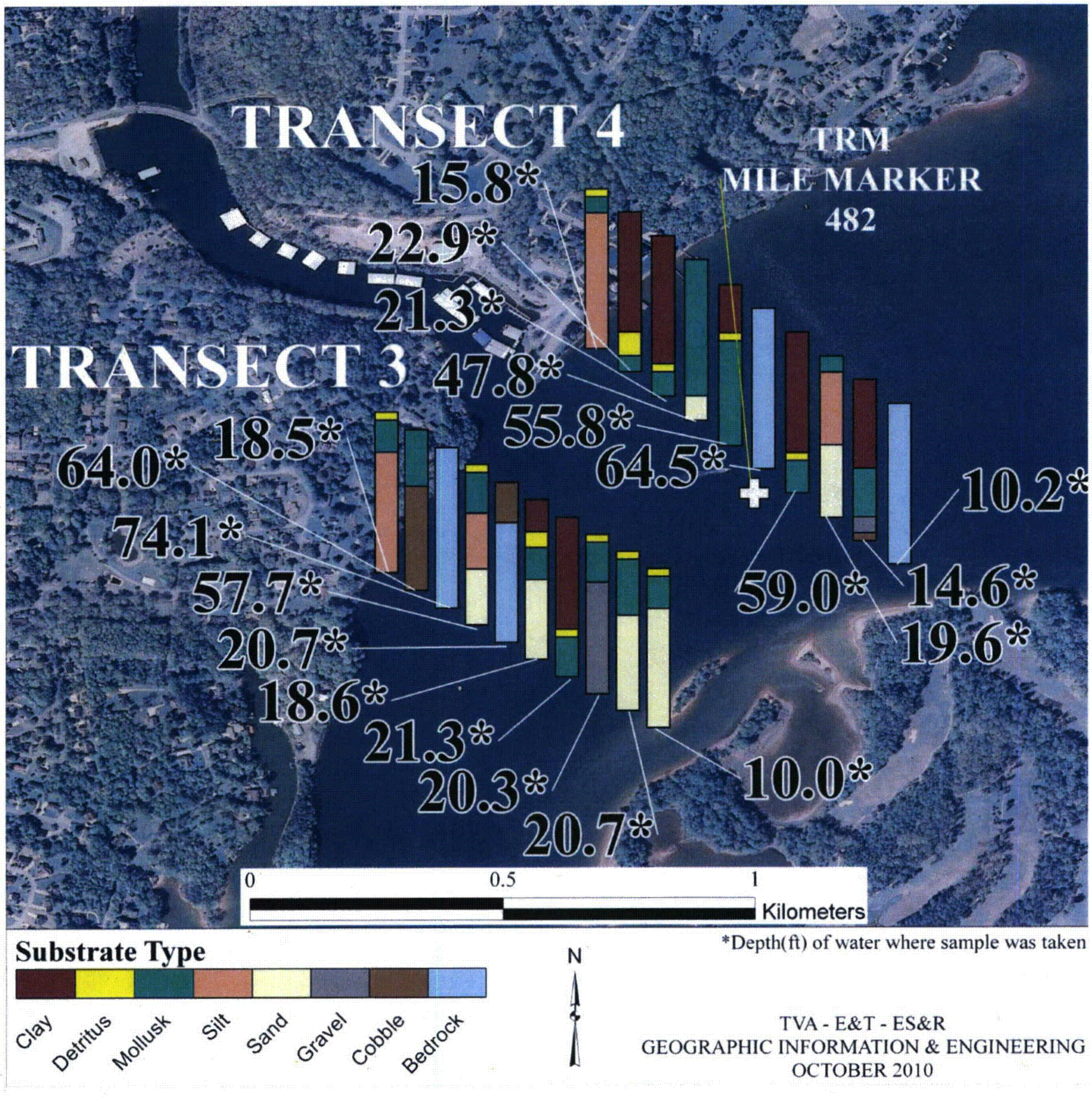


Figure 8. Substrate composition at ten equally spaced points per transect (3 and 4) across the Tennessee River downstream of SQN. *Water depth (ft) at each point is denoted.

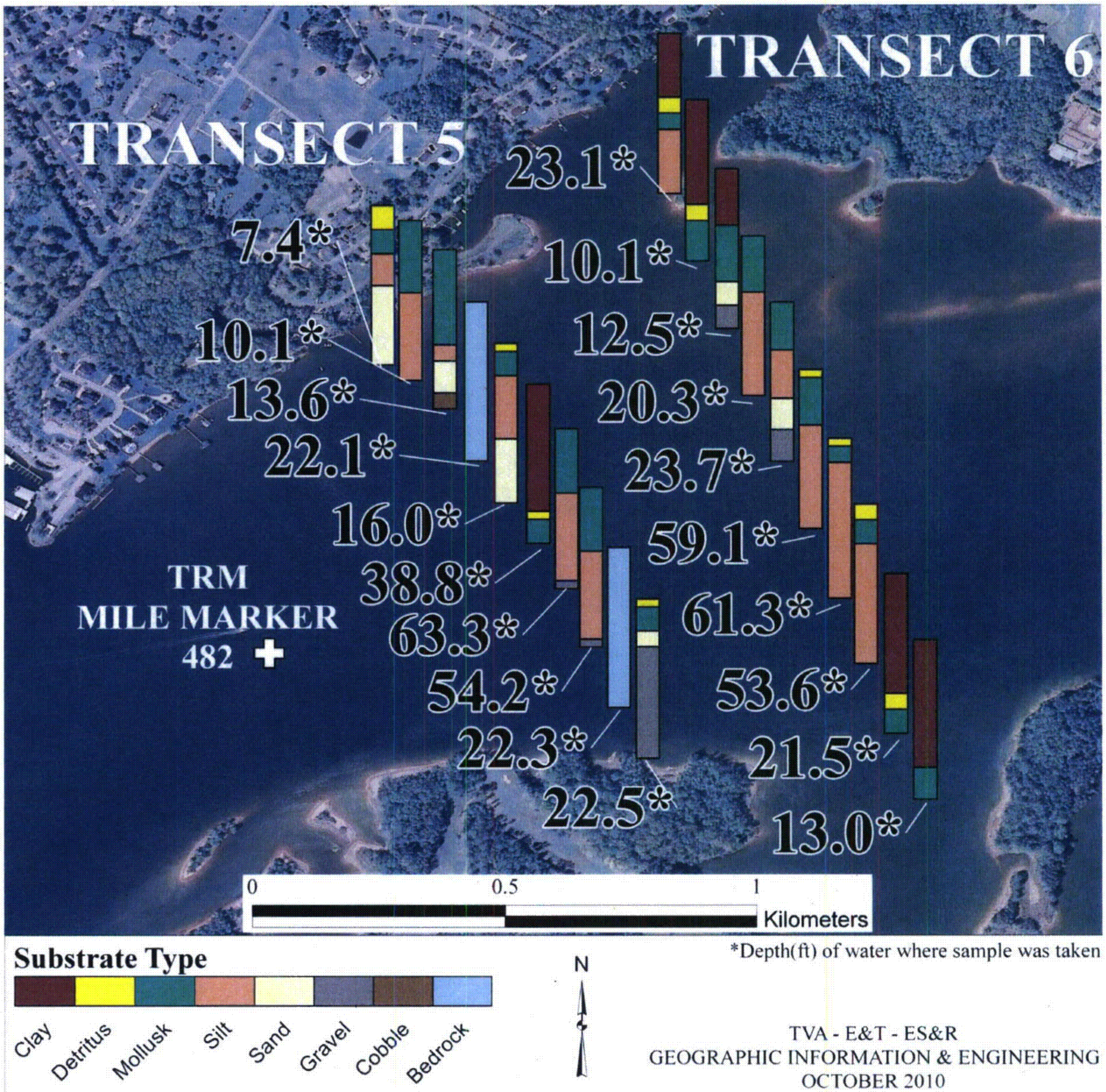


Figure 9. Substrate composition at ten equally spaced points per transect (5 and 6) across the Tennessee River downstream of SQN. *Water depth (ft) at each point is denoted.

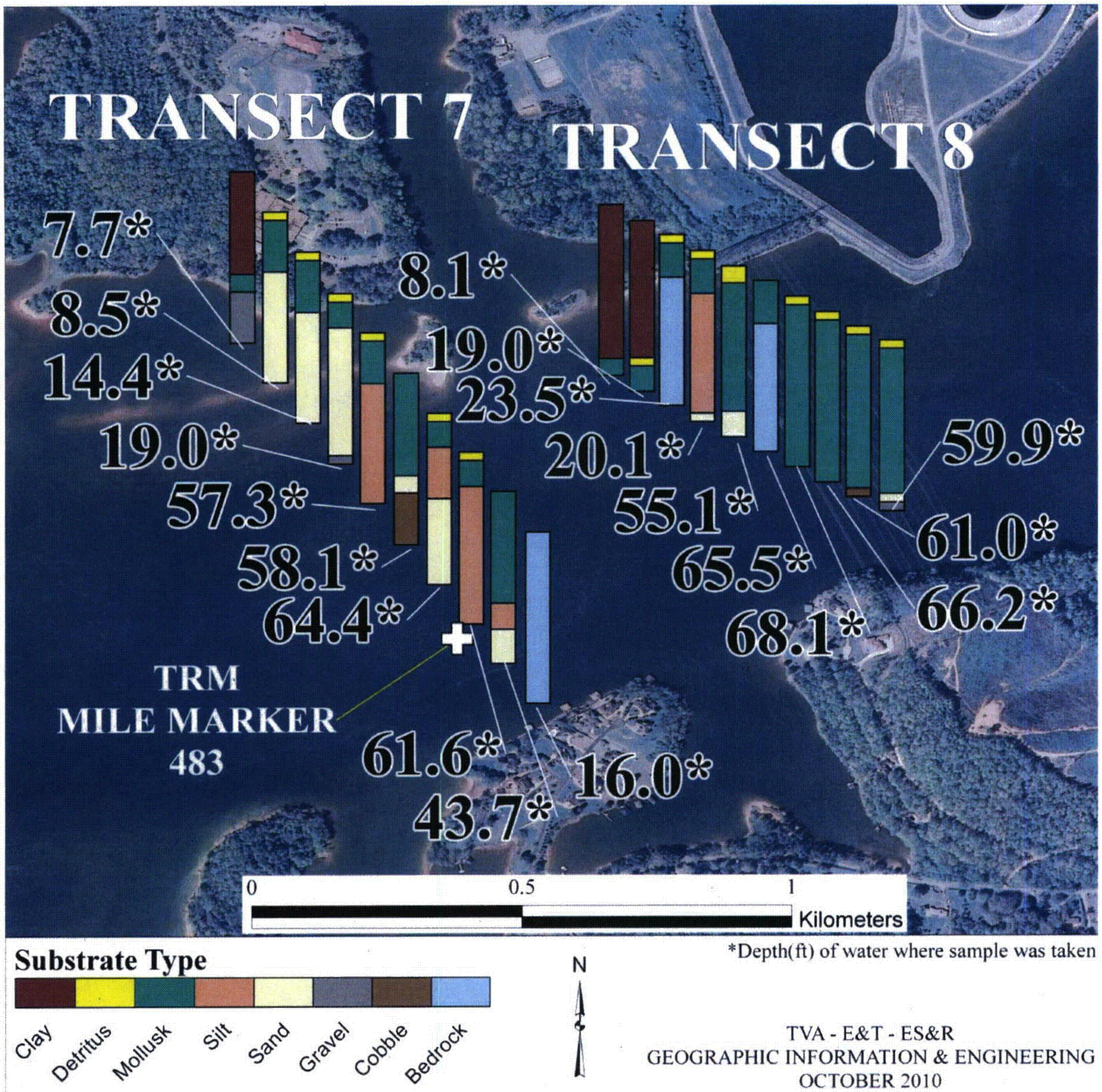


Figure 10. Substrate composition at ten equally spaced points per transect (7 and 8) across the Tennessee River downstream of SQN. *Water depth (ft) at each point is denoted.

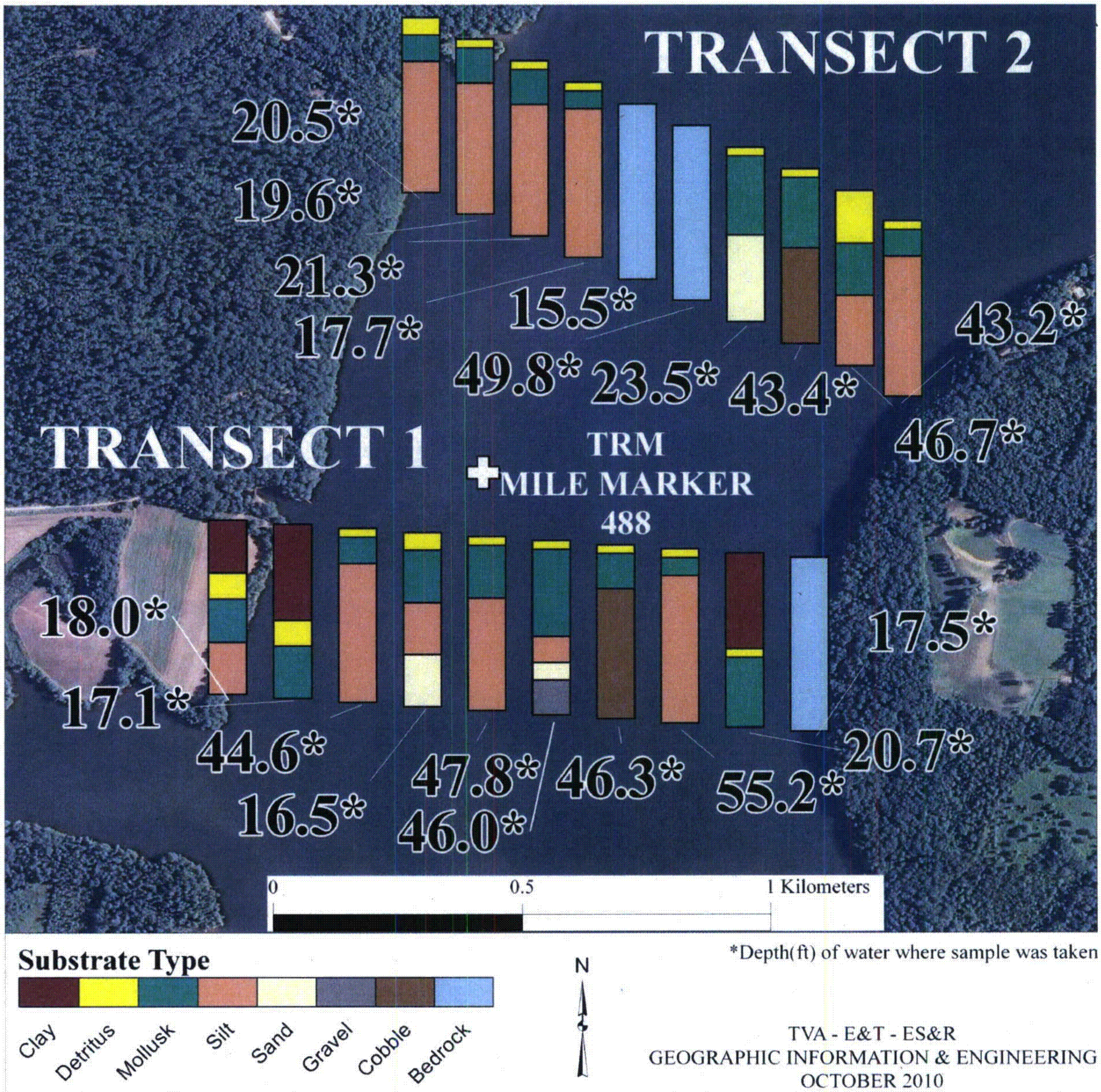


Figure 11. Substrate composition at ten equally spaced points per transect (1 and 2) across the Tennessee River upstream of SQN. *Water depth (ft) at each point is denoted. Transects 1 and 2 are the most downstream of the eight transects upstream of the SQN discharge.

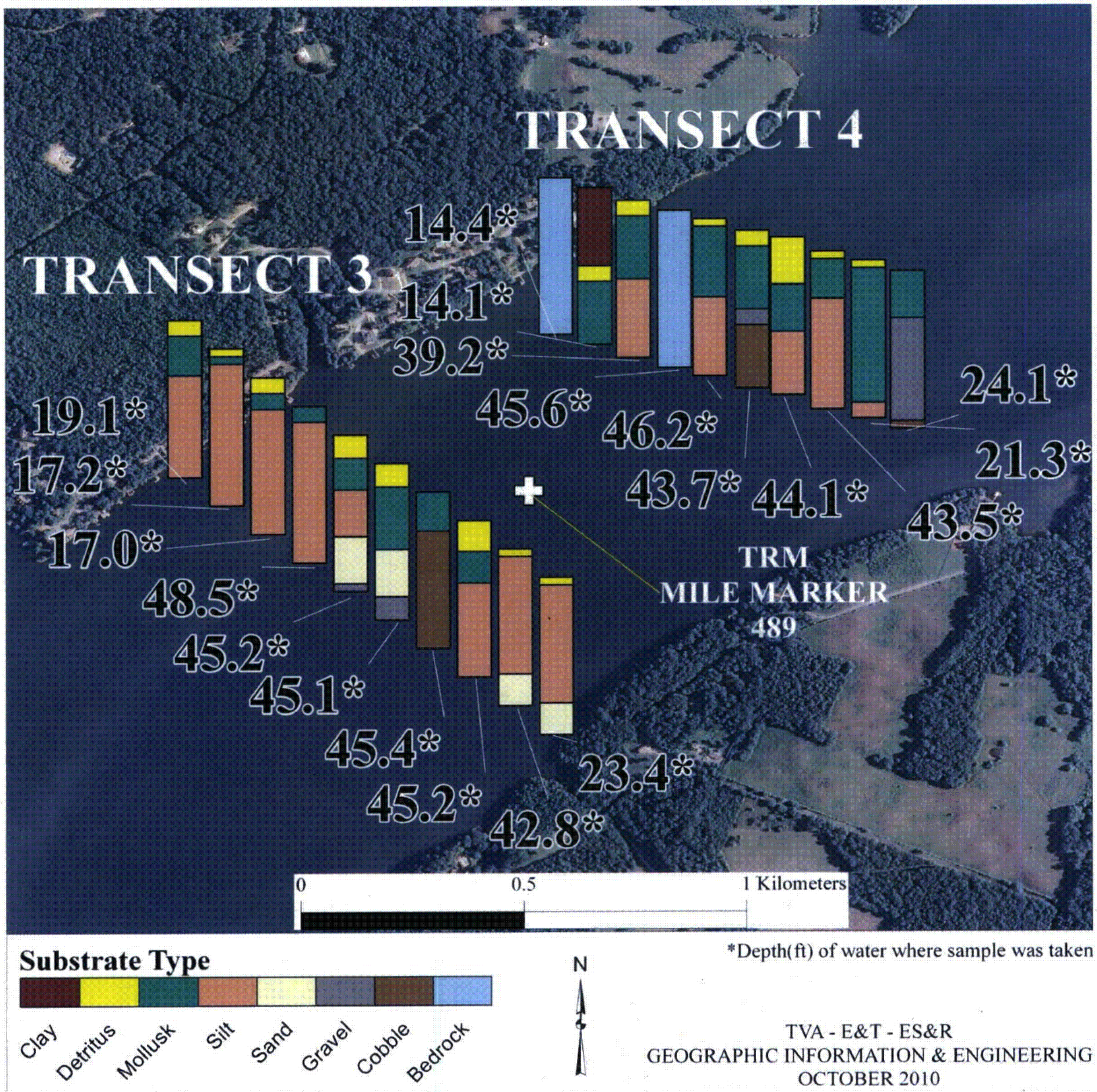


Figure 12. Substrate composition at ten equally spaced points per transect (3 and 4) across the Tennessee River upstream of SQN. *Water depth (ft) at each point is denoted.

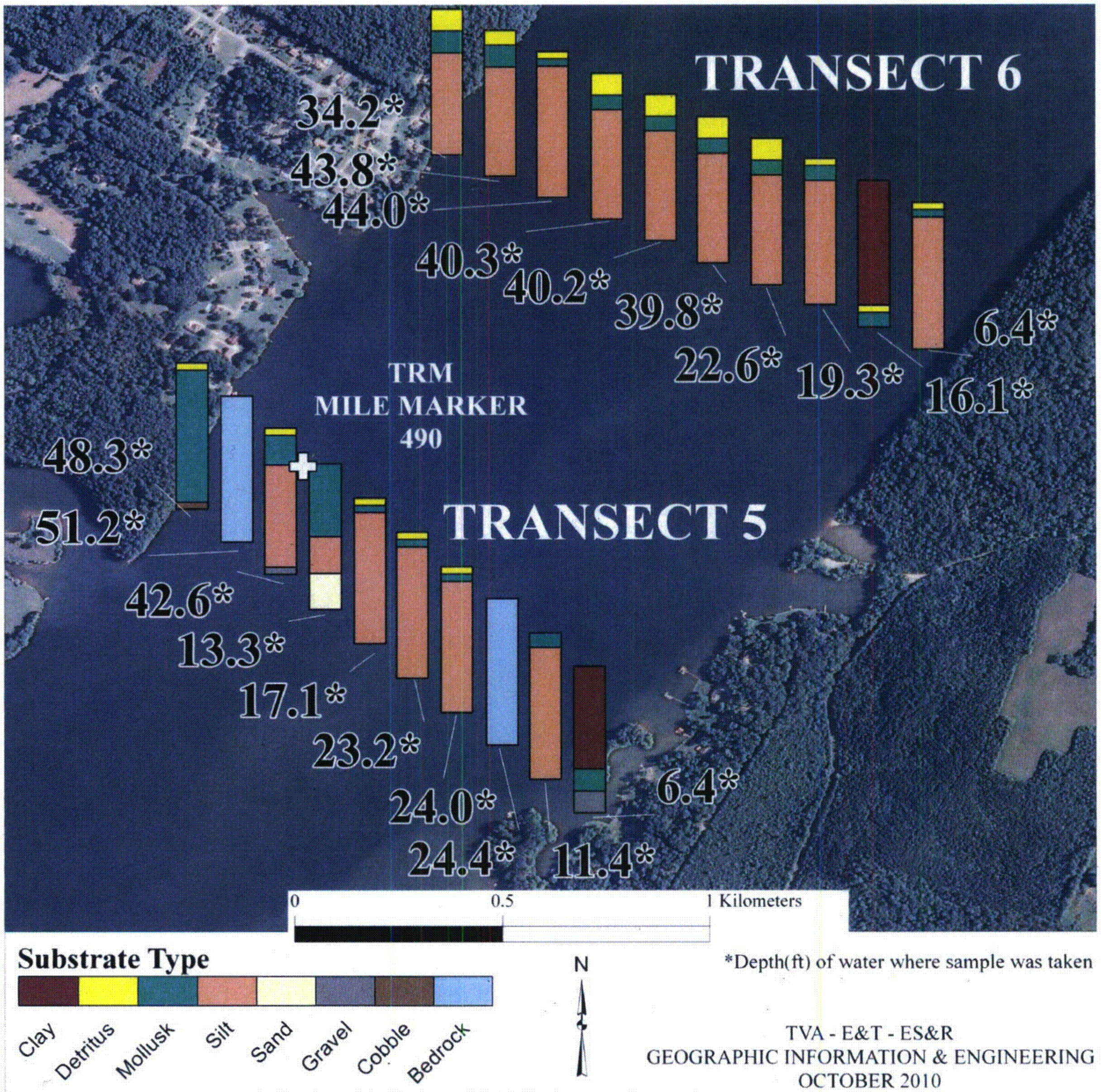


Figure 13. Substrate composition at ten equally spaced points per transect (5 and 6) across the Tennessee River upstream of SQN. *Water depth (ft) at each point is denoted.

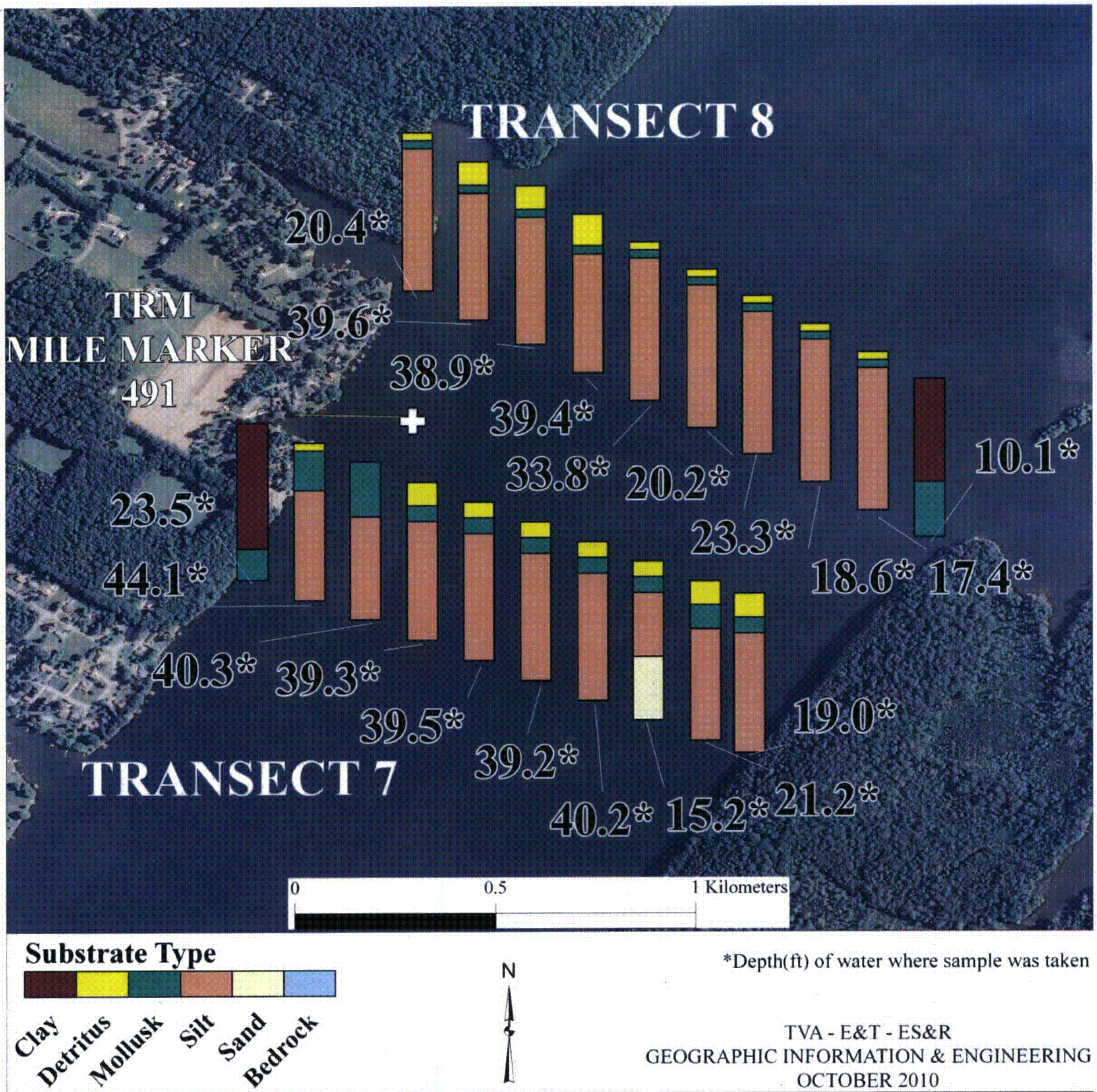


Figure 14. Substrate composition at ten equally spaced points per transect (7 and 8) across the Tennessee River upstream of SQN. *Water depth (ft) at each point is denoted.

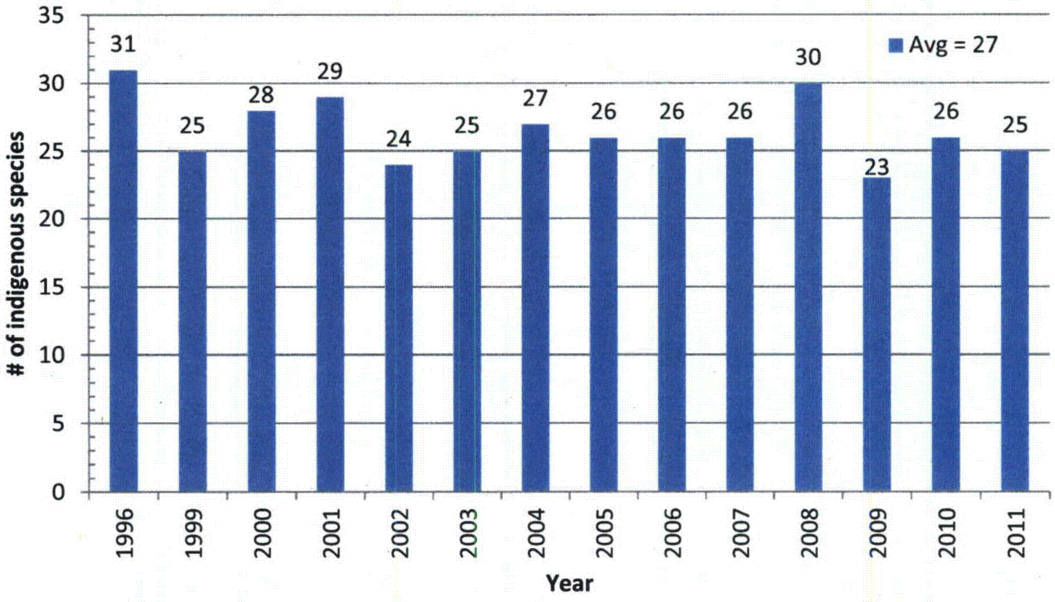


Figure 15. Number of indigenous fish species collected during RFAI samples downstream of SQN (TRM 482) during 1996 and 1999 through 2011.

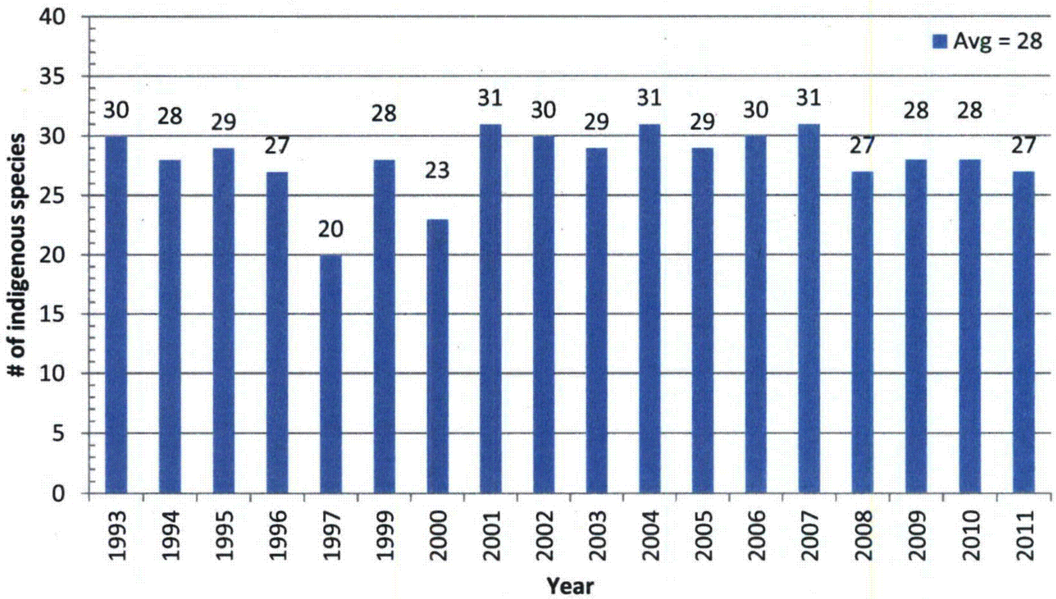


Figure 16. Number of indigenous fish species collected during RFAI samples upstream of SQN (TRM 490.5) during 1993 to 1997 and 1999 through 2011.

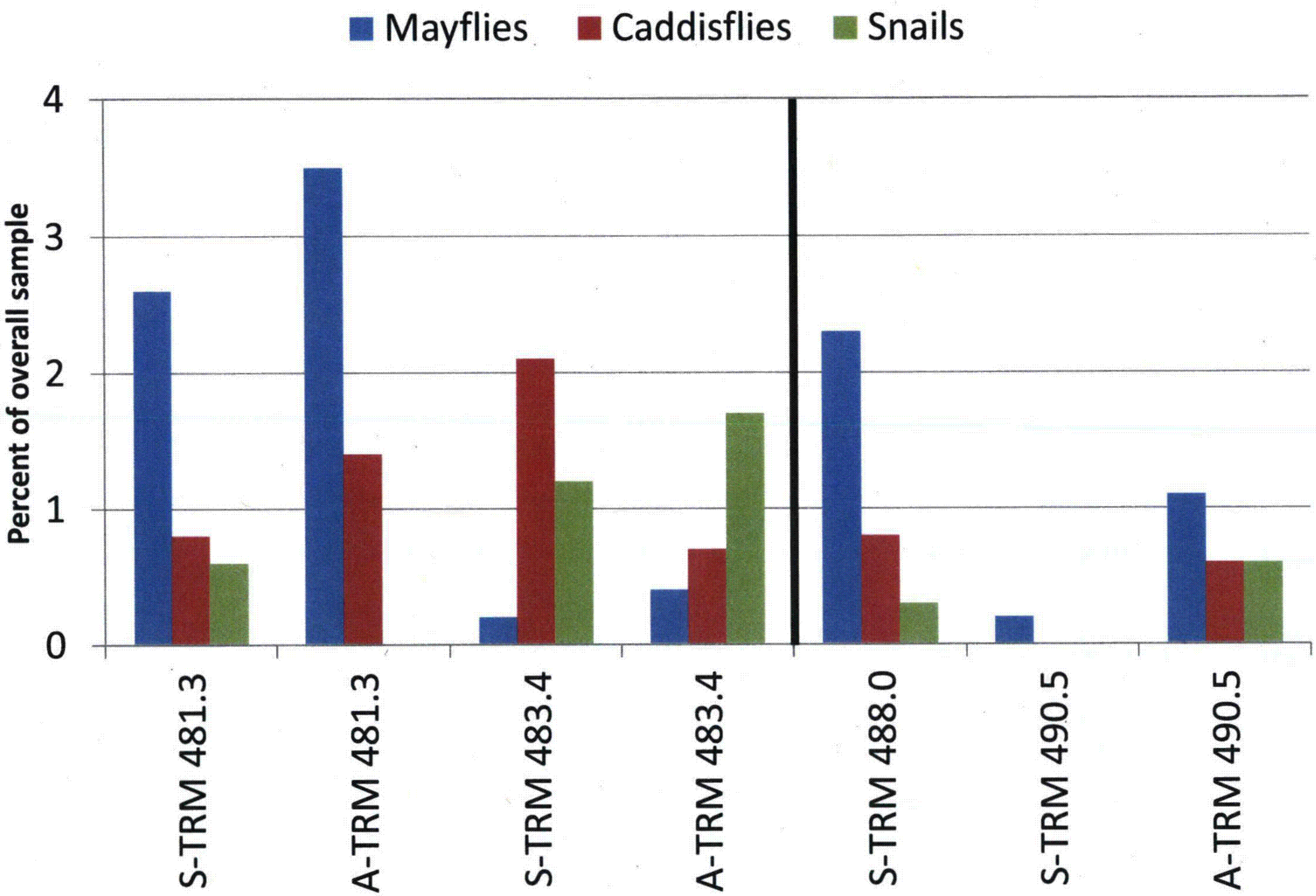


Figure 17. Proportions of selected benthic taxa from Ponar dredge sampling at locations upstream and downstream of SQN, summer and autumn 2011.

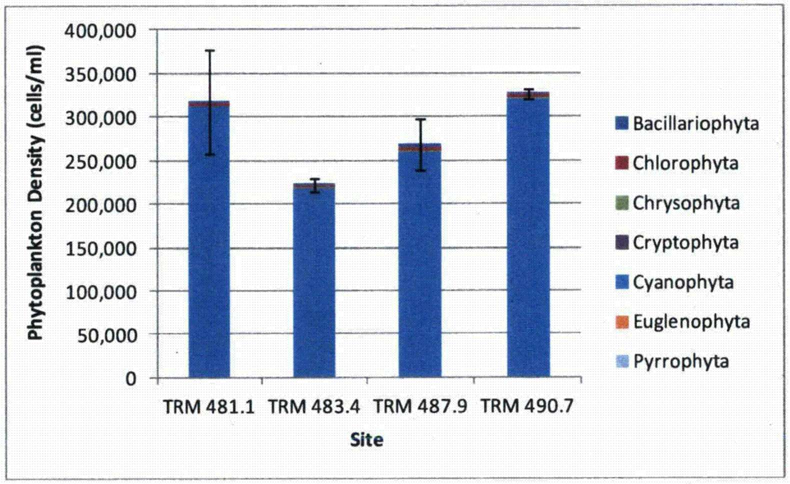


Figure 18. Mean phytoplankton densities (cells/ml) for samples collected August 25, 2011.

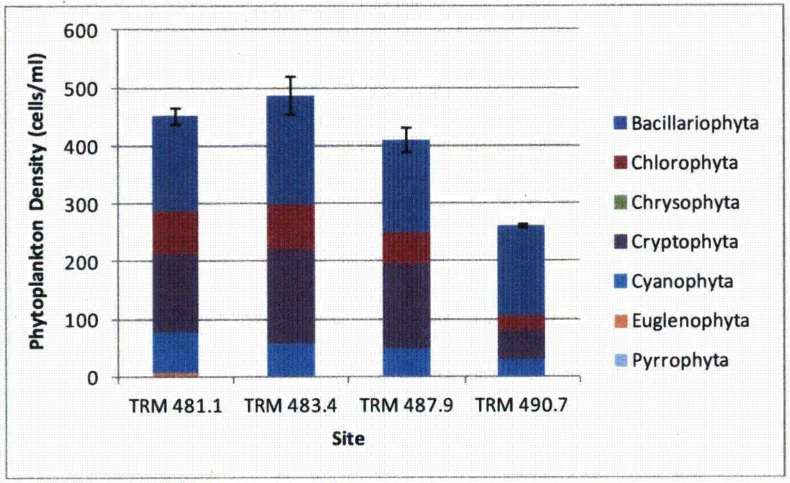


Figure 20. Mean phytoplankton densities (cells/ml) for samples collected October 10, 2011.

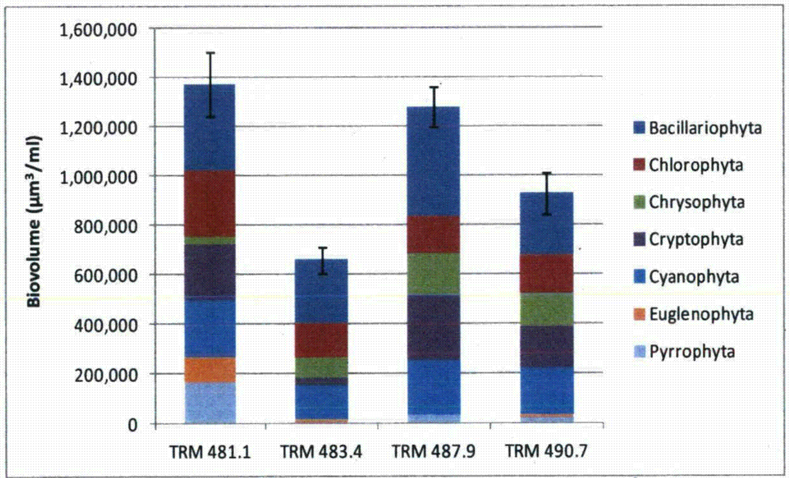


Figure 19. Mean phytoplankton biovolume (μm^3/ml) for samples collected August 25, 2011.

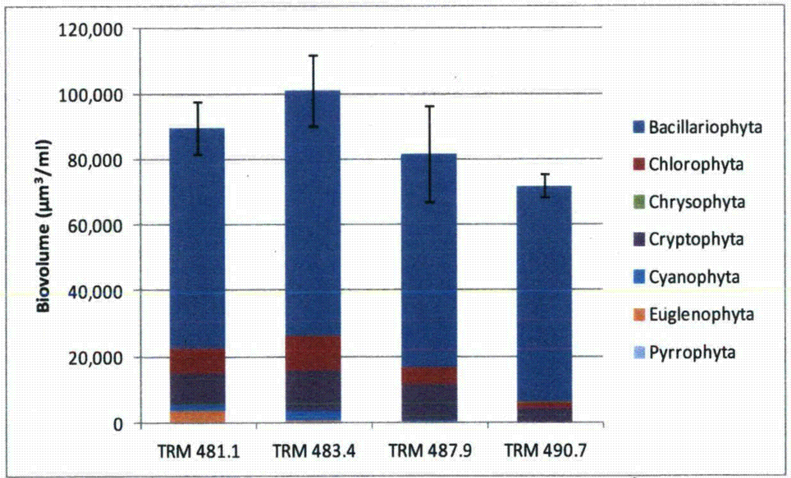


Figure 21. Mean phytoplankton biovolume (μm^3/ml) for samples collected October 10, 2011.

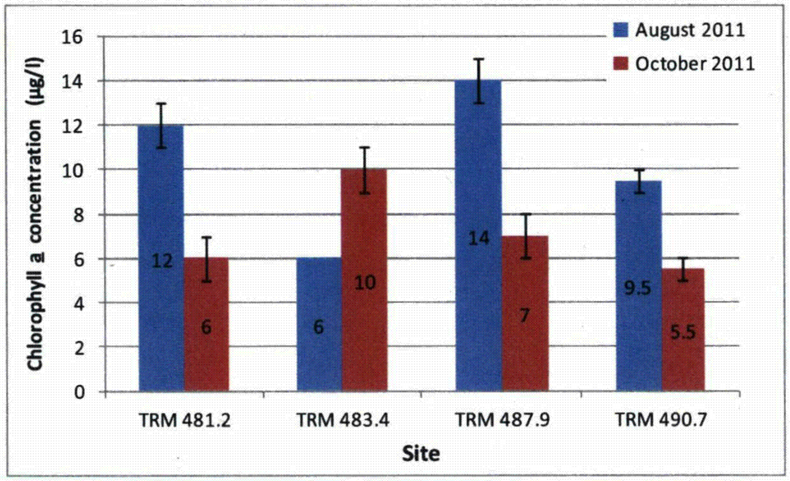


Figure 22. Mean chlorophyll a concentrations for samples collected August 25 and October 10, 2011.

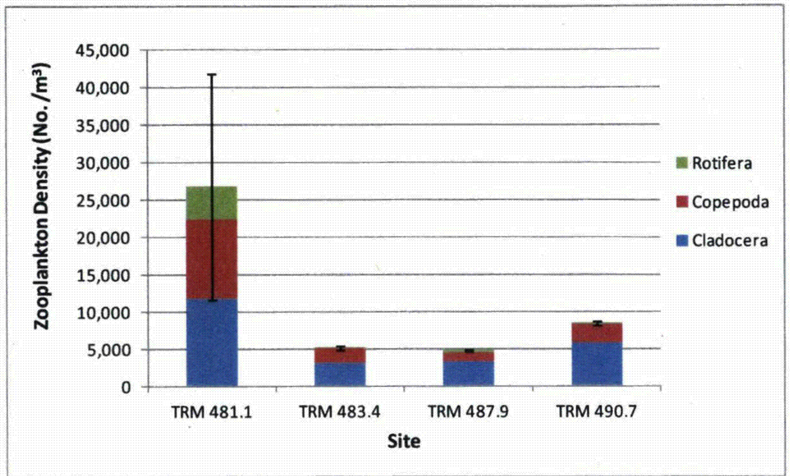


Figure 24. Mean zooplankton densities (number/m^3) for samples collected October 10, 2011

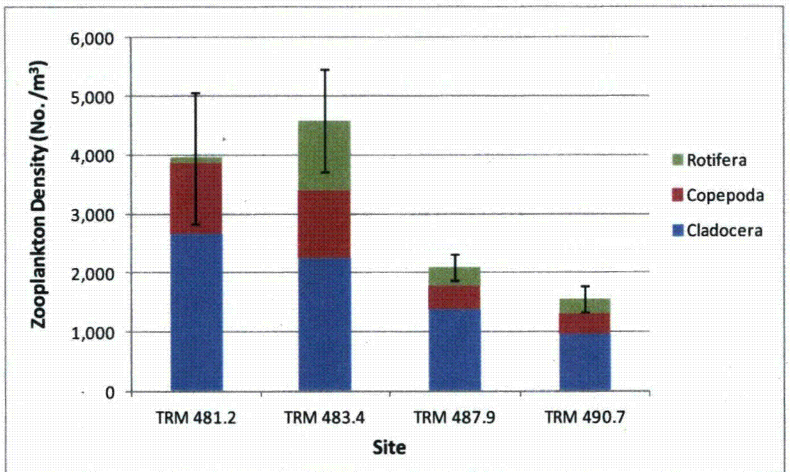


Figure 23. Mean zooplankton densities (number/m^3) for samples collected August 25, 2011.

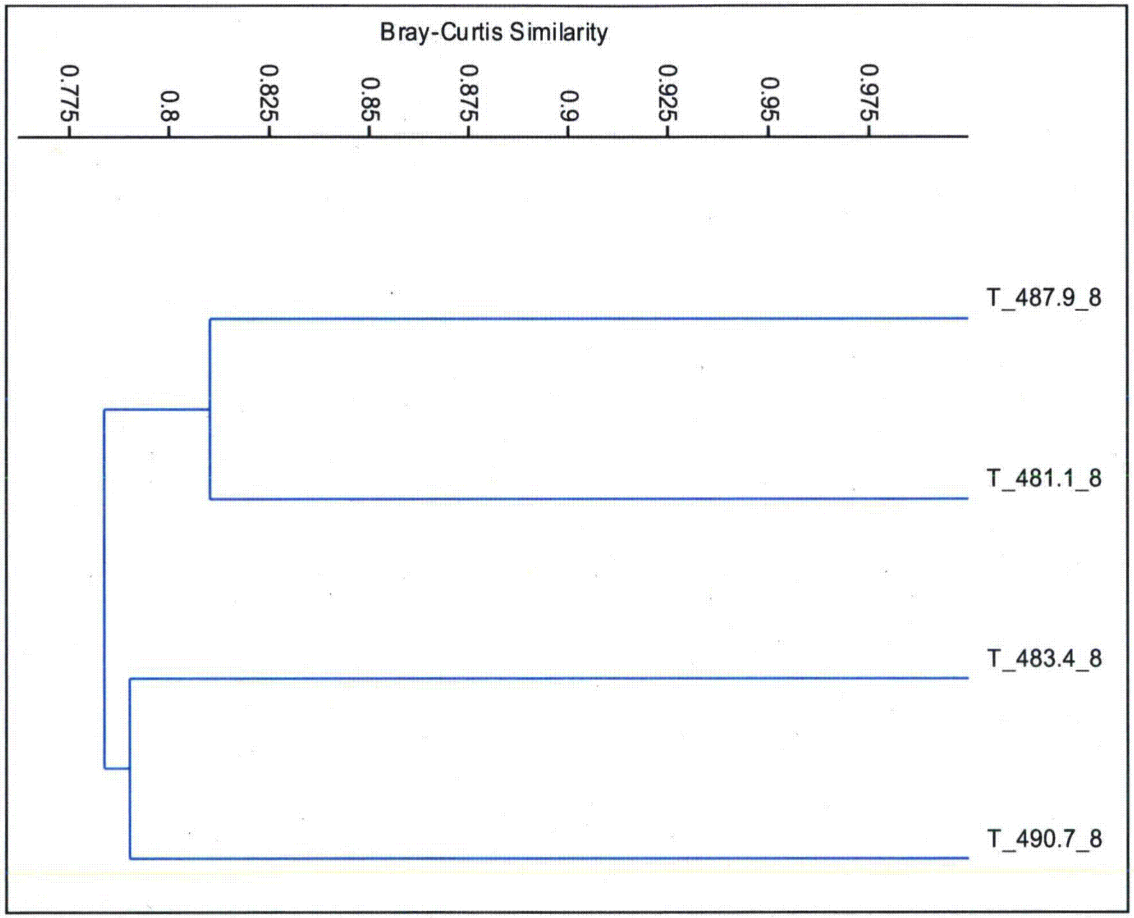


Figure 25. Dendrogram of phytoplankton community (taxa density, $\log_{10}$+1) cluster analysis (average distance) based on Bray-Curtis distance matrix among samples collected August 25, 2011. Samples for each location are coded by river mile and month. (Coph. Corr = 0.89)

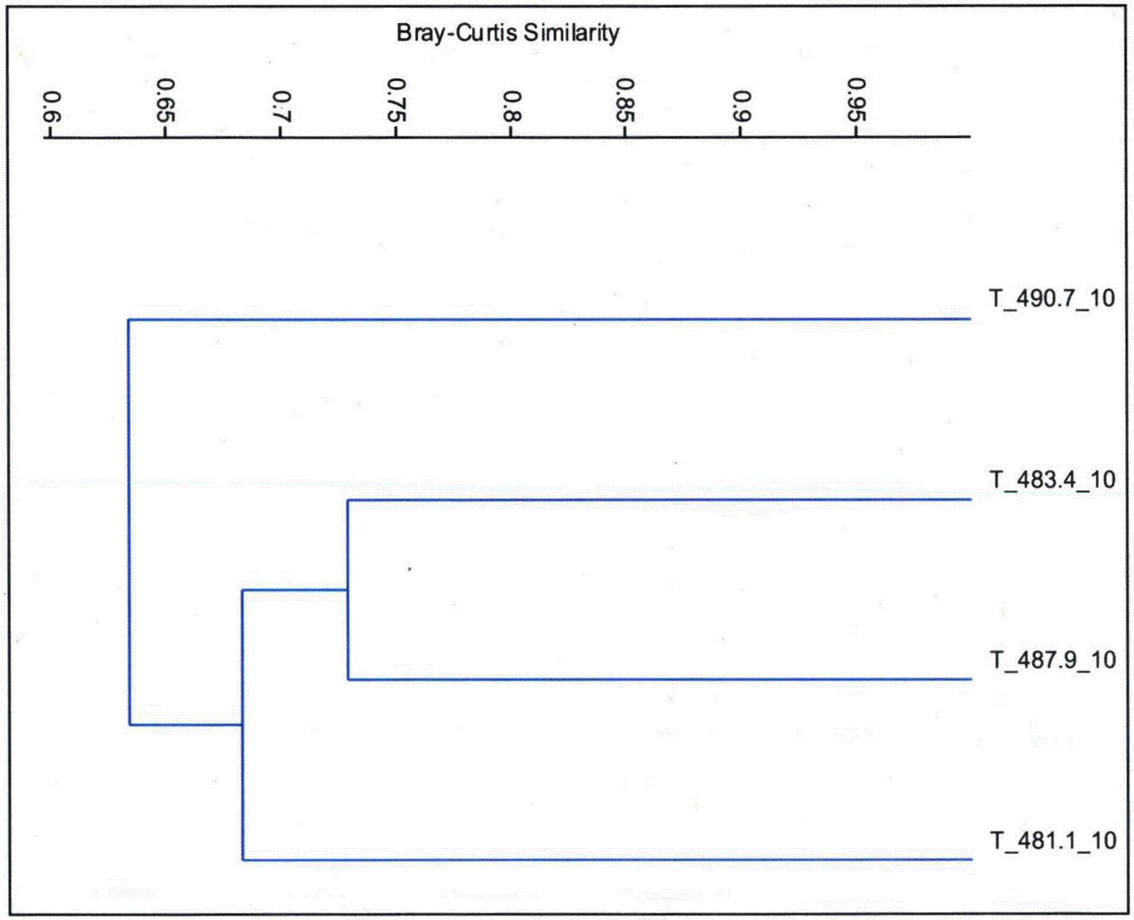


Figure 26. Dendrogram of phytoplankton community (taxa density, $\log_{10}$+1) cluster analysis (average distance) based on Bray-Curtis distance matrix among samples collected October 10, 2011. Samples for each location are coded by river mile and month. (Coph. Corr = 0.78)

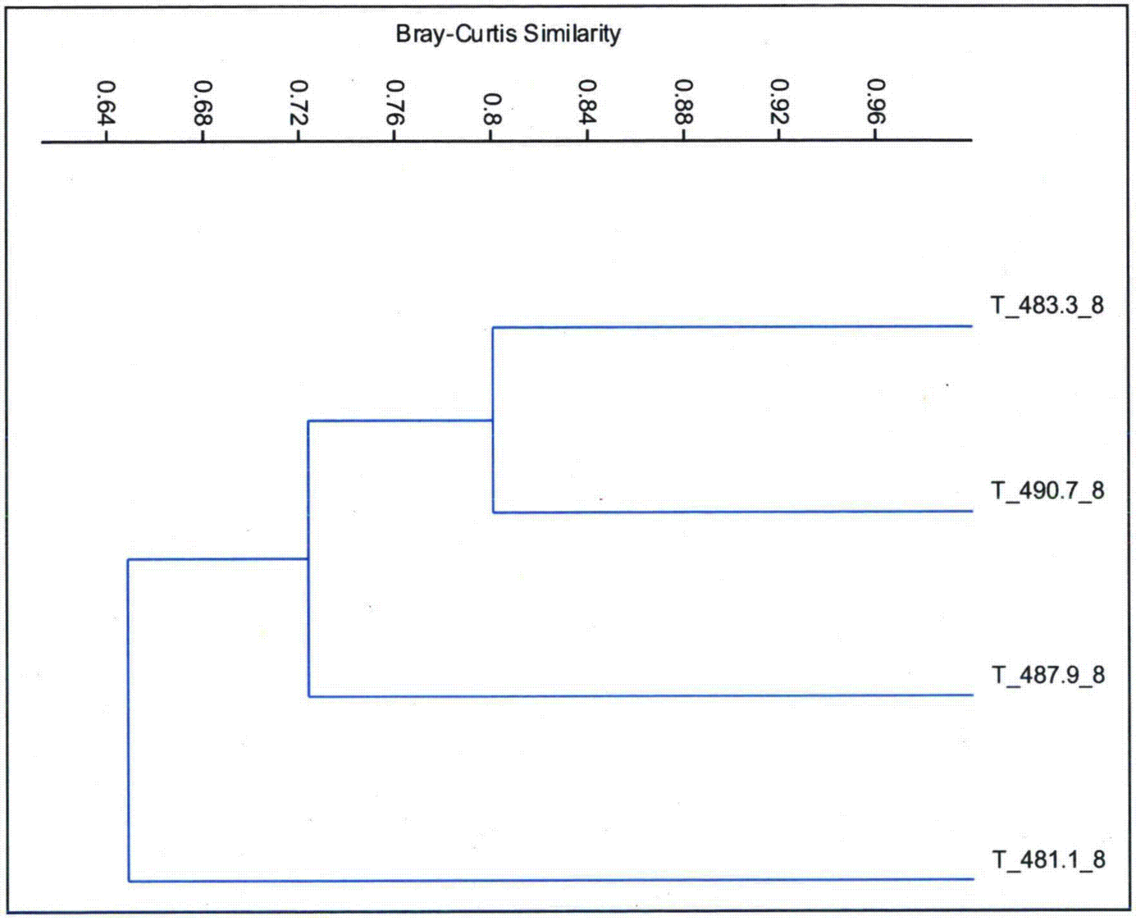


Figure 27. Dendrogram of zooplankton community (taxa density, $\log_{10}$+1) cluster analysis (average distance) based on Bray-Curtis distance matrix among samples collected <u>August 25, 2011</u>. Samples for each location are coded by river mile and month. (Coph. Corr = 0.87)

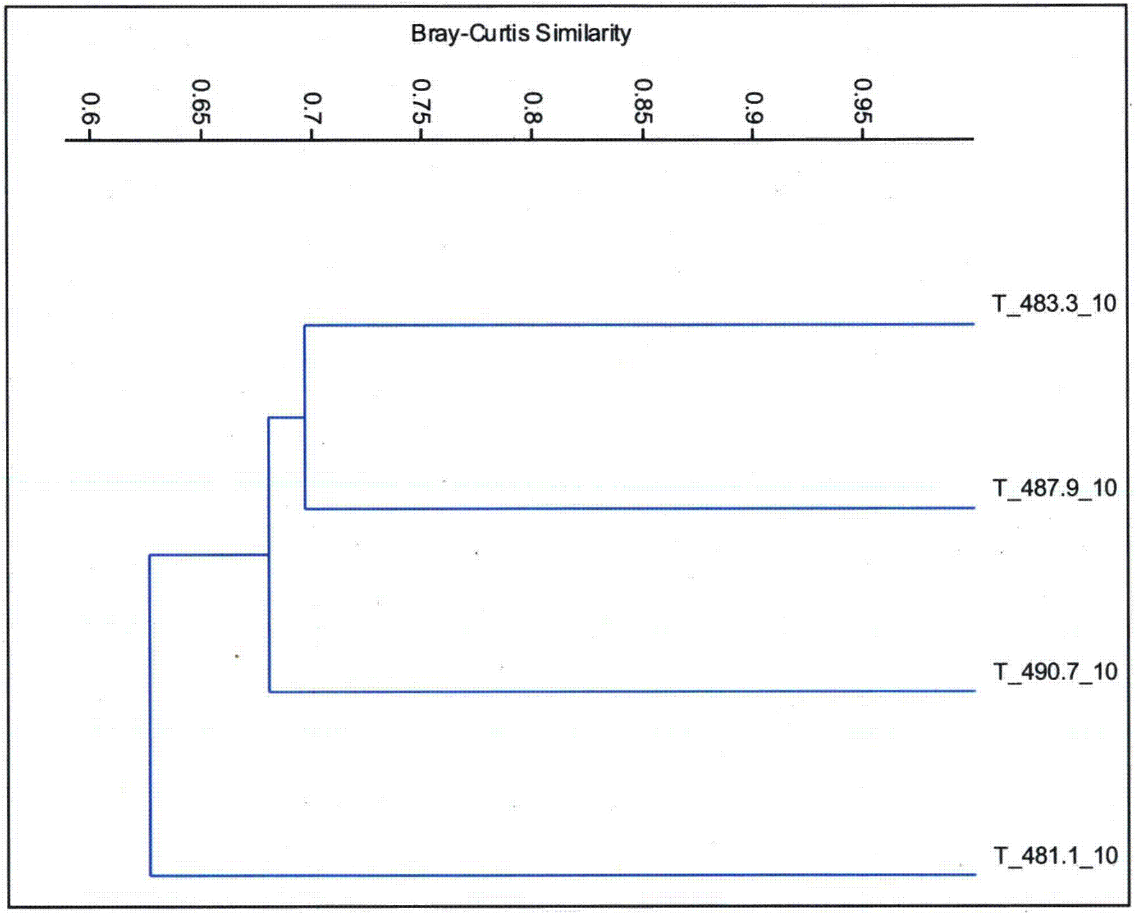


Figure 28. Dendrogram of zooplankton community (taxa density, $\log_{10}$+1) cluster analysis (average distance) based on Bray-Curtis distance matrix among samples collected October 10, 2011. Samples for each location are coded by river mile and month. (Coph. Corr = 0.78)

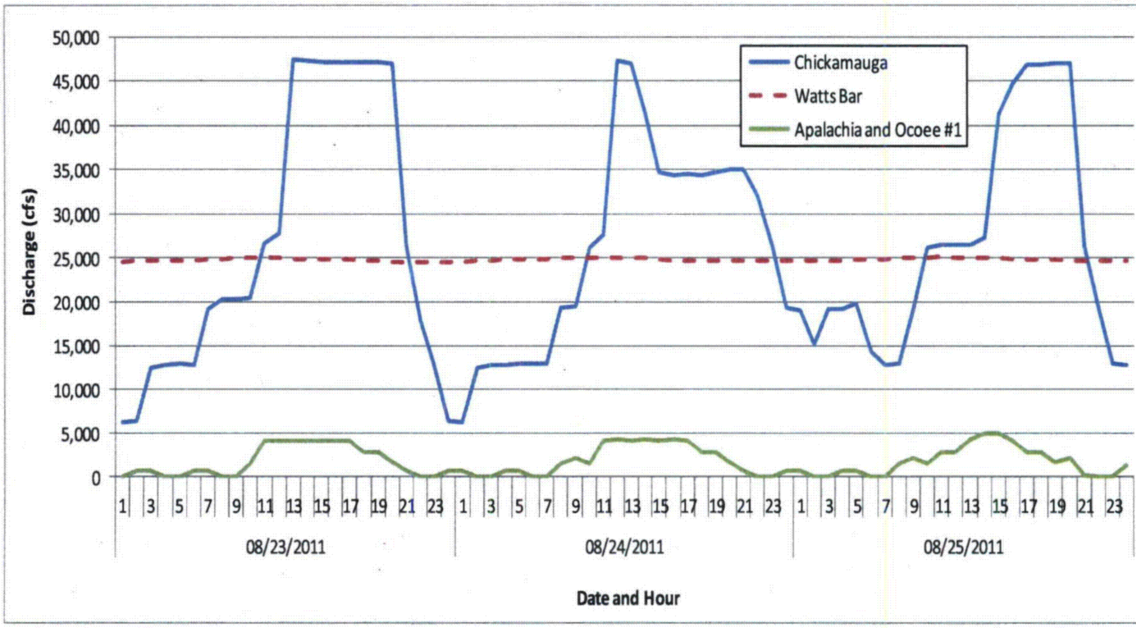


Figure 29. Average hourly discharge from Chickamauga, Watts Bar, Apalachia, and Ocoee #1 dams, August 23 through August 25, 2011

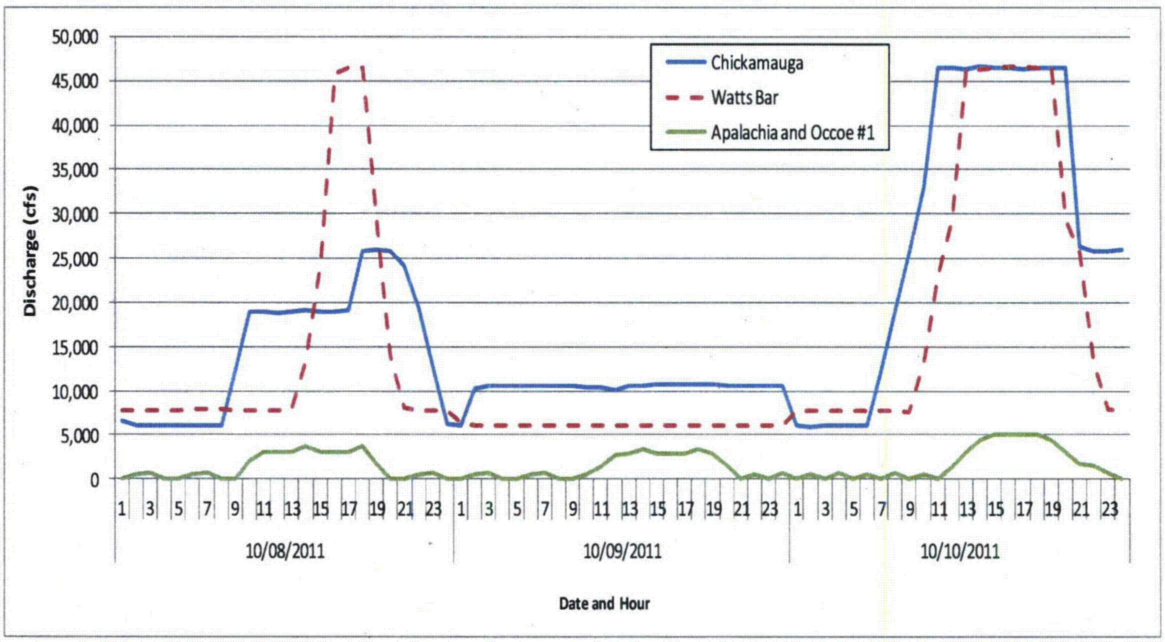


Figure 30. Average hourly discharge from Chickamauga, Watts Bar, Apalachia, and Ocoee #1 dams, October 8 through October 10, 2011

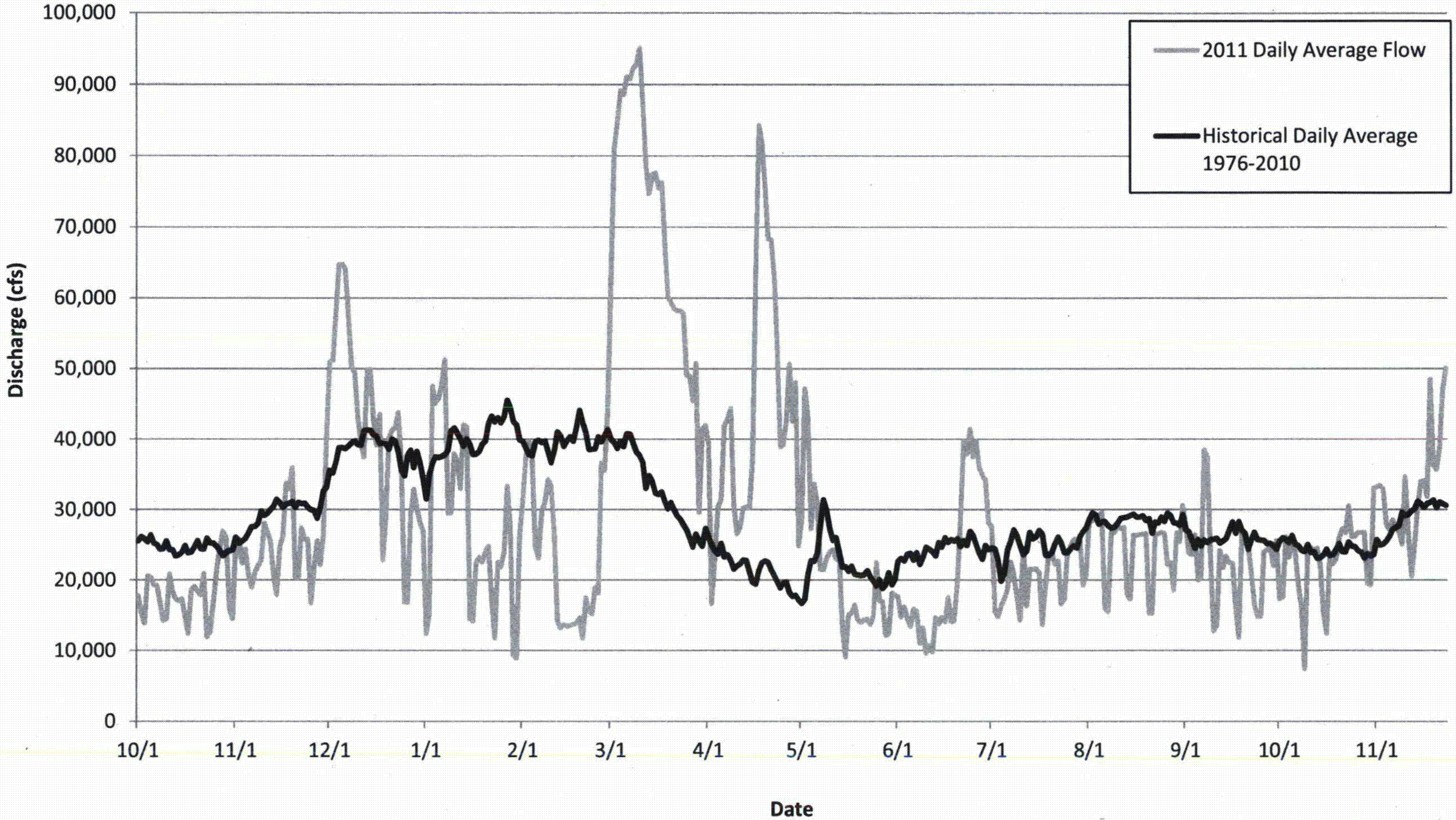


Figure 31. Total daily average releases (cubic feet per second) from Watts Bar, Apalachia, and Ocoee 1 dams, October 2010 through November 2011 and historic daily average flows averaged for the same period 1976 through 2010.

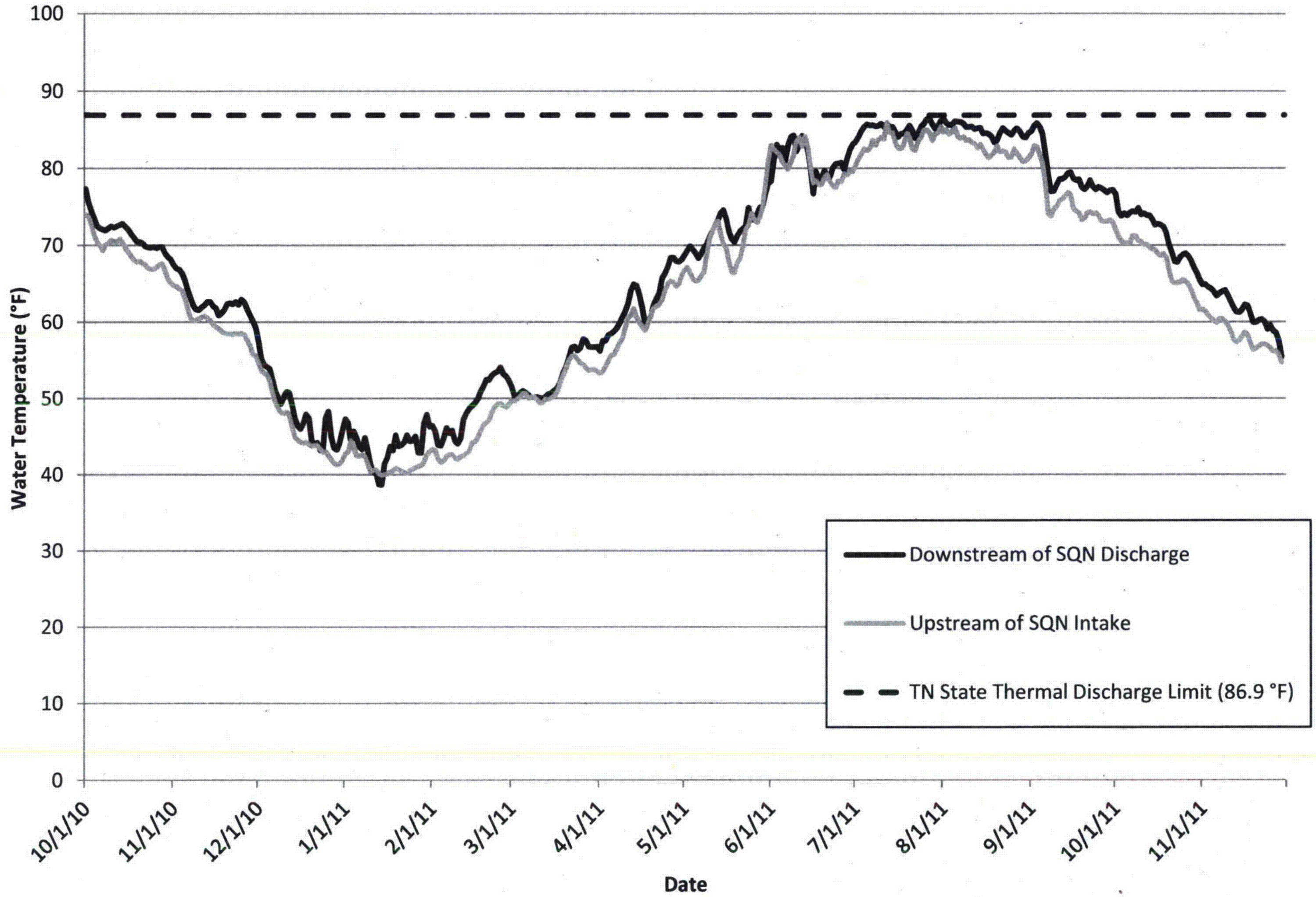


Figure 32. Daily average water temperatures (°F) at a depth of five feet, recorded upstream of SQN intake (Station 14) and downstream of SQN discharge (Station 8), October 2009 through November 2010.

April 19, 2013

Bradley M. Love, OPS 5N-SQN

SEQUOYAH NUCLEAR PLANT (SQN)--RIVER SCHEDULING FOR LOW FLOW CONDITONS

Part III.F.1.b. and Part III.F.1.c. of the current SQN National Pollutant Discharge Elimination System (NPDES) permit summarize requirements related to monitoring thermal compliance for Outfall 101, the plant diffuser discharge to the Tennessee River. In particular, in these parts of the permit, ranges for the daily average flow past SQN are defined wherein special field surveys are required to verify the adequacy of the plant ambient river temperature and the adequacy of the plant diffuser mixing zone. These ranges in flow are given both for river conditions characterized by unsteady flow and river conditions characterized by steady flow. The type of unsteady flows of concern is the type created by strong hydro peaking, sustained day after day with low daily average flows. Similarly, the type of steady flows of concern is the type created by continuous, unvarying hydro operation, again sustained day after day, but at daily average flows lower than those of concern for low flow hydro peaking. To verify compliance to these requirements for special field surveys, the NPDES permit specifies that river flow data shall be submitted with the application for re-issuance of the permit. The purpose of this memo is to provide these data.

In general, in the current NPDES permit, the daily average river flows past SQN that trigger the need for special field surveys are as follows:

<u>No units in operation at SQN</u>: No field surveys required.

<u>One unit in operation at SQN</u>: Field surveys required if the daily average flow past SQN drops below 3,000 cfs in steady hydro operation or below 6,500 cfs in unsteady/peaking operation.

<u>Two units in operation at SQN</u>: Field surveys required if the daily average flow past SQN drops below 6,000 cfs in steady hydro operation or below 13,000 cfs in unsteady/peaking operation.

The current TVA strategy for managing these requirements is to schedule the operation of Chickamauga Reservoir in a manner so that there is no need to perform these special surveys. Thus far, there has been no need to schedule daily average river flows past SQN at a level below the trigger for steady-related surveys. And thus far, when it has been necessary to schedule river flows at a level below the trigger for unsteady-related surveys, such has been accomplished by limiting hydro peaking at Chickamauga Dam and Watts Bar Dam.

Given in Attachment 1 is a plot showing the daily average flow past SQN for the period beginning March 1, 2011 and ending March 31, 2013. This period spans the time from the effective date of the current NPDES permit through the most recent full month (as of the date of this memo). Based on the actual operation of SQN, also given are the trigger levels summarized above. As shown, within the period of record, the daily average flow past SQN never dropped below the steady trigger for special field surveys. The daily average flow past SQN dropped below the unsteady trigger only for single events in May 2011 and October 2011, and several events from April 2012 through July 2012. In these events, and as presented above, hydro peaking at Chickamauga Dam and Watts Bar Dam was limited to move Chickamauga Reservoir toward steady operation, providing a more predictable behavior of the SQN thermal effluent and precluding the need for special field surveys.

In limiting peaking operations at Chickamauga Dam and Watts Bar Dam, restrictions are provided in as much as such is feasible in consideration of TVA's responsibility for providing public safety, navigation, power supply, recreation, water supply, and water quality. Peaking operations are characterized by providing hydro releases only during those hours of the day wherein there is a large demand for power, with little or no releases made during off-peak hours. In peaking operations, hydro releases can be suspended for eight or more hours per day (i.e., zero flow), followed by a period of intense high flow, creating significant sloshing in Chickamauga Reservoir. In contrast, when peaking operations are limited, efforts are made to provide hydro releases around-the-clock. Furthermore, if a change in flow is needed, an attempt is made to implement such as a single step from one steady condition to another steady condition. In practice, it is not uncommon for a hydro unit to trip out of service, temporarily interrupting the flow. Incidents in the immediate vicinity of the dams also can cause interruptions (e.g., capsized boat). In such events, releases are usually resumed within a short period of time following the incident, and may require a short duration release at a higher flow to preserve the total volume of release required for that day. Short duration releases at a higher flow also are sometimes required in response to unexpected disturbances in the power system, such as a shortfall in power supply due to the unexpected trip of a large generating unit.

For the same period of time as in Attachment 1, given in Attachment 2 is a plot of the hourly releases from Chickamauga Dam and Watts Bar Dam. Release patterns associated with hydro peaking are apparent, with hourly flows from each hydro plant regularly varying within a single day between 5,000 cfs or less and over 45,000 cfs. Periods of zero flow also are common, particularly at Chickamauga Dam. Given in Attachment 3 is the same plot as in Attachment 2, but showing only those periods containing special hydro operations in support of SQN (i.e., as prompted by the requirements of Part III.F.1.b. and Part III.F.1.c. of the SQN NPDES permit). Within the period of record, a total of 762 days, there were a total 77 days requiring special hydro operations in support of SQN. For these periods, the limitations on peaking operations are apparent, with flow variations far less than those shown in Attachment 1. Given in Attachment 4 is the same plot as Attachment 3, but showing only the period from April 2012 through July 2012, which contained most of the events with daily average river flows below the unsteady trigger of 13,000 cfs. As shown, peaking operations as describe above are absent. At Watts Bar Dam, there were no events where the flow had to be interrupted or where higher releases were required in response to a river or power system need. At Chickamauga Dam, there were four events where the flow was temporarily interrupted and three events where higher releases were required on a short term basis in response to river or power system needs.

In conclusion, by the operating strategy discussed above and by the data presented herein, SQN thus far has operated in compliance with the requirements of Part III.F.1.b. and Part III.F.1.c. of the current NPDES permit. TVA River Scheduling will continue to maintain notes in their special operations database in support of these requirements, as long as they are found in the NPDES permit. Furthermore, TVA River Scheduling is prepared to manage special field surveys if there is a need to operate Chickamauga Reservoir in a manner that necessitates such by the NPDES permit requirements.

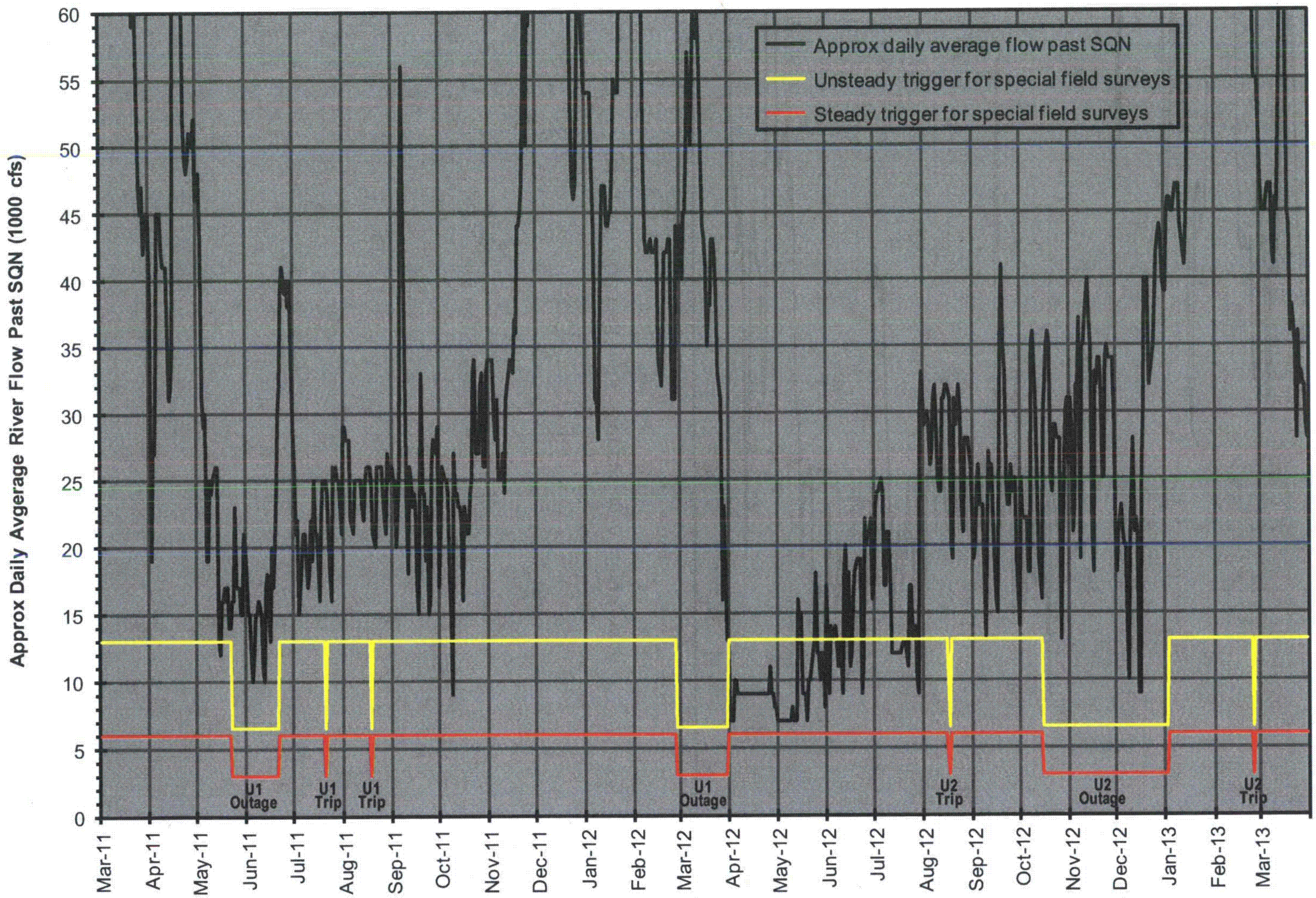
Please contact me if you have any questions regarding the contents of this memo.

Paul N. Hopping
Technical Specialist
River Scheduling
WT 10B-K

PNH:JGP
Attachments
cc (Attachments):
T. W. Barnett, WT 10C-K
L. D. Bean, WT 10B-K
J. H. Everett, WT 10C-K
T. R. Markum, BR 4A-C
EDMS Vault - Knoxville, WT CA - K

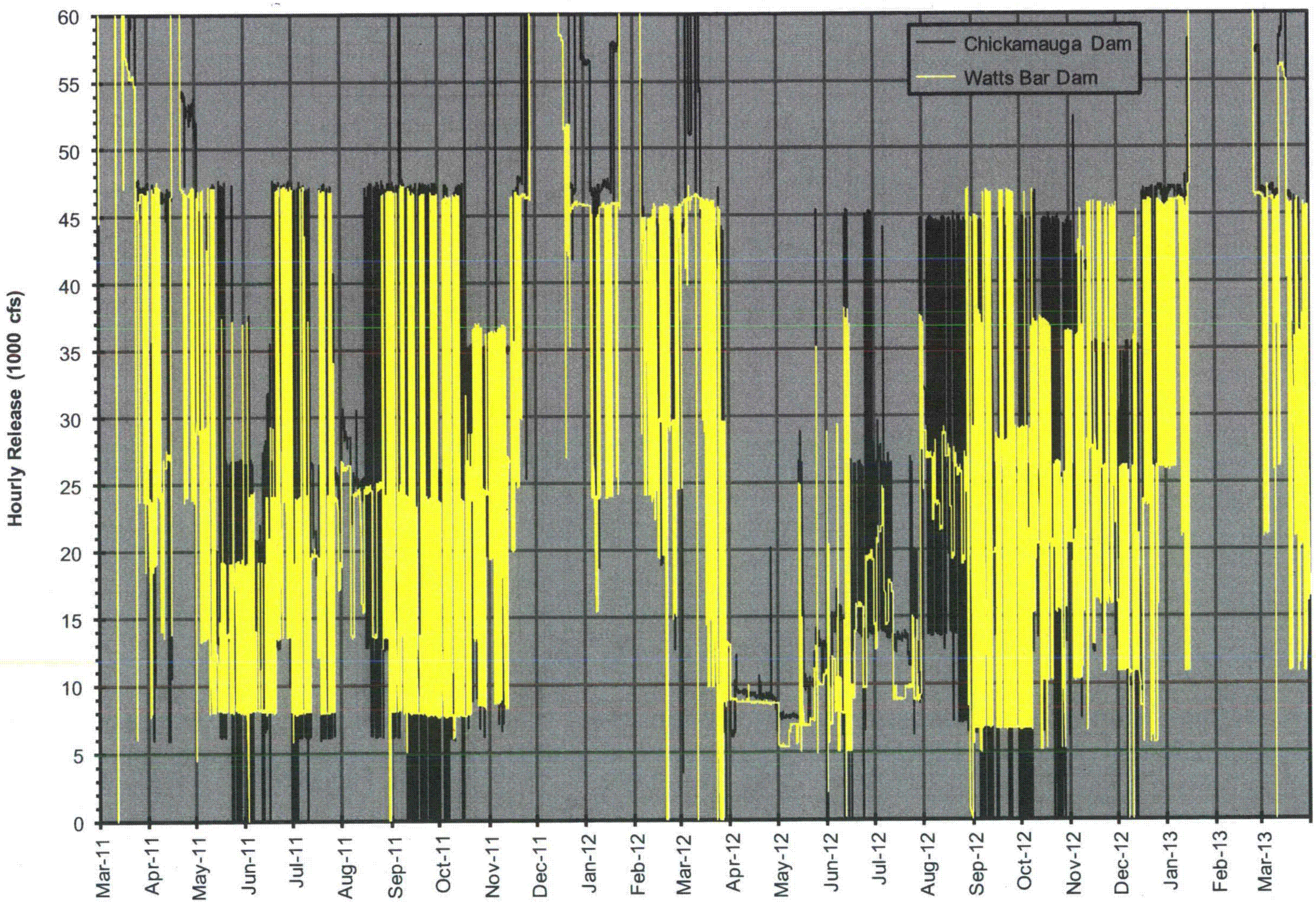
Attachment 1

Approximate Daily Average Flow Past SQN from March 1, 2011 through March 31, 2013



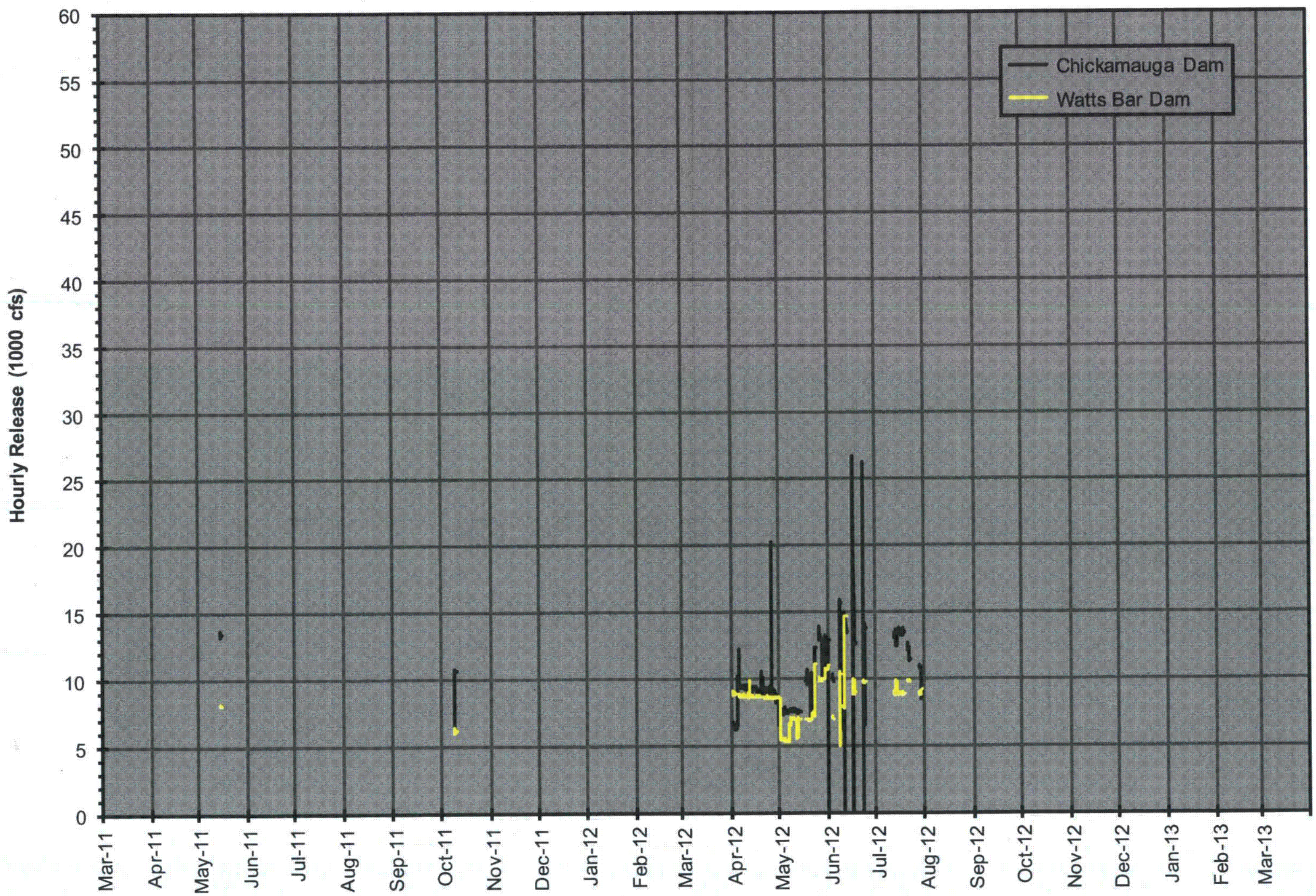
Attachment 2

Hourly Releases from Chickamauga Dam and Watts Bar Dam from March 1, 2011 through March 31, 2013



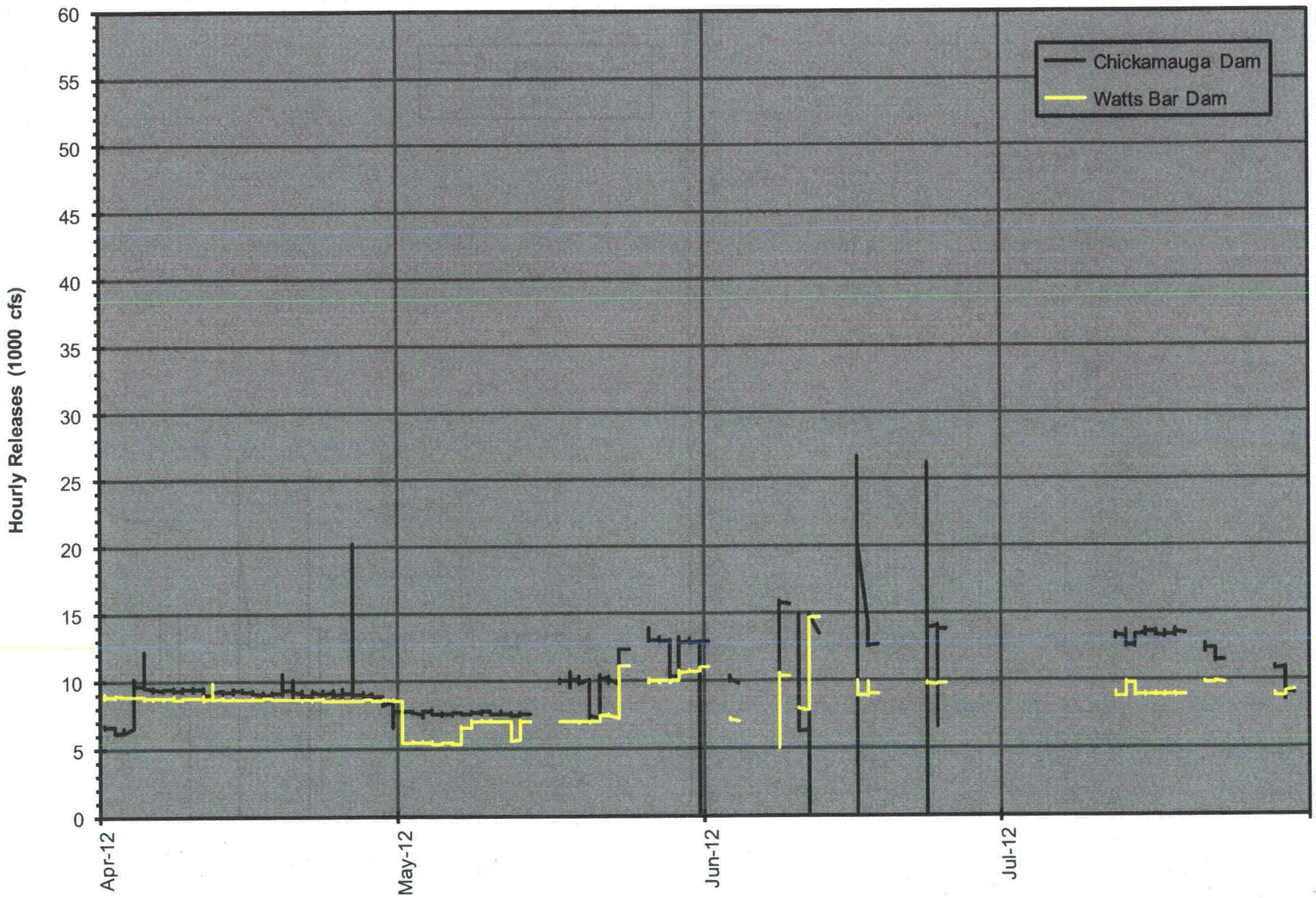
Attachment 3

Hourly Releases from Chickamauga Dam and Watts Bar Dam for Periods Requiring Special Hydro Operations for SQN



Attachment 4

Hourly Releases from Chickamauga Dam and Watts Bar Dam for Periods Requiring Special Hydro Operations for SQN, April 2012 through July 2012



March 5, 2013

Bradley M. Love, OPS 5N-SQN

SEQUOYAH NUCLEAR PLANT UPDATE OF FLOWRATE CHARACTERISTICS THROUGH THE DIFFUSERS

Part III, Section G of the current Sequoyah Nuclear Plant (SQN) National Pollutant Discharge Elimination System (NPDES) permit states that: *"The permittee shall calibrate the flowrate characteristics through the diffusers on a schedule of at least once every two years."* In fulfillment of this requirement, a test of the flowrate characteristics through the diffusers was conducted on November 16, 2012. Plant conditions for the test included the operation of three Condenser Cooling Water pumps and three Essential Raw Cooling Water pumps. In the test, the flowrate through the diffusers was determined based on measurements of water velocities in the diffuser pond using an acoustic doppler current profiler. Measurements for the diffuser head were made using the stage recorders belonging to the SQN Environmental Data Station. All instruments were certified prior to the test.

The results of the measurements, which include a summary of all tests since 1986, are provided in Attachment 1. The rating curve for computing the diffuser flowrate has been updated based on the new information and is provided in Attachment 2. With the updated curve, the root-mean-square error between the computed and measured diffuser flowrates is about 6.5 percent. This error falls within the ±10 percent standard given by the NPDES inspection manual and demonstrates that the hydraulic characteristics of the diffusers continue to provide a good method to estimate the discharge from SQN to the Tennessee River. The updated rating curve will be incorporated into the compliance model for Outfall 101.

If you have any questions regarding this work, please call me at (423) 632-2881.

Paul N. Hopping
Technical Specialist
River Scheduling
WT 10B-K

PNH:JGP
Attachments
cc (Attachments):
Matthew T. Boyington, WT 10B-K
Kelie H. Hammond, WT 10C-K
Gary D. Lucas, WT 10B-K
Travis R. Markum, BR 4A-C
Robert D. Stone, MP 5G-C
EDMS, WT 10C-K

Attachment 1

Calibration Data for SQN Diffuser Discharge, 1986 – 2012

Test Date	Number Of Pumps		Field Measurements				
			Discharge Measurement Method [(A)]	Water Surface Elevation [(B)]		Diffuser Head H	Diffuser Discharge Q
				Diffuser Pond	River		
	CCW	ERCW		(feet MSL)	(feet MSL)	(feet)	(cfs)
12/18/1986	2	4	MM	678.03	677.00	1.03	889
12/17/1986	3	4	MM	678.46	676.90	1.56	1,297
12/18/1986	4	4	MM	680.41	676.90	3.51	1,686
12/19/1986	6	4	MM	683.53	677.17	6.36	2,490
03/28/1989	5	4	MM	680.80	676.46	4.34	2,015
03/29/1989	5	4	MM	680.82	676.35	4.47	2,161
03/22/1990	2	3	MM	678.44	677.27	1.17	943
04/05/1990	3	4	MM	680.57	678.54	2.03	1,470
10/05/1990	3	4	MM	682.30	680.20	2.10	1,457
12/19/1990	6	4	MM	682.54	676.26	6.28	2,350
04/03/1991	6	4	MM	684.20	678.18	6.02	2,511
05/22/1991	6	4	MM	688.70	682.60	6.10	2,451
12/10/1991	5	4	MM	682.70	677.90	4.80	2,213
04/10/1992	2	3	MM	680.13	679.12	1.01	879
02/18/1994 [(C)]	2	3	MM	679.42	678.13	1.29	871
06/14/1994	6	4	MM	688.50	682.00	6.50	2,507
04/03/1997 [(D)]	3	3	MM	679.50	677.30	2.20	1,223
05/23/1997	6	3	MM	688.40	681.80	6.60	2,551
05/06/1998	6	3	ADCP	688.20	681.70	6.50	2,345
05/11/1999	6	3	ADCP	689.20	682.60	6.60	2,274
10/10/2001	6	3	ADCP	687.10	680.30	6.80	2,359
07/272002	6	4	ADCP	689.40	682.40	7.00	2,759
04/23/2003 [(E)]	3	4	ADCP	684.05	682.20	1.85	1,552
03/07/2006	6	3	ADCP	682.06	675.97	6.09	2,511
11/04/2007	3	4	ADCP	680.88	678.66	2.22	1,291
11/17/2009	3	3	ADCP	679.71	677.67	2.04	1350
12/17/2009	6	3	ADCP	683.29	677.15	6.14	2354
01/03/2011	6	3	ADCP	686.08	678.90	7.18	2360
11/16/2012	3	3	ADCP	681.08	678.62	2.46	1299

Notes:

(A) MM=Marsh-McBirney instrumentation. ADCP=Acoustic Doppler Current Profiler instrumentation.

(B) Water surface elevations for the diffuser pond and river recorded by instrumentation of the SQN Environmental Data Station. MSL=Mean Sea Level.

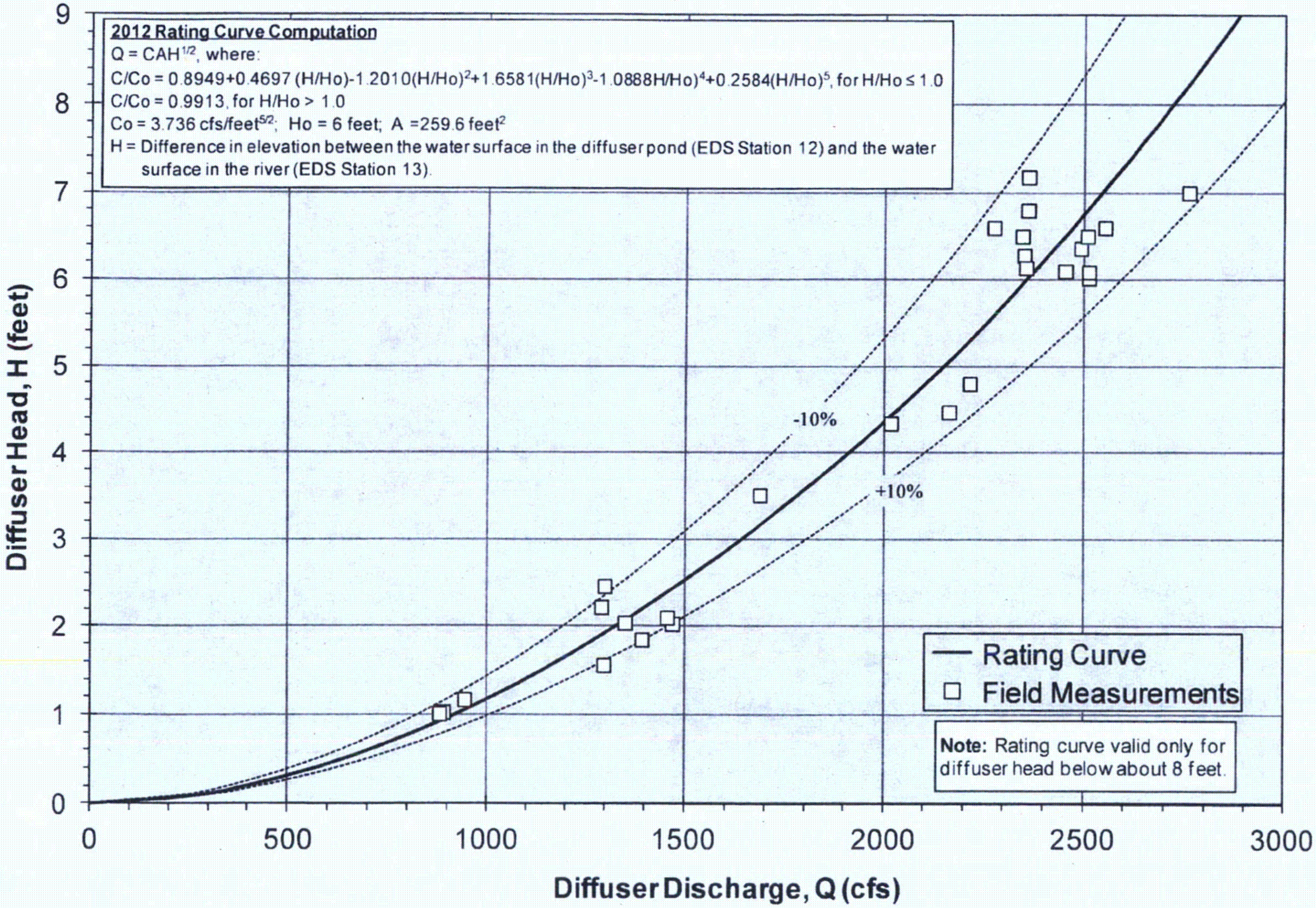
(C) The test of 02/18/94 was performed with very windy conditions, making it difficult to keep the boat steady. Due to the potential error introduced by these conditions, the resulting measurement was not used to determine the head-discharge relationship for the diffuser discharge.

(D) The test of 04/03/97 included a malfunction of the Marsh-McBirney compass, which prohibited the collection of data for flow direction. The diffuser discharge is based on an assumed flow direction. Due to the potential error introduced by these conditions, the resulting measurement was not used to determine the head-discharge relationship for the diffuser discharge.

(E) The test of 04/23/03 was performed with an ADCP setting that likely overestimated the volume of water passing through the diffuser pond. The resulting discharge significantly exceeded the capacity of pumps in service at the time. Due to the potential error introduced by these conditions, the resulting measurement was not used to determine the head-discharge relationship for the diffuser discharge.

Attachment 2

Rating Curve for SQN Diffuser Discharge



TENNESSEE VALLEY AUTHORITY
River Operations & Renewable

Study to Confirm the Calibration of the Numerical Model for the Thermal Discharge from Sequoyah Nuclear Plant as Required by NPDES Permit No. TN0026450 of March 2011

WR2013-1-45-152

Prepared by

T. Matthew Boyington
Paul N. Hopping
Walter L. Harper

Knoxville, Tennessee

April 2013

EXECUTIVE SUMMARY

The National Pollutant Discharge Elimination System (NPDES) permit for Sequoyah Nuclear Plant (SQN) identifies the release of cooling water to the Tennessee River through the plant discharge diffusers as Outfall 101. The primary method to monitor compliance with the NPDES temperature limits for this outfall includes the use of a numerical model that solves a set of governing equations for the hydrothermal conditions produced in the river by the interaction of the SQN release and the river discharge. The numerical model operates in real-time and utilizes a combination of measured and computed values for the temperature, flow, and stage in the river; and the temperature and flow from the SQN discharge diffusers. Part III, Section G of the permit states: *The numerical model used to determine compliance with the temperature requirements for Outfall 101 shall be subject of a calibration study once during the permit cycle. The study should be accomplished in time for data to be available for the next permit application for re-issuance of the permit. A report of the study will be presented to the division of Water Pollution Control.* This report is provided in fulfillment of these requirements.

The basic formulation of the numerical model is presented herein. Three empirical parameters are used to calibrate the model. The first is the effective width of the diffuser slot, and the second is a relationship used to compute the entrainment of ambient water along the trajectory of the plume. The third parameter is a relationship for the amount of diffuser effluent that is re-entrained into the diffuser plume for periods of sustained low river flow.

Temperature measurements across the downstream end of the SQN mixing zone from fifty samples collected between 1982 and 2012 were used in this calibration study. These observed data were compared with computed downstream temperatures from the numerical model for the same periods of time. In this process, sensitivity tests were performed for the effective diffuser slot width, entrainment relationship, and plume re-entrainment function. The results show acceptable agreement between computed and measured temperatures, particularly at river temperatures greater than 75°F. The overall average discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy was about 0.38 F° (0.21 C°). There was no significant change in the model performance compared to the previous calibration, and as a result, no update was required in the model parameter set.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Sequoyah Nuclear Plant (SQN) is located on the right bank of Chickamauga Reservoir at Tennessee River Mile (TRM) 484.5. As shown in Figure 1, the plant is northeast of Chattanooga, Tennessee, about 13.5 miles upstream and 45.4 miles downstream of Chickamauga Dam and Watts Bar Dam, respectively. As shown in Figure 2, the reservoir in the vicinity of SQN contains a deep main channel with adjacent overbanks and embayments. The main channel is approximately 900 feet wide and 50 to 60 feet deep, depending on the pool elevation in Chickamauga Reservoir. The overbanks are highly irregular and usually less than 20 feet deep.

SQN has two units with a total summertime gross generating capacity of about 2350 MWe and an associated waste heat load of about 15.6×10^9 Btu/hr (TVA, 2010). The heat transferred from the steam condensers to the cooling water is dissipated to the atmosphere by two natural draft cooling towers, to the river by a two-leg submerged multiport diffuser, or by a combination of both. The release to the river is identified in the National Pollutant Discharge Elimination System (NPDES) Permit as Outfall 101.

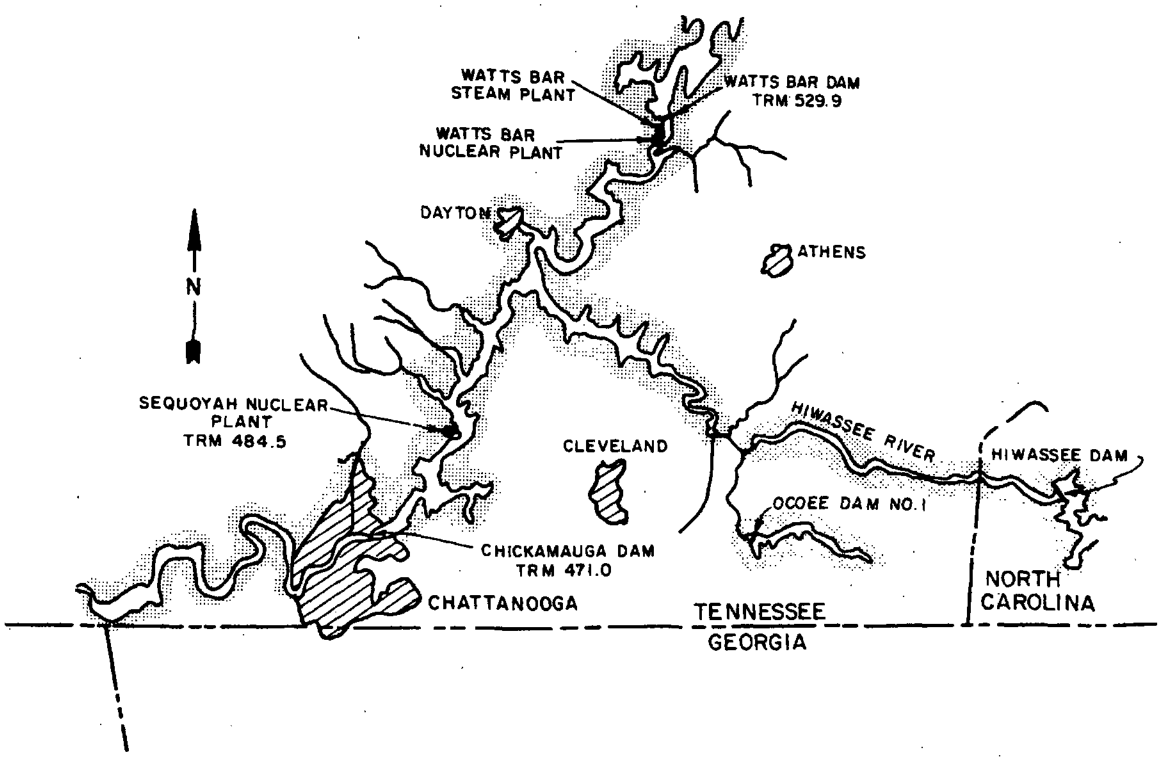


Figure 1. Location of Sequoyah Nuclear Plant

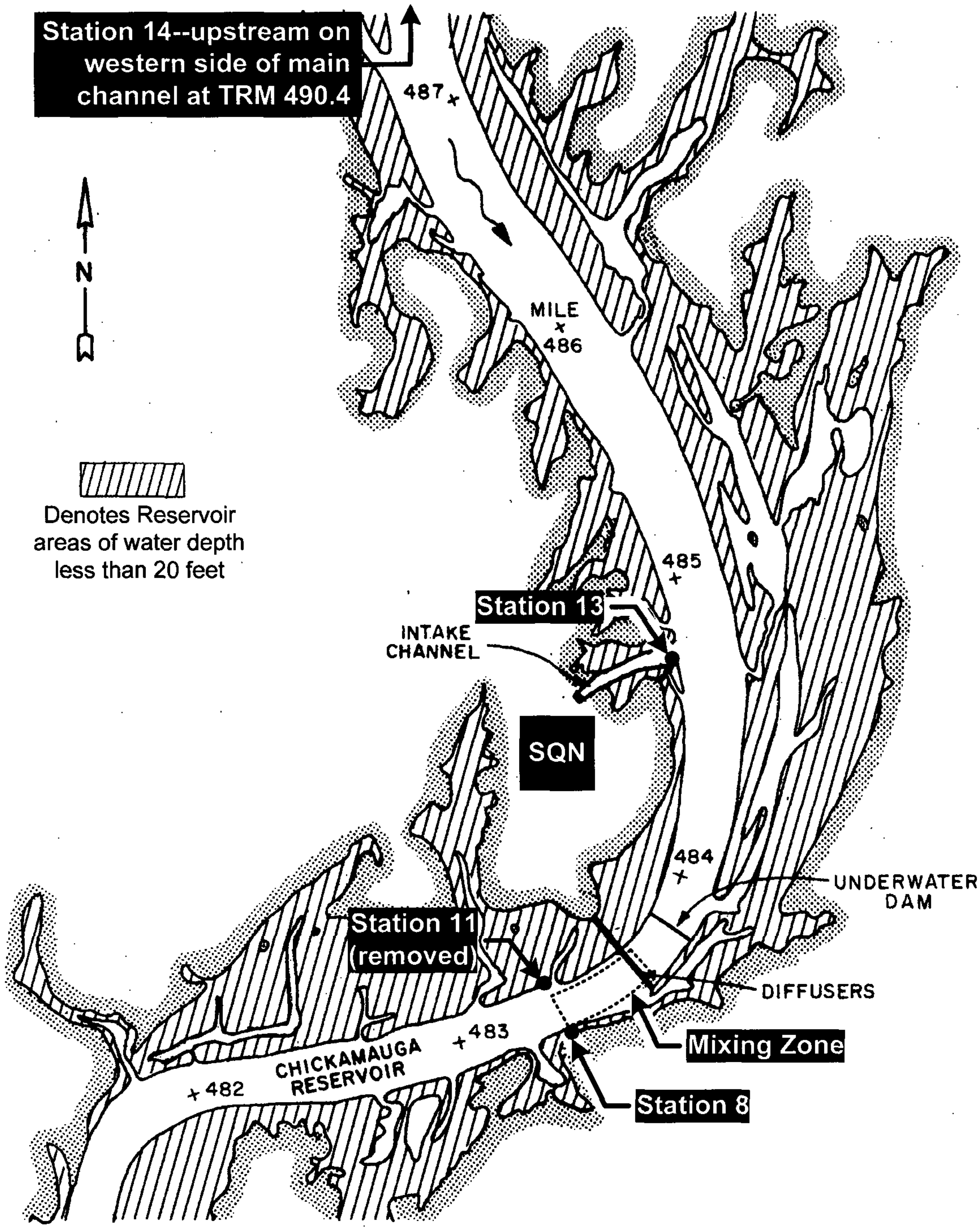


Figure 2. Chickamauga Reservoir in the Vicinity of Sequoyah Nuclear Plant

The compliance of SQN operation with the instream temperature limits specified in the NPDES permit (TDEC, 2011) is based on a downstream temperature that is calculated on a real-time basis by a numerical computer model. Part III, Section G of the permit states:

> *The numerical model used to determine compliance with the temperature requirements for Outfall 101 shall be subject of a calibration study once during the permit cycle. The study should be accomplished in time for data to be available for the next permit application for re-issuance of the permit. A report of the study will be presented to the Division of Water Pollution Control. Any adjustments to the numerical model to improve its accuracy will not need separate approval from the Division of Water Pollution Control; however, the Division will be notified when such adjustments are made.*

This report presents a summary of compliance model and the required calibration study.

BACKGROUND

The original method of monitoring thermal compliance for the SQN diffuser discharge (i.e., Outfall 101), included two temperature stations located near the downstream corners of the mixing zone, Station 8 and Station 11 (see Figure 2). Because of the necessity to keep the navigation channel free of obstructions, temperature stations could not be situated between these locations to monitor the center of the thermal plume. The upstream ambient river temperature was measured at Station 13, located on the plant intake skimmer wall. In August 1983, the Tennessee Valley Authority (TVA) reported the results of six field studies of the SQN diffuser performance under various river and plant operating conditions (TVA, 1983a). The data summarized in the report showed that based on measured temperature variations across the downstream edge of the mixing zone, Station 8 and Station 11 were inadequate in providing a representative cross-sectional average temperature of the thermal plume. In particular, it was found that Station 11 often was not in the main path of flow of the thermal plume and did not always show elevated temperatures. The remaining downstream monitor, Station 8, also was not considered adequate because it again was located outside the navigation channel. In the report, TVA proposed an alternate method to monitor thermal compliance involving the use of a numerical model to simulate the behavior of the thermal plume in the mixing zone. The model would provide a real-time assessment of compliance with the thermal discharge limitations. Information required for the model included: the ambient river temperature upstream of the diffuser mixing zone (measured at Station 13, see Figure 2), the discharge in the river at SQN (determined from measurements at Watts Bar Dam and Chickamauga Dam), the depth of flow in the river (measured at Station 13), the temperature of the flow issuing from the plant diffusers (measured at Station 12, see Figure 2), and the discharge of the flow issuing from the diffusers (determined from measurements at both Station 12 and Station 13). A PC, located in the SQN Environmental Data Station (EDS), was to be used collect the required data, compute the thermal compliance parameters, and distribute the results to plant operators (see TVA, 1983b). The August 1983 report presented results demonstrating the validity of using the numerical model for tracking compliance with the Outfall 101 thermal limitations.

The method of using the numerical model was sent to the Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC), requesting approval for implementation as a valid means for monitoring SQN thermal compliance. The key advantage of the method includes a representation of the cross-sectional average downstream temperature that is at least as good as the instream temperature measurements from Station 8 and Station 11. The method also provides consistency with procedures that are used for scheduling releases from Watts Bar Dam and Chickamauga Dam, as well as procedures for operating Sequoyah Nuclear Plant. This consistency helps TVA minimize unexpected events that can potentially threaten the NPDES thermal limits for Outfall 101. In March 1984 approval was granted for TVA to use the numerical model as the primary method to track thermal compliance. Except for infrequent outages, the model has been in use ever since. Subsequently, Station 11 was removed from the river. However, Station 8 was retained to provide an optional method to track thermal compliance should there be a need to remove the model from service.

Due to the ever changing understanding of the hydrothermal aspects of Chickamauga Reservoir, as well as the operational aspects of the nuclear plant and river system, modifications have been necessary over the years for both the numerical model and thermal criteria for Outfall 101. The current version of the model is presented in more detail later. The current thermal criteria are presented in Table 1. The limit for the temperature at the downstream end of the mixing zone (T_d) is a 24-hour average value of 86.9°F (30.5°C) and an hourly average value of 93.0°F (33.9°C). The instream temperature rise (ΔT) is limited to a 24-hour average of 5.4 F° (3.0 C°) for months April through October, and 9.0 F° (5.0 C°) for months November through March. The latter "wintertime" limit was obtained by a 316(a) variance. The temperature rate-of-change at the downstream end of the mixing zone (dT_d/dt) is limited to ±3.6 F°/hr (±2 C°/hr). With the compliance model, dT_d/dt is based on 24-hour average river conditions and 15 minute plant conditions. Other details related to the temperature limits for Outfall 101 are provided in the notes accompanying Table 1. It is important to note that compliance with instream temperature limits are based on a computed downstream temperature at a depth of 5.0 feet. And in a similar fashion, the upstream temperature is measured at the 5.0 foot depth, based on the average of temperature readings at the 3-foot, 5-foot and 7-foor depths.

Originally, the ambient river temperature for the temperature rise was measured at Station 13, about 1.1 miles upstream of the discharge diffusers. However, under sustained low flow conditions, it was discovered that heat from the diffusers can migrate upstream and reach the area of Station 13. In this manner, the ambient temperature can become elevated, thereby artificially reducing the measured impact of the plant on the river (i.e., ΔT). As such, in late March 2006, a new ambient temperature station was installed in the river further upstream at TRM 490.4, about 6.8 miles upstream of the diffusers. The location of the new monitor, entitled Station 14, is shown in Figure 3.

Table 1. Summary of SQN Instream Thermal Limits for Outfall 101

Type of Limit	Averaging (hours)	NPDES Limit[2]
Max Downstream Temperature, T_d	24	86.9°F (30.5°C)
Max Downstream Temperature, T_d	1	93.0°F (33.9°C)
Max Temperature Rise, ΔT	24	5.4 F°/9.0 F° (3.0 C°/5.0 C°)
Max Temperature Rate-of-Change, dT_d/dt	Mixed	±3.6 F°/hr (±2 C°/hr)

Notes:

1. Compliance with the river limitations (river temperature, temperature rise, and rate of temperature change) shall be monitored by means of a numerical model that solves the thermohydrodynamic equations governing the flow and thermal conditions in the reservoir. This numerical model will utilize measured values of the upstream temperature profile and river stage; flow, temperature and performance characteristics of the diffuser discharge; and river flow as determined from releases at the Watts Bar and Chickamauga Dams. In the event that the modeling system described here is out of service, an alternate method will be employed to measure water temperatures at least one time per day and verify compliance of the maximum river temperature and maximum temperature rise. Depth average measurements can be taken at a downstream backup temperature monitor at the downstream end of the diffuser mixing zone (left bank Tennessee River mile 483.4) or by grab sampling from boats. Boat sampling will include average 5-foot depth measurements (average of 3, 5, and 7-foot depths). Sampling from a boat shall be made outside the skimmer wall (ambient temperature) and at quarter points and mid-channel at downstream Tennessee River mile 483.4 (downstream temperature). The downstream reported value will be a depth (3, 5, and 7-foot) and lateral (quarter points and midpoint) average of the instream measurements. Monitoring in the alternative mode using boat sampling shall not be required when unsafe boating conditions occur.
2. Compliance with river temperature, temperature rise, and rate of temperature change limitations shall be applicable at the edge of a mixing zone which shall not exceed the following dimensions: (1) a maximum length of 1500 feet downstream of the diffusers, (2) a maximum width of 750 feet, and (3) a maximum length of 275 feet upstream of the diffusers. The depth of the mixing zone measured from the surface varies linearly from the surface 275 feet upstream of the diffusers to the top of the diffuser pipes and extends to the bottom downstream of the diffusers. When the plant is operated in closed mode, the mixing zone shall also include the area of the intake forebay.
3. Information required by the numerical model and evaluations for the river temperature, temperature rise, and rate of temperature change shall be made every 15 minutes. The ambient temperature shall be determined at the 5-foot depth as the average of measurements at depths 3 feet, 5 feet, and 7 feet. The river temperature at the downstream end of the mixing zone shall be determined as that computed by the numerical model at a depth of 5 feet.
4. Daily maximum temperatures for the ambient temperature, the river temperature at the downstream edge of the mixing zone, and temperature rise shall be determined from 24-hour average values. The 24-hour average values shall be calculated every 15 minutes using the current and previous ninety-six 15-minute values, thus creating a 'rolling' average. The maximum of the ninety-six observations generated per day by this procedure shall be reported as the daily maximum value. For the river temperature at the downstream end of the mixing zone, the 1-hour average shall also be determined. The 1-hour average values shall be calculated every 15 minutes using the average of the current and previous four 15-minute values, again creating a rolling average.
5. The daily maximum 24-hour average river temperature is limited to 86.9°F (30.5°C). Since the state's criteria makes exception for exceeding the value as a result of natural conditions, when the 24-hour average ambient temperature exceeds 84.9°F (29.4°C) and the plant is operated in helper mode, the maximum temperature may exceed 86.9°F (30.5°C). In no case shall the plant discharge cause the 1-hour average downstream river temperature at the downstream of the mixing zone to exceed 93.0°F (33.9°C) without the consent of the permitting authority.
6. The temperature rise is the difference between the 24-hour average ambient river temperature measured at Station 14 and the computed 24-hour average temperature at the downstream end of the mixing zone. The 24-hour average temperature rise shall be limited to 5.4F° (3.0 C°) during the months of April through October. The 24-hour average temperature rise shall be limited to 9.0F° (5.0 C°) during the months of November through March.
7. The rate of temperature change shall be computed at 15-minute intervals based on the current 24-hour average ambient river temperature, current 24-hour-hour average river flow, and current values of the flow and temperature of water discharging through the diffuser pipes. The 1-hour average rate of temperature change shall be calculated every 15-minutes by averaging the current and previous four 15-minute values. The 1-hour average rate of temperature change shall be limited to 3.6F° (2 C°) per hour.

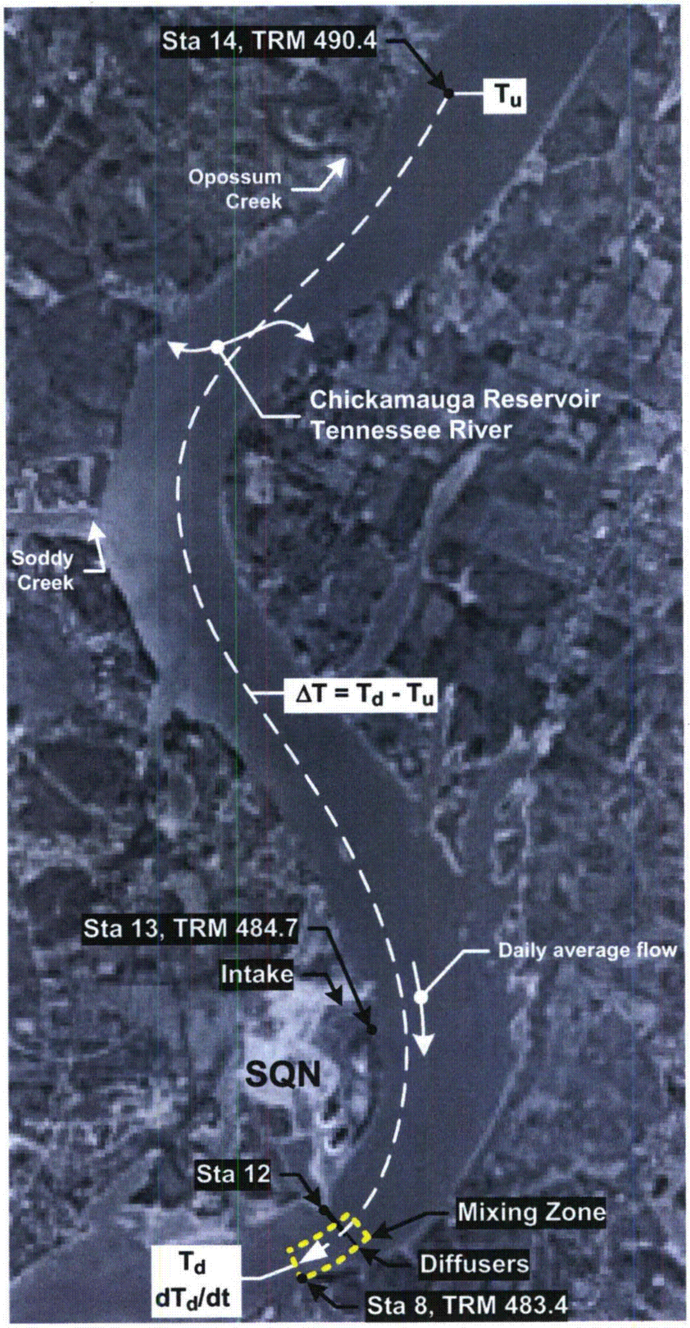


Figure 3. Locations of Instream Temperature Monitors for Sequoyah Nuclear Plant

NUMERICAL MODEL

The diffusers at SQN are located on the bottom of the navigation channel in Chickamauga Reservoir. As shown in Figure 4, each diffuser is 350 feet long, and contains seventeen 2-inch diameter ports per linear foot of pipe, arranged in rows over an arc of approximately 18 degrees in the downstream upper quadrant of the diffuser conduit. The two diffuser legs rest on an elevated pad approximately 10 feet above the bottom of the river, occupying the 700 feet of navigation channel on the plant-side of the river (right side of the channel, looking downstream). The flow in the immediate vicinity of the ports is far too complex to be analyzed on a real-time basis with current computer technology. Therefore, a simplifying assumption is made that the diffusers can be treated as a slot jet with a length equal to that of the perforated sections of the pipe. The width of this assumed slot is one of three empirical parameters used to calibrate the model. The second is a relationship used to compute the entrainment of ambient water along the trajectory of the plume and the third is a relationship for the amount of diffuser effluent that is re-entrained into the diffuser plume for sustained low river flow.

The initial development of the numerical model is described in detail by Benton (2003). Based on later studies that provided evidence that re-entrainment occurs (TVA, 2009), the original numerical model was modified to better reflect the local buildup of heat that occurs in the river under such conditions. Before presenting calibration results, it is appropriate first to provide a brief description of the model formulation.

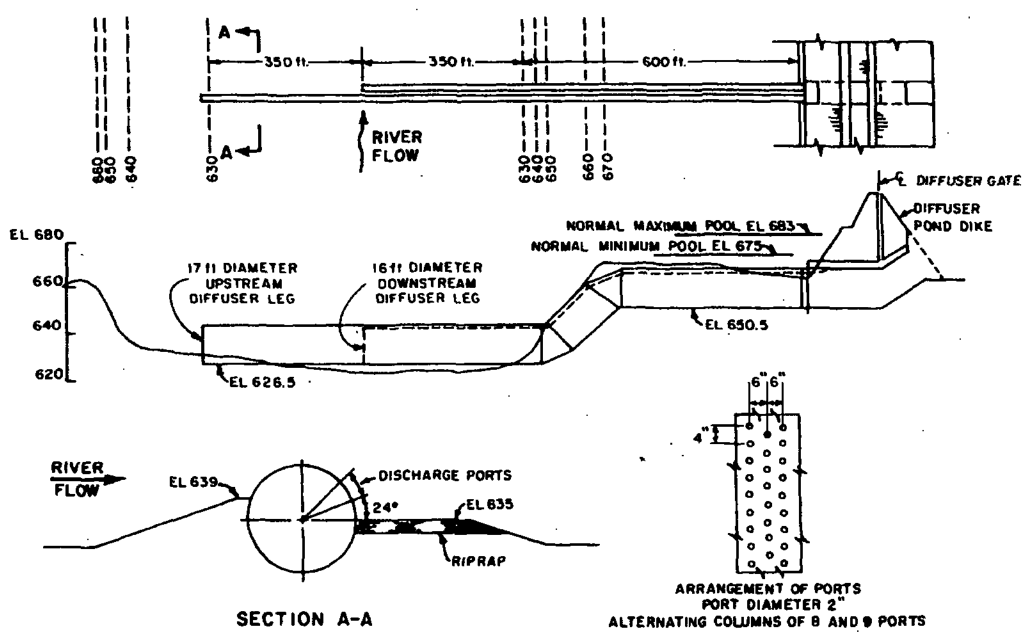


Figure 4. Sequoyah Nuclear Plant Outfall 101 Discharge Diffusers

In general, the model treats the effluent discharge from the diffusers as a fully mixed, plane buoyant jet with a two-dimensional (vertical and longitudinal) trajectory. This is shown schematically in Figure 5. The jet discharges into a temperature-stratified, uniform-velocity flow and entrains ambient fluid as it evolves along its trajectory. The width, *b*, of the jet and the dilution of the effluent heat energy increase along the jet trajectory, decreasing the bulk mixed temperature along its path.

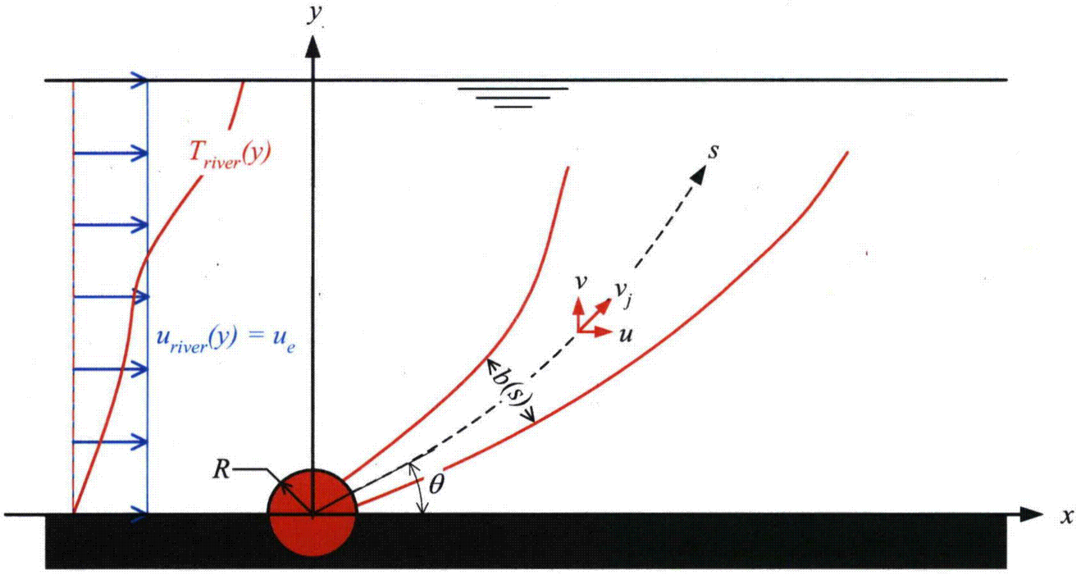


Figure 5. Two-Dimensional Plane Buoyant Jet Model for a Submerged Diffuser

Consideration of the mass, momentum, and energy for a cross section of the plume orthogonal to the jet trajectory and having a differential thickness *ds,* yields the following system of ordinary differential equations,

$$\frac{d}{ds}(\rho_j v_j b) = m_e \text{ (conservation of mass in jet),} \tag{1}$$

$$\frac{d}{ds}(\rho_j v_j bu) = m_e u_e \text{ (conservation of x momentum in jet),} \tag{2}$$

$$\frac{d}{ds}(\rho_j v_j bv) = m_e v_e + bg(\rho_e - \rho_j) \text{ (conservation of y momentum in jet),} \tag{3}$$

$$\frac{d}{ds}(\rho_j v_j bcT_j) = m_e cT_e \text{ (conservation of thermal energy in jet),} \tag{4}$$

$$\frac{dx}{ds} = \frac{u}{v_j}\text{, and} \tag{5}$$

$$\frac{dy}{ds} = \frac{v}{v_j}\text{, (velocity of jet tangent to trajectory).} \tag{6}$$

The following auxiliary relationships also are needed to solve the differential equations,

$$m_e = \alpha\rho_e\left[(u_e - u)^2 + v^2\right]^{1/2}, \tag{7}$$

$$\rho_j = \rho_{water}(T_j), \tag{8}$$

$$\rho_e = \rho_{water}(T_e), \tag{9}$$

$$T_e = T_{river}(y), \tag{10}$$

$$u_e = u_{river}, \tag{11}$$

$$v_e = 0\text{, and} \tag{12}$$

$$v_j = \left(u^2 + v^2\right)^{1/2}. \tag{13}$$

In these equations, the subscripts *j* and *e* denote conditions within the buoyant *jet* and conditions within the water upstream of the mixing zone that is *entrained* by the jet, respectively. Thus, ρ_j denotes the density of water at a point inside the jet and ρ_e denotes the density of water entrained from upstream of the mixing zone. T_e denotes the temperature of the water upstream of the mixing zone that is entrained by the jet. The x-velocity of the entrained water, u_e, is the same as the river velocity, u_{river}, which is negligible in the vertical direction (i.e., $v_e = 0$). The magnitude of the velocity along the jet trajectory is denoted by v_j, with x- and y-components u and v, respectively. The individual jets issuing from the array of 2-inch diameter outlet ports of each diffuser are modeled as a plane jet issuing from a slot of width b_0. Ideally, the slot width is chosen to preserve the total momentum flux issuing from the circular ports of the diffuser. However, as indicated earlier, for this formulation, the slot width is used as a term to calibrate the numerical model. The river velocity u_{river} *is* computed by a one-dimensional unsteady flow model of Chickamauga Reservoir. Apart from information for the reservoir geometry, the basic input for the flow model includes the measured hydro releases at Watts Bar Dam and Chickamauga Hydro Dam and the measured river water surface elevation at SQN.

The transverse gradients of velocity, temperature, and density that occur within the jet due to turbulent diffusion of the effluent momentum and energy are modeled as an entrainment mass flux, m_e, induced by the vectorial difference between the velocity of the jet and that of the river flow upstream of the mixing zone. Empirical relationships for the entrainment coefficient α are based on arguments of jet self-similarity and asymptotic behavior. These relationships incorporate non-dimensional parameters, such as a Richardson or densimetric Froude number, that describe the relative strengths of buoyancy and momentum flux in the jet (e.g., see Fischer et al., 1979). Again, as indicated earlier, the entrainment coefficient, like the slot width, is adjusted as part of the calibration process.

The initial conditions required by the model include,

$$b\big|_{s=s_0} = b_0\,, \tag{14}$$

$$x\big|_{s=s_0} = R\cos\theta\,, \tag{15}$$

$$y\big|_{s=s_0} = R\sin\theta\,, \tag{16}$$

$$u\big|_{s=s_0} = \frac{q_0}{b_0}\cos\theta\,, \tag{17}$$

$$v\big|_{s=s_0} = \frac{q_0}{b_0}\sin\theta\,, \text{ and} \tag{18}$$

$$T_j\big|_{s=s_0} = T_0\,. \tag{19}$$

This system of differential equations, auxiliary equations, and initial conditions comprise a first-order, initial-value problem that can be integrated from the diffuser slot outlet ($s = s_0$) to any point along the plume trajectory. Note in the above that R is the radius of the diffuser conduit, b_0 is the effective width of the diffuser slot, θ is the exit angle of the diffuser jet, T_0 is the temperature of effluent issuing from the slot, and q_0 is the effluent discharge per unit length of diffuser. In practice, integration of the governing equations is halted when the jet centerline reaches a point five feet below the water surface (the regulatory compliance depth) or when the upper boundary of the jet reaches the water surface. The jet temperature, T_j, at this point is reported as the fully-mixed temperature to which the thermal regulatory criteria are applied or to which monitoring station data at the edge of the regulatory mixing zone are compared. The integration is done with an adaptive step-size, fourth-order Runge-Kutta algorithm.

In the model, Station 13 (Figure 2), located 1.1 miles upstream of the diffusers, is used to represent the temperature of the water entrained in the mixing zone, $T_e = T_{river}(y)$. Whereas this is a good assumption for river flows where the effluent plume is carried downstream, it weakens for low river flows. Based on the understanding gained in recent studies (TVA, 2009), it is known that partial re-entrainment of the effluent plume occurs at sustained low river flow, increasing the temperature of the water entering the mixing zone above that represented by Station 13. To simulate this phenomenon, the model modifies the Station 13 temperature profile for low river flows. For each point in the profile, a local densimetric Froude number is computed as

$$F_r = \frac{u_{river}}{\sqrt{g\left(\frac{\rho_e - \rho_p}{\rho_e}\right)(Z_e - Z_b)}}\,, \tag{20}$$

where u_{river} is the average river velocity, Z_e-Z_b is the elevation of the profile point relative to the bottom elevation of the river, ρ_e is the entrainment water density at that elevation, and ρ_p is the density of the effluent plume at the 5-foot compliance depth. The densimetric Froude number represents the ratio of momentum forces to buoyancy forces in the river flow. If F_r is less than 1.0 (i.e., buoyancy greater than momentum), it is assumed that the buoyancy of the plume is sufficient to cause part of the plume to travel upstream and become re-entrained into the flow, thereby increasing the temperature of the water entering the mixing zone. The modified entrainment temperature T_e^N at each point in the Station 13 profile is computed by repeatedly evaluating

$$T_e^n = R \times T_p + (1.0 - R) \times T_e^{n-1} \tag{21}$$

for values of n from 1 to N, where N is the number of iterations of Eq. (21), R is a re-entrainment fraction, $T_e^{n=0}$ is the original Station 13 temperature, and T_p is the computed plume temperature at the 5-foot depth. N and R are functions of the 24-hour average river velocity. After new Station 13 temperatures have been computed for the entire profile, the mixing zone computation is performed again, using the modified profile to get a new plume temperature at the 5-foot depth. It is emphasized that the final result of the model is the computed temperature at the downstream end of the mixing zone. The instream temperature rise is still computed based on the temperature measurement at the new ambient temperature monitor, Station 14.

Values for N and R are calibrated based on observed temperatures at the downstream end of the diffuser mixing zone for low river flow conditions, as indicated earlier. Depending on the river stage, the modifications by Equation 21 begin to take effect as the 24-hour average river flow drops through the range of 17,000 cfs to 25,000 cfs, and increases as the 24-hour average river flow continues to drop. For river flows above this range, no modification is needed for re-entrainment.

The downstream temperature and instream temperature rise provided by the model are computed every 15 minutes, using instantaneous values of the measured diffuser discharge temperature (Station 12), measured upstream temperature profile (Station 13), measured ambient temperature (Station 14), measured river elevation (Station 13), and computed values of the river velocity (one-dimensional unsteady flow model of Chickamauga Reservoir) and diffuser discharge. The diffuser discharge is computed based on the difference in water elevation between the SQN diffuser pond (Station 12) and the river (Station 13). All computations are performed every 15 minutes to provide rolling hourly and 24-hour average values. The hourly averages are based on the current and previous four 15-minute values, whereas the 24 hour averages are based on current and previous ninety-six 15-minute values. The temperature rate-of-change is determined slightly different, being computed every 15 minutes based on current 24-hour average river conditions and current 15-minute values of the flow and temperature of water discharging from the SQN diffusers. This method was adopted in August 2001 in order to distinguish between rate-of-change events due to changes in SQN operations (i.e. changes in plant discharge flow and/or temperature) and those due to non-SQN changes in operations (e.g., changes in river flow). Prior to this change, SQN was held accountable for temperature rate-of-change events over which it had very little control or influence.

Plume Entrainment

Two empirical relationships for the plume entrainment coefficient are available in the numerical model. The first, developed by McIntosh, was inferred from a relationship for the entrainment coefficient determined from the data reported in 1983 (TVA, 1983a) and is given by

$$\alpha = \begin{cases} 0.27 \;\; for\; F_d < 0.75 \\ \dfrac{0.27}{F_d^{2.5}} \; for\; 0.75 \le F_d \le 1.00, \\ 0.55 \; for\; F_d > 1.00 \end{cases} \tag{22}$$

where F_d is the densimetric Froude number of the diffuser discharge defined by

$$F_d = \frac{w_d}{\sqrt{g b_o \dfrac{(\rho_d - \rho_o)}{\rho_o}}}. \tag{23}$$

The term w_d is the velocity of the diffuser discharge, g is the gravitational constant, b_0 is the diffuser slot width, ρ_d is the density of the diffuser discharge, and ρ_o is the density of the ambient river water at the discharge depth.

The second entrainment coefficient, based on laboratory data, was originally developed by Benton in 1986 and is given by

$$\alpha = 0.31 + 1.69\left[\frac{1 + tanh(6.543 * rmf - 2.0584)}{2}\right], \tag{24}$$

where

$$rmf = u_{river}^3 / b, \tag{25}$$

and

$$b = Q_0\left(\frac{g}{l}\right)\left(\frac{\rho_o - \rho_d}{\rho_o}\right). \tag{26}$$

Term u_{river} is the ambient river velocity, as previously defined, Q_0 is the diffuser discharge flowrate, and l is the length of the ported section of the diffuser.

Diffuser Effluent Re-Entrainment

Partial re-entrainment of the diffuser plume is known to occur under conditions of low river flow. When the diffuser plume attempts to entrain an amount of ambient flow greater than what is available from further upstream, the upper portions of the plume tend to migrate upstream and plunge downward to be mixed with the flow in the lower portion of the river. The formulation to simulate this phenomenon was presented earlier (Eqs. 20 and 21). The unknown coefficients to be determined in the calibration process are the number of iterations N and re-entrainment fraction R in Eq. (21), which are functions of the 24-hour average river velocity.

CALIBRATION

The numerical model is calibrated to achieve the best match between computed downstream temperatures and field measurements at the downstream end of the mixing zone. Field measurements at the downstream end of the mixing zone are of two types—those including samples from field surveys across the entire width of the mixing zone and those from Station 8, which includes samples only at the left-hand corner of the mixing zone (e.g., see Figure 2). Higher priority is given to matching data from field surveys, since such measurements are made across the entire width of the plume mixing zone and are more representative of the average temperature in the thermal plume at the 5-foot compliance depth.

Previous Calibration Data and Calibration Work

Prior to the NPDES permit of March 2011, field surveys were performed in 1981, 1982, 1983, 1987, 1996, 1997, 1999, 2000, 2002, 2003, 2004, 2006, and 2007. In July 1981, TVA conducted the first field survey of the SQN thermal discharge (TVA, 1982). The results of the field surveys were compared to projections from modeling relationships developed from mixing theory and a physical model test of the discharge diffusers. Adequate agreement was achieved between measured data and model projections. In cases where there were discrepancies, the model under-predicted the observed dilutions (i.e., over-predicted temperatures).

Between April 1982 and March 1983, five field surveys containing seventeen sets of samples across the downstream end of the mixing zone were performed to acquire data for validation of the computed compliance technique (TVA, 1983a). The results of these surveys are given in Table 2. Only one SQN unit was operating during the March 1983 test—the other five tests were for operation with two units. The results of the numerical model compared favorably with the field-measured downstream temperatures. On average, the discrepancy between the measured and computed downstream temperatures was about 0.40 F° (0.22 C°). Since the accuracy of the temperature sensors used by TVA are only about ±0.25 F° (±0.14 C°), the agreement between the field measurements and the computer model was considered good. A similar comparison between the Station 8 and Station 11 temperatures and the measured average temperatures across the downstream edge of the mixing zone revealed that the discrepancy for Station 8 was about 0.79 F° (0.44 C°) and for Station 11 about 0.65 F° (0.36 C°). Consequently, it was concluded

that the numerical model is not only an accurate representation of the downstream temperature but also is likely superior to the monitoring approach using Station 8 and Station 11.

In September 1987, TVA released a report describing the field surveys in support of the validation and calibration of the SQN numerical model that had been performed up to that date (TVA, 1987). In the report, a chart was introduced that described the ambient and operational conditions for which field surveys had been performed. This chart indicated combinations of river flow, season, and number of operating units, showing what tests had been performed, and assigning relative priorities for tests to be performed in the future. With this guidance, six more field surveys were performed between March 1996 and April 2003, to measure downstream temperatures for various river flows and at different times of year. The results of these surveys produced ten sets of samples across the downstream end of the mixing zone, as given in Table 3.

Between 2004 and 2007 a number of additional field surveys were performed, providing twenty-three more sets of samples containing temperature measurements across the downstream end of the diffuser mixing for various river flows and at different times of the year. The results of these surveys are given in Table 4.

Table 2. Thermal Surveys at SQN from April 1982 through March 1983

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (°F)	T_d Measured (°F)	ΔT Measured (°F)
04/04/1982	0900 CST	19900	676.46	56.8	61.9	5.1
04/04/1982	1000 CST	19800	676.46	56.7	60.1	3.4
04/04/1982	1100 CST	19600	676.47	56.7	61.2	4.5
04/04/1982	1200 CST	19700	676.50	57.2	61.9	4.7
04/04/1982	1300 CST	19700	676.45	57.4	62.2	4.8
05/14/1982	0900 CDT	7200	682.43	74.5	71.8	-2.7
05/14/1982	1100 CDT	9100	682.40	73.4	71.8	-1.6
05/14/1982	1300 CDT	6300	682.42	72.1	73.6	1.5
09/02/1982	1400 CDT	38500	680.30	78.1	80.1	2.0
11/10/1982	1300 CST	36200	677.57	59.0	60.1	1.1
11/10/1982	1400 CST	31600	677.59	59.0	60.6	1.6
11/10/1982	1500 CST	32300	677.58	59.0	60.4	1.4
03/31/1983	1100 CST	9800	676.34	51.4	54.3	2.9
03/31/1983	1200 CST	9400	676.34	50.4	54.7	4.3
03/31/1983	1300 CST	9300	676.34	52.5	54.5	2.0
03/31/1983	1400 CST	9500	676.34	51.4	54.9	3.5
03/31/1983	1500 CST	9400	676.36	51.4	54.9	3.5

Table 3. Thermal Surveys at SQN from March 1996 through April 2003

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (°F)	T_d Measured (°F)	ΔT Measured (°F)
03/01/1996	1100 CST	42456	676.96	45.9	48.8	2.9
03/01/1996	1445 CST	28136	677.04	46.2	50.2	4.0
03/01/1996	1600 CST	21962	677.00	46.1	51.4	5.3
03/01/1996	1700 CST	20280	677.00	46.0	51.5	5.5
07/24/1997	1550 CDT	40441	682.57	83.5	84.7	1.2
03/24/1999*	1250 CST	35731	677.46	51.9	54.5	2.7
08/02/2000	1000 CDT	12472	682.20	82.1	85.1	3.0
08/02/2000	1100 CDT	8624	682.20	82.1	85.3	3.1
07/27/2002	1250 CDT	17231	682.37	84.0	86.6	2.6
04/23/2003	1445 CDT	34178	682.53	63.7	64.2	0.5

* The survey of 03/24/1999 is lacking valid upstream temperature data and was not used in the calibration.

Table 4. Thermal Surveys at SQN from February 2004 through November 2007

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (°F)	T_d Measured (°F)	ΔT Measured (°F)
02/14/2004	0600 CST	51133	677.50	43.7	46.3	2.6
02/22/2004	1800 CST	18468	678.40	45.8	50.5	4.7
08/22/2004	1800 CST	12340	682.00	79.8	84.1	4.3
08/23/2004	1800 CST	39238	682.20	79.8	82.4	2.6
04/01/2006	1915 CST	7084	677.20	59.7	63.5	3.8
04/04/2006	0015 CST	7996	677.70	59.3	63.9	4.6
04/04/2006	1105 CST	8251	677.80	59.6	61.3	1.7
04/04/2006	2030 CST	8258	678.00	59.0	63.2	4.2
04/05/2006	0915 CST	7917	678.20	59.2	62.8	3.6
04/05/2006	2215 CST	8277	678.40	60.4	64.2	3.8
04/06/2006	0915 CST	8174	678.50	59.7	63.3	3.6
04/06/2006	2315 CST	8077	678.70	61.0	64.5	3.5
04/07/2006	0840 CST	8162	678.80	59.9	63.9	4.0
04/07/2006	1435 CST	7889	678.80	60.0	64.7	4.7
05/22/2006	1445 CST	14511	682.00	73.4	72.9	-0.5
05/23/2006	1455 CST	17878	682.20	73.5	73.9	0.4
05/28/2006	1440 CST	13396	682.30	76.6	76.7	0.1
05/29/2006	1435 CST	13713	682.40	77.5	77.6	0.1
05/30/2006	1425 CST	14304	682.40	79.7	79.2	-0.5
09/20/2007	1200 CST	8545	681.80	79.3	83.4	4.1
09/21/2007	1300 CST	8629	681.70	80.6	82.5	1.9
09/22/2007	0600 CST	6969	681.70	79.5	81.8	2.3
11/04/2007	1200 CST	7664	678.70	64.9	69.5	4.6

The most recent calibration of the numerical model was performed in 2009 to support the NPDES permit of September 2005 (TVA, 2009). The data from Table 2, Table 3, and Table 4 were used in this calibration. The average overall discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy improved to about 0.38 F° (0.21 C°).

New Calibration Data and Calibration Work

Since the 2009 model calibration, an additional field study was performed in November 2012 (Table 5). The study included the operation of one unit at SQN and was conducted concurrently with independent measurements for the discharge through the diffusers (TVA, 2013). With this, altogether fifty data points with sets of temperature samples across the downstream end of the mixing zone were available for updating the model calibration (i.e., Table 2 through Table 5).

Table 5. Thermal Surveys at SQN from November 2012

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (°F)	T_d Measured (°F)	ΔT Measured (°F)
11/16/2012	1400 CST	12599	678.62	57.0	60.3	3.3

Diffuser Slot Width

The effective slot width for a multiport diffuser of the type at SQN can be assumed to fall somewhere between the width of a rectangle with length equal to that of the diffuser section and area equal to the total area of the ports; and the width a rectangle with length equal to that of the diffuser section and area equal to the arc length of the perforated section of the diffuser. For the SQN diffuser, this slot width would be between 0.37 feet and 2.67 feet. Multiple slot widths in this range were evaluated and compared with fifty measured data points from the field surveys (i.e., from Table 2 through Table 5). The results, given in Figure 6, show that larger slot widths yielded better agreement with the measured data. The nominal arc length of the perforated section of the diffuser (i.e., 2.67 feet) was selected as the best diffuser slot width to be used in the numerical model. This is the same value used in the 2009 model calibration.

Plume Entrainment Coefficient

Figure 7 shows the comparison with measured data of downstream temperatures computed with the McIntosh (Eq. 22) and Benton (Eq. 24) entrainment coefficients, again based on fifty data points from the field surveys in Table 2 through Table 5. Both entrainment coefficients result in relatively close matches with the measured data. Although the McIntosh coefficient seems to perform better at low ambient river temperatures, temperatures computed using the Benton coefficient more closely match measured downstream temperatures at higher river temperatures.

Since the accuracy of the computation is more critical at temperatures approaching the NPDES limit for downstream temperature, the Benton coefficient, Eq. (24) is used in the compliance model.

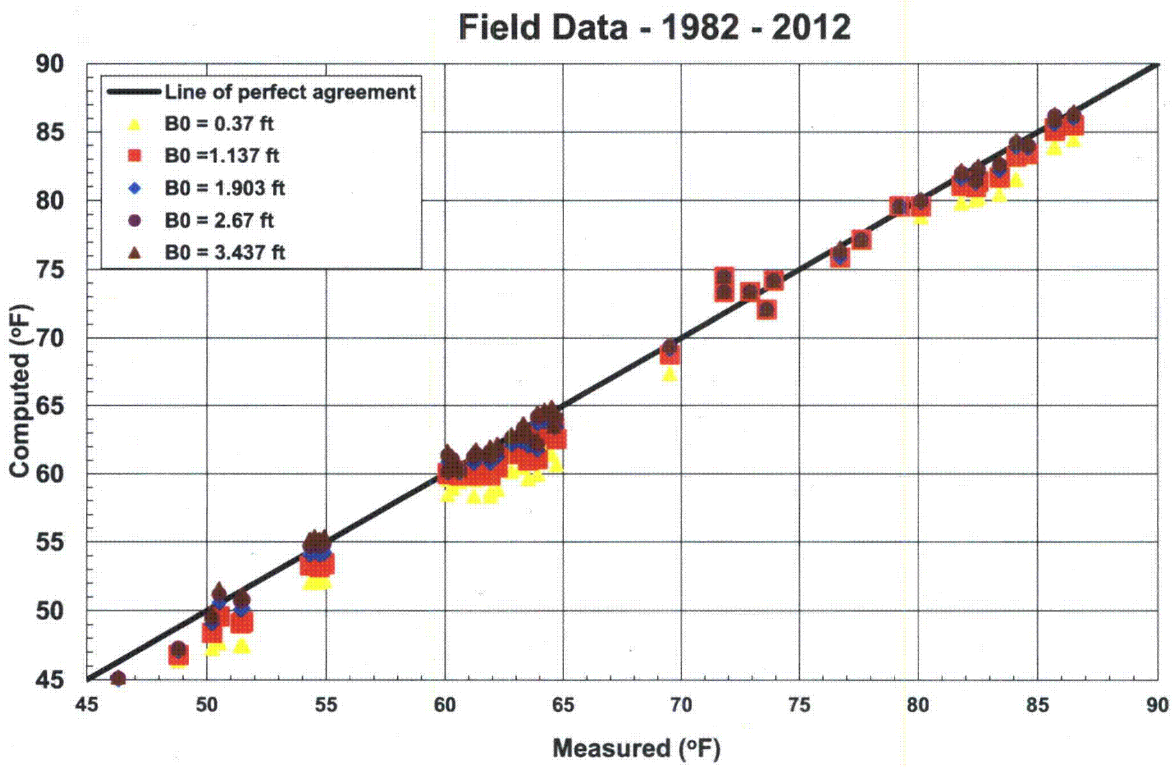


Figure 6. Sensitivity of Computed Temperature T_d to Diffuser Effective Slot Width

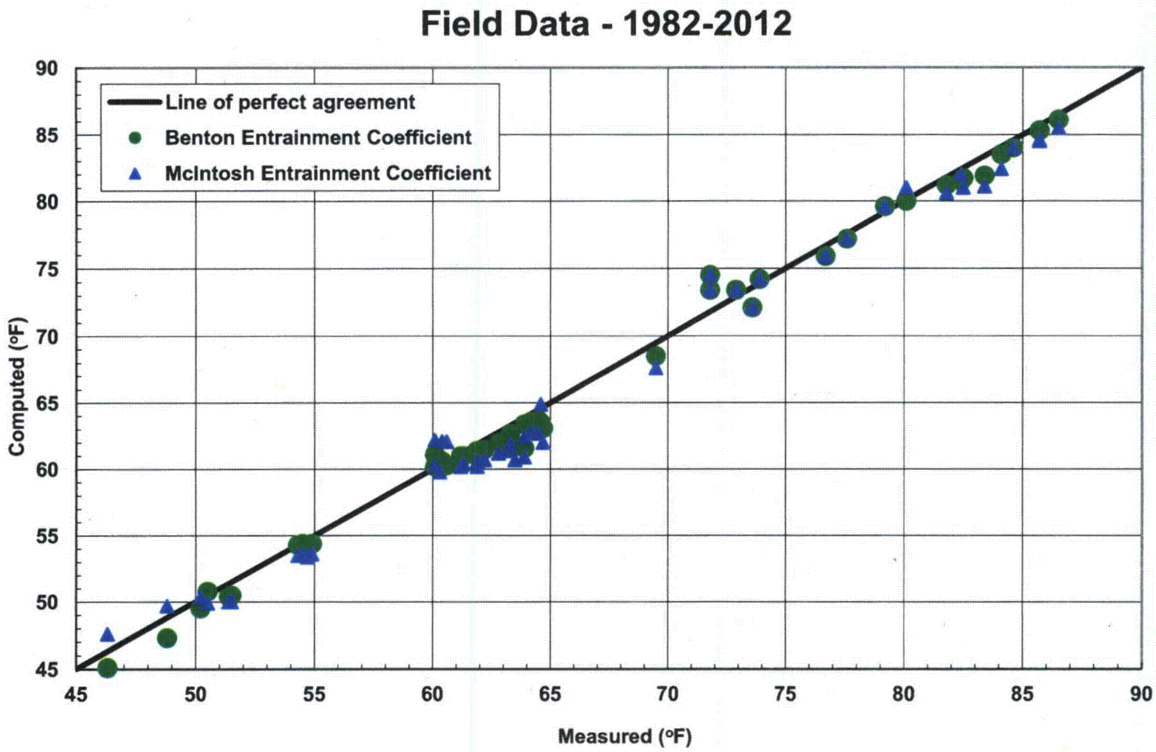


Figure 7. Sensitivity of Computed Temperature T_d to Plume Entrainment Coefficient

Diffuser Effluent Re-Entrainment

Based on the evaluation of numerous combinations of *N* and *R* for diffuser effluent re-entrainment (Eq. 20 and 21), Table 6 gives the values that resulted in computed downstream temperatures that most closely matched measurements in the field surveys (i.e., fifty data points from Table 2 through Table 5). For river velocities between the values given in Table 6, the re-entrainment factor *R* is interpolated between the table values. The number of iterations *N* is interpolated and then rounded to the nearest integer. No re-entrainment correction is performed for 24-hour river velocities greater than the highest value in the table.

Figure 8 shows the comparison of measured and computed downstream temperatures with and without the correction for plume re-entrainment as given in Table 6. Temperatures computed using the plume re-entrainment correction more closely matched measured values for twenty-seven of the fifty data points. Temperatures computed without using the plume re-entrainment correction more closely matched measured values for six data points, with no significant differences for the remaining data points. Based upon these results the re-entrainment correction method is used.

Table 6. Plume Re-Entrainment Iteration Numbers and Factors

River Velocity (ft/sec)	Number of Iterations *N*	Re-entrainment Factor R
0.000	3	0.21930
0.050	3	0.13300
0.075	3	0.11000
0.100	3	0.10000
0.200	3	0.02670
0.300	3	0.03507
0.400	3	0.00893
0.500	3	0.00447
0.600	0	0.00000

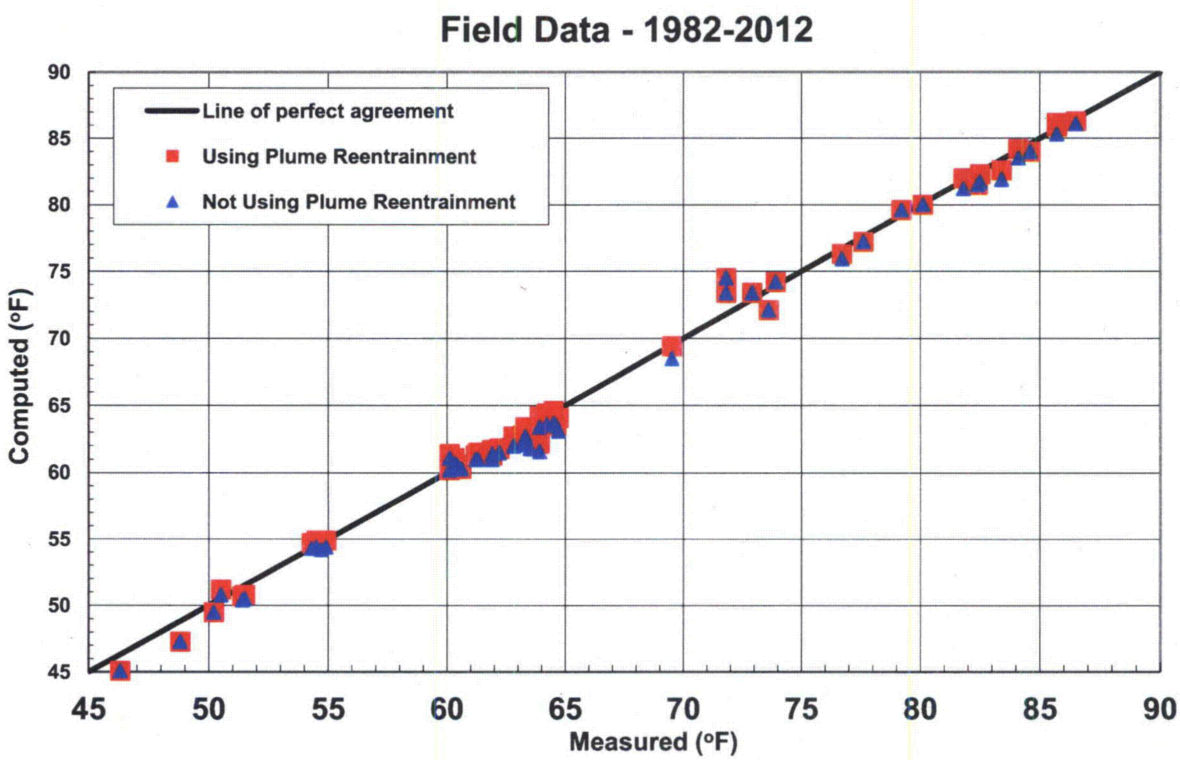


Figure 8. Sensitivity of Computed Temperature T_d to Effluent Re-Entrainment Function

Results of Updated Calibration

For the assumed diffuser slot width and entrainment coefficient, and updated calibration including the re-entrainment function for low river flow, the computed and measured downstream temperatures for the fifty downstream temperature data points collected in SQN field surveys since March 1982 are shown in Figure 9. The average discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy was 0.38 F° (0.21 C°). There was no significant change in the model performance compared to the previous calibration.

To be consistent with the 24-hour averaging specified in the current NPDES permit, the 24-hour average temperatures measured in 2010 at the downstream temperature monitor, Station 8, are compared to those computed by numerical model in Figure 10. 2010 was selected because it represents a new climatic extreme in East Tennessee for the period of record for this model. As before, the measured temperatures correspond to the average of sensor readings at the 3-foot, 5-foot, and 7-foot depths. The overall average discrepancy between the measured and computed 24-hour average downstream temperatures was about 0.71 F° (0.39 C°), and about 0.63 F° (0.35 C°) for downstream temperatures above 75°F.

Measured downstream hourly average temperatures for the same time period are compared to those computed by numerical model in Figure 11. As expected, the temperature data are much more scattered for the hourly temperatures. The average discrepancy between the measured and computed hourly average downstream temperatures was 0.86 F° (0.48 C°) for the full range of river temperatures, decreasing to 0.71 F° (0.39 C°) for downstream temperatures above 75°F.

It needs to be emphasized that in Figure 10 and Figure 11, the data from Station 8 is not necessarily representative of the average temperature across the downstream end of the mixing zone. However, in monitoring the NPDES compliance for Outfall 101, data from Station 8 is considered valuable for verifying basic trends in the downstream temperature as determined by the numerical model, thus providing the motivation for presenting the comparisons given in these figures.

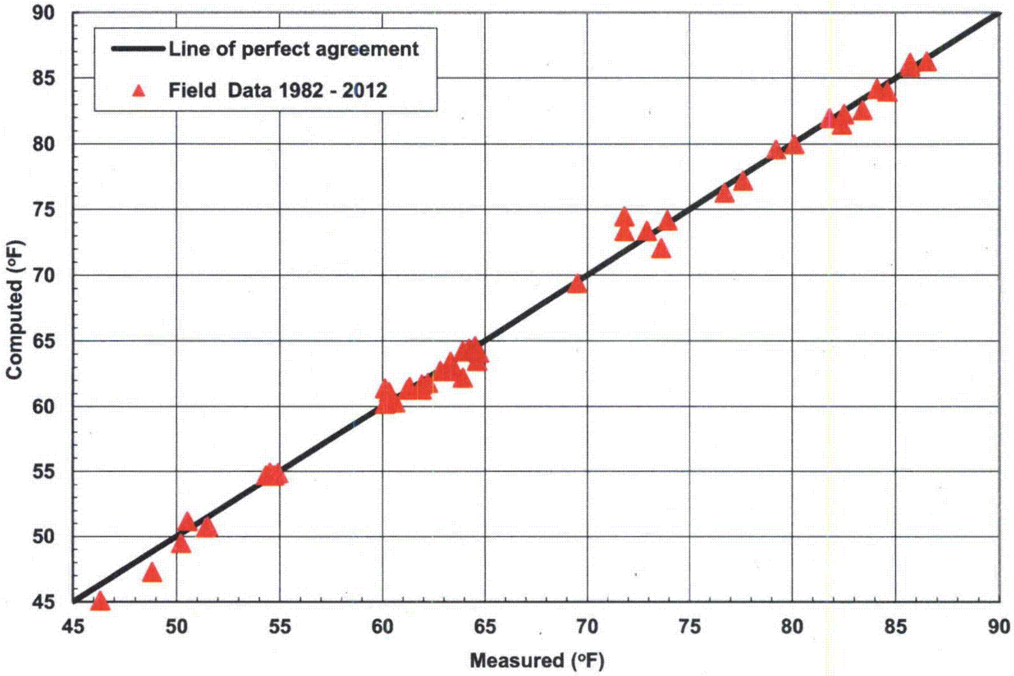


Figure 9. Comparison of Computed and Measured Temperatures T_d for Field Studies from April 1982 through November 2012

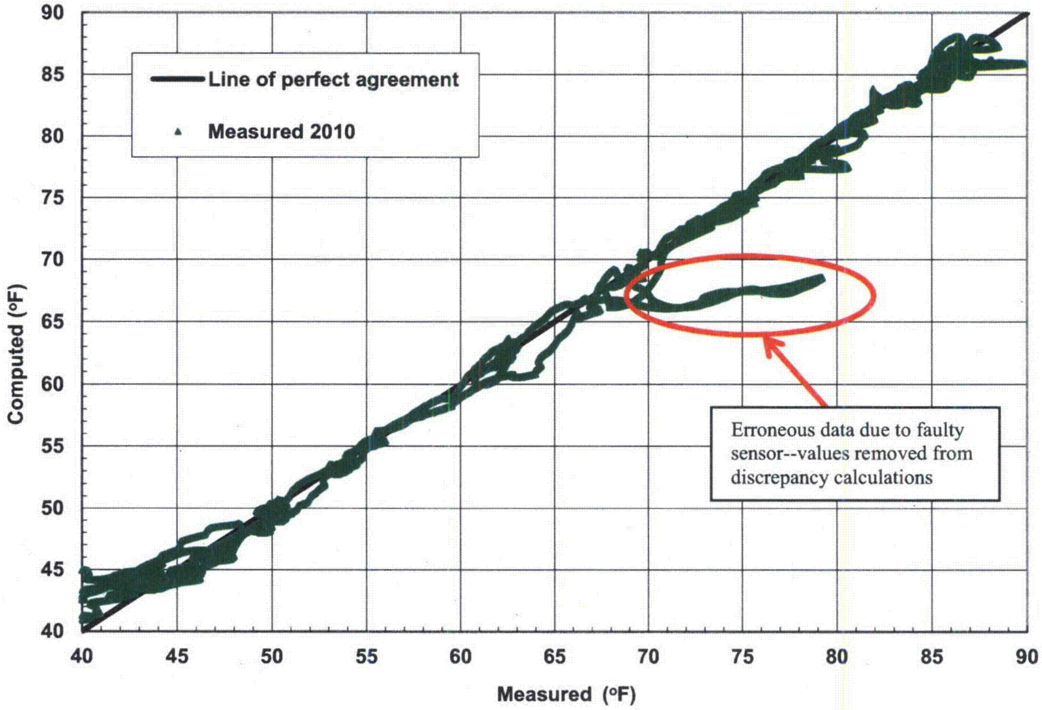


Figure 10. Comparison of Computed and Measured 24-hour Average Temperatures T_d for Station 8 for 2010

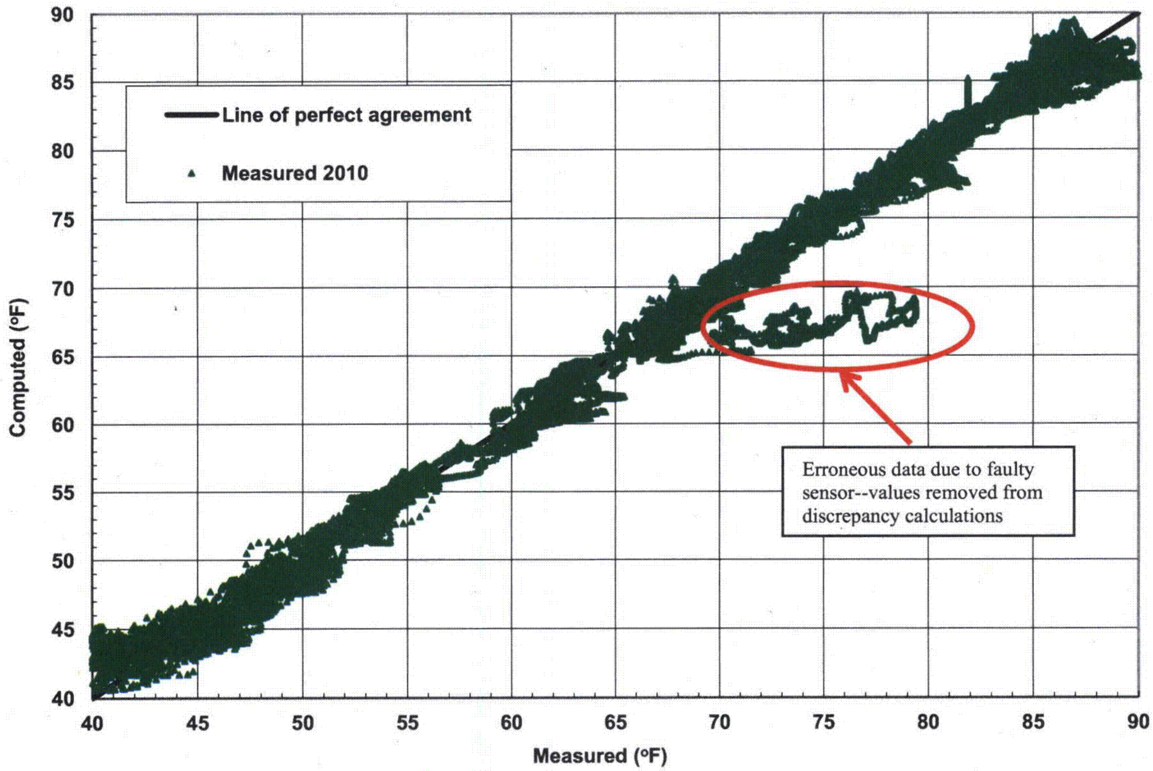


Figure 11. Comparison of Computed and Measured Hourly Average Temperatures T_d for Station 8 for 2010

CONCLUSIONS

The numerical model for the SQN effluent discharge computes the temperature at the downstream end of the mixing zone with sufficient accuracy for use as the primary method of verifying thermal compliance for Outfall 101. In the updated calibration study summarized herein, which used the results from fifty sets of temperature samples across the downstream end of the diffuser mixing zone, the average discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy improved to about 0.38 F° (0.21 C°). There was no significant change in the model performance compared to the previous calibration, and as a result, no update was required in the model parameter set.

REFERENCES

Benton, D.J. (2003), "Development of a Two-Dimensional Plume Model," Dynamic Solutions, LLC, Knoxville, Tennessee, May 2003.

Fischer, H. B., E. J. List, R. C. Y. Yoh, J. Imberger, and N. H. Brooks (1979), *Mixing in Inland and Coastal Waters,* Academic Press: New York, 1979.

TDEC (2005), "NPDES Permit No. TN0026450, Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES)", Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Nashville, Tennessee 37243-1534, July 29, 2005.

TDEC (2011), "NPDES Permit No. TN0026450, Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES)", Tennessee Department of Environment and Conservation, Division of Water Pollution Control, Nashville, Tennessee 37243-1534, January 31, 2011.

TVA (1982), McIntosh, D.A., B.E. Johnson, and E.B. Speaks, "A Field Verification of Sequoyah Nuclear Plant Diffuser Performance Model One-Unit Operation," TVA Division of Air and Water Resources, Water Systems Development Branch, Report No. WR28-1-45-110, October 1982.

TVA (1983a), McIntosh, D.A., B.E. Johnson, and E.B. Speaks, "Validation of Computerized Thermal Compliance and Plume Development at Sequoyah Nuclear Plant," Tennessee Valley Authority, Division of Air and Water Resources, Water Systems Development Branch Report No. WR28-1-45-115, August 1983.

TVA (1983b), Waldrop, W.R., and D.A. McIntosh, *Real-Time Computation of Compliance with Thermal Water Quality Standards*, Proceedings of Microcomputers in Civil Engineering, University of Central Florida, Orlando, Florida, November 1983.

TVA (1987), Ostrowski, P., and M.C. Shiao, "Quality Program for Verification of Sequoyah Nuclear Plant Thermal Computed Compliance System," Tennessee Valley Authority, Office of Natural Resources and Economic Development, Division of Air and Water Resources Report No. WR28-3-45-134, September 1987.

TVA (2003), Harper, W.L., "Study to Confirm the Calibration of the Numerical Model for the Thermal Discharge from Sequoyah Nuclear Plant as Required by NPDES Permit No. TN0026450 of August 2001, Report No. WR2003-1-45-149, Tennessee Valley Authority, River Operations, June 2003.

TVA (2009), Harper, W.L. and P.N. Hopping, "Study to Confirm the Calibration of the Numerical Model for the Thermal Discharge from Sequoyah Nuclear Plant as Required by NPDES Permit No. TN0026450 of September 2005, Report No. WR2009-1-45-150, Tennessee Valley Authority, River Operations, January 2009.

TVA (2009), "Ambient Temperature and Mixing Zone Studies for Sequoyah Nuclear Plant as Required by NPDES Permit No. TN0026450 of September 2005," Report No. WR2009-1-45-151, Tennessee Valley Authority, River Operations, January 2009.

TVA (2010), "Sequoyah Nuclear Plant (SQN) – Revised Thermal Performance Baseline and Capacity Ratings," Memo from Scott D. Terry to J.D. Williams (B85100419001), April 14, 2010.

TVA (2013), "Sequoyah Nuclear Plant (SQN)--Update of Flowrate Characteristics Through the Diffusers," Memo from Paul N. Hopping to Bradley M. Love, March 4, 2013.

RECEIVED
90 JAN 18 AM 10:05
OFFICE OF
SECRETARY OF STATE

STATE OF TENNESSEE
DEPARTMENT OF HEALTH AND ENVIRONMENT

IN THE MATTER OF:	)	
	)	OFFICE OF WATER
TENNESSEE VALLEY AUTHORITY	)	MANAGEMENT
	)	DIVISION OF WATER POLLUTION CONTROL
	)	No. 89-3036
	)	
	)	DOCKET No. 17.30-D-89-0674A
RESPONDENT	)	

AGREED ORDER

This cause came to be heard before the Water Quality Control Board in open meeting upon the motion of the parties that the Board approve the parties' settlement as embodied herein.

By signatures of the parties' counsel, as entered below, representing that each attorney is acting with the full and explicit authority of their clients, the Board finds that these named parties have agreed to the terms and conditions of this agreed and final order as a resolution between said parties regarding the Commissioners's Order and Assessment issued to Respondent on May 22, 1989.

The Commissioner's Order and Assessment alleges that fish were killed as a result of the operation of Respondent TVA's Sequoyah Nuclear Plant in the summer of 1988 in violation of T.C.A. Section 69-3-114(a) and (b). Division personnel determined the cause of the fish kills to be low dissolved oxygen and high temperature conditions in the waters affected by Respondent's operation of Sequoyah Nuclear Plant. TVA contends that during this period, thermal requirements in the plant's National Pollutant Discharge Elimination System (NPDES) permit No. TN0026450 were not violated and that dissolved oxygen levels were not lowered due to operation of the plant in accordance

with the NPDES permit. However, TVA desires to fully resolve this matter as provided herein.

The Board now finds the Agreement of these parties to be as follows, and it is so found and ordered by the Board that:

FINDINGS OF FACT

1. TVA is a corporate agency and instrumentality of the United States Government. It operates the Sequoyah Nuclear Plant for the purpose of producing electrical power as authorized by an act of Congress known as the Tennessee Valley Authority Act of 1933, 16 U.S.C. §§ 831-831dd (1988).

2. TVA is authorized to discharge wastewater from a facility located at the Sequoyah Nuclear Plant in Hamilton County, Tennessee, to receiving waters named Tennessee River, Plant Intake Embayment (hereinafter "Intake Embayment"), and Diffuser Pond in accordance with the terms and conditions of NPDES permit No. TN0026450. The NPDES permit was issued by the United States Environmental Protection Agency in conjunction with the State of Tennessee's Certification Conditions. Tennessee's Certification Conditions state that TVA is in no way relieved from any liability for damages which might result from the discharge of wastewater. The primary nature of the wastewater in question is a thermal discharge resulting from TVA's plant operations.

3. Cooling water for TVA's Sequoyah Nuclear Plant is drawn into the Intake Embayment below a deep skimmer wall to provide cooler water from the lower depths of the Tennessee River. The bottom of the skimmer wall is about 12 feet from the river bottom and about 39.5 feet below the normal maximum summer elevation of the water surface. Dissolved oxygen and temperature conditions in the Intake Embayment are thus related to the conditions present in the lower strata of the river where summer temperatures are cooler and summer dissolved oxygen levels are lower than those in the lower strata.

4. In open mode operation, the cooling water is discharged from the condensers into the Diffuser Pond and then to the Tennessee River through two diffusers. In helper mode, the cooling water is pumped through the cooling towers into the Diffuser Pond and then discharged to the Tennessee River through the diffusers. In closed mode, the cooling water is pumped through the cooling towers and recirculated into the Intake Embayment. The plant was operated in open mode until approximately 6:30 p.m. on August 2 when operation in helper mode commenced to lower the temperature of the discharged water.

5. The Tennessee River, Intake Embayment, and Diffuser Pond are "waters" of the State, as defined by T.C.A. Section 69-3-103(33). Pursuant to T.C.A. Section 69-3-105(a)(1), all waters of the State of Tennessee have been classified by the Tennessee Water Quality Control Board for suitable uses. The above waters are classified by Rule 1200-4-4-.01 of the Official Compilation, Rules and Regulations of the State of Tennessee (hereinafter referred to as Rules) for all classified uses including the use of fish and aquatic life. The waters of the Diffuser Pond are physically separated from the Tennessee River by a dike.

6. In addition to earlier reported fish kill events, the Division was notified by TVA on August 1, 1988, of a fish kill in the Intake Embayment at Sequoyah Nuclear Plant. Division personnel investigated the reported fish kill and counted 278 dead fish in the Intake Embayment. A reading of the dissolved oxygen at the location of the fish kill ranged from 0.2 to 0.7 mg/l.

7. On August 2, 1988, a second site investigation of Sequoyah was conducted. The dissolved oxygen present in the Intake Embayment was measured by Division personnel. One location showed dissolved oxygen to range from 1.9 to 2.5 mg/l. A second location showed dissolved oxygen to range from 0.2 to 0.4 mg/l.

The Diffuser Pond was also inspected on this date. Dead and dying fish were observed. The temperature of the water in the Diffuser Pond was measured at 37°C (98°F) (within allowable temperature limits under NPDES permit No. TN0026450 for the Diffuser Pond). Dissolved oxygen was less than 1.0 mg/l.

8. On August 4, 1988, Division personnel took measurements of dissolved oxygen in the Tennessee River. Midchannel dissolved oxygen readings at the 5-foot depth ranged from 4.3 to 8.7 mg/l with most readings approximating 7.5 mg/l. Dissolved oxygen readings at the 15-foot depth and below, from where water is drawn into the Intake Embayment below the deep skimmer wall, corresponded to the dissolved oxygen levels in the Intake Embayment.

9. On August 25, 1988, the Division received a report from TVA regarding the August 1, 1988, fish kill. The report stated that the loss of fish in the Intake Embayment was undoubtedly related to extremely low dissolved oxygen levels in the Intake Embayment.

10. In October of 1988, TVA submitted a report to the Division on "The Effects of Sequoyah Nuclear Plant on Temperature and Dissolved Oxygen in Chickamauga Reservoir During Summer 1988" in response to the Division's request that TVA document the conditions in the reservoir and actions taken by TVA to mitigate the impacts of its thermal discharge. TVA reported that it had released cold water from Norris Dam in an effort to lower water temperatures and raise the level of dissolved oxygen in the water. Also, cooler water from Watts Bar Dam and near bank turbines were used to achieve higher dissolved oxygen releases from Watts Bar Dam. It was also reported that water entered Sequoyah at approximately 27.5°C (82°F), was warmed to about 40.5°C (105°F) through the plant, cooled to about 31°C (88°F) with a cooling tower (after switching to helper mode on August 2), then discharged back to the reservoir through the Diffuser Pond at approximately 31.7°C (89.8°F) in compliance with applicable

thermal criteria established in the NPDES permit for the Diffuser Pond discharge. The reported temperatures were based upon an August 25, 1988, in-plant survey.

11. On October 20, 1988, the Division received a summary from TVA of dead fish observed in the Sequoyah Nuclear Plant Intake Embayment and Diffuser Pond from August 3 to September 14, 1988. The total number of dead fish observed during this time period was reported to be 16,372 in the Intake Embayment and 392 in the Diffuser Pond.

12. On March 14, 1989, the Division received a report from the Tennessee Wildlife Resources Agency ("TWRA") which contained calculations of fishery value loss and TWRA personnel salary expenses. TWRA reported the following costs:

Diffuser Pond

Total fishery value lost:	$ 56.92
Personnel salaries:	95.03
Total	$151.95

Intake Embayment

Total fishery value lost:	$1,233.93
Personnel salaries:	117.39
Total	$1,351.32

13. The Division has incurred costs in the form of expenses for travel, salaries, and analyses costs in the amount of $588.70.

14. TVA has cooperated with the Division in its investigations.

CONCLUSIONS OF LAW

1. The operation of the intake pumps at TVA's Sequoyah Nuclear Plant to draw low dissolved oxygen water into the Intake Embayment and the discharge of heated water into the Diffuser Pond caused a condition which resulted in harm to fish in said embayment and pond for which condition, if not properly authorized, the Commissioner may assess damages under T.C.A. Section 69-3-116.

2. A discharge resulting in harm to fish and aquatic life which is not properly authorized is pollution and in violation of T.C.A. Section 69-3-114(a) and (b).

ORDER

WHEREFORE, premises considered, it is Ordered by the Board that TVA shall:

1. Operate Sequoyah Nuclear Plant in full compliance with its NPDES permit and applicable provisions of the Act and rules promulgated thereunder.

2. Pay the State of Tennessee a monetary amount of TWO THOUSAND NINETY-ONE DOLLARS AND NINETY-SEVEN CENTS ($2,091.97) within thirty (30) days of the effective date of this Order.

3. Prepare and submit a plan to the Division, within ninety (90) days of receipt of this Order, which details TVA's proposed systems and procedures to prevent damage to fish and aquatic life from TVA's discharges. Either party may request that the Board review and receive comments on the plan from the parties.

4. The facts and conclusions of law recited herein are to be used only in administrative proceedings before the Board between these parties. Neither party waives any rights or defenses regarding the facts and conclusions of law stated herein by entering into this Agreed Order.

Furthermore, TVA is advised that the foregoing Order is not in any way to be construed as a waiver, express or implied, of any provision of the law or regulations, including, but not limited to, future enforcement for violations of the Act and Regulations which are not charged as violations of this Order. However, compliance with the Order will be one factor considered in any decision whether to take enforcement action against TVA in the future.

REASONS FOR DECISION

It appears to the Board that the parties signatory hereto have proposed this Order in good faith and in the interest of settling these proceedings in accord and in the interest of avoiding the time and expense of prolonged litigation. The Board has reviewed the Order and finds nothing in it which is contrary to the public interest and the purposes and intent of the Water Quality Control Act.

The Board wishes to encourage such agreed resolutions when they do not endanger public health, safety, and welfare, consistent with the provisions of the Uniform Administrative Procedures Act which encourage informal settlements as a means to resolve a contested case.

The proposed final order is proper and lawful. There being no good and satisfactory reason for the Board to set aside the voluntary agreement of the parties, it will be approved as they have executed it.

REVIEW OF THE FINAL ORDER

Any person aggrieved by the entry of this Order is entitled to file a petition for reconsideration before the Board within ten (10) days after the date of entry of this Order. If no action is taken upon the petition within twenty (20) days of its receipt by the Board, the petition shall be deemed to have been denied. See T.C.A. Section 4-5-317. Further, any party may petition the Board to stay the effectiveness of this Order within seven (7) days of its entry. See T.C.A. Section 4-5-316.

Any person aggrieved by the entry of this Order is entitled to petition the Chancery Court of Davidson County for review within sixty (60) days of the entry of this Order. See T.C.A. Section 69-3-111 and Section 4-5-322. A petition for reconsideration of the Order does not act to extend this sixty (60) day period which begins to run on the effective date of the Order disposing of the petition.

This the 17 day of JANUARY, 1990.

Chairman
The Tennessee Water Quality
Control Board

APPROVED FOR ENTRY:

FOR THE COMMISSIONER
OF THE TENNESSEE DEPARTMENT
OF HEALTH AND ENVIRONMENT

Gloria Snavely
Gloria Snavely
Assistant General Counsel

James E. Fox - by permission GS
James E. Fox, Deputy General Counsel
Attorney for Respondent, Tennessee Valley Authority

Filed in the Administrative Procedures Division, Office of the Secretary of State, on this 18th day of January, 1990.

Charles C. Sullivan II
Charles C. Sullivan, II, Director
Administrative Procedures Division

E3149320/D6/OGC

PROCEDURE

Sequoyah Nuclear Plant

Title: Operating Procedure for Intake Forebay Fish Refuge

Purpose: This procedure identifies (1) how low dissolved oxygen (DO) concentrations within the Sequoyah Nuclear Plant (SQN) Intake Forebay will be predicted; (2) how SQN will create a DO enhanced fish refuge within the Intake Forebay to prevent a possible DO induced fish kill; and (3) establishes protocol interfaces with appropriate State agencies.

Procedure:

Norris Engineering Laboratory will monitor Chickamauga Reservoir for DO concentrations. Methodology employed will include continuous measurement of DO from stations in the Watts Bar Hydro (WBH) tailrace. Additional DO measurements will be taken routinely from stations located at Tennessee River Miles (TRM) 472.3 and 490.5. The SQN intake is located between these stations at TRM 484.7. Norris Engineering Laboratory will use the Box Exchange Transport Temperature Ecology Reservoir (BETTER) model to simulate Chickamauga Reservoir and predict DO concentrations at the SQN intake skimmer wall. Results will be displayed on the TVA Environment and River Resource Aide (TERRA) so that predictions are available to Reservoir System Operations, Environmental Compliance, and SQN Environmental Section. DO predictions from the model will be updated daily (Monday through Friday). The predictions will cover a period of three days and will use the most recent data for measured DO, forecast meteorology, and forecast river flows.

Engineering Services Central Region and SQN Environmental Section will be alerted by Norris Engineering Laboratory if the measured or the predicted DO at the SQN intake skimmer drops to 4.0 mg/L or lower.

Norris Engineering Laboratory will alert SQN Environmental Section to implement daily sampling if:

- The measured or predicted DO at any station drops to below 2.5 mg/L (i.e., WBH tailrace, TRM 472.3, or TRM 490.5).
- The predicted DO at the SQN skimmer drops to 3.0 mg/L.

To implement daily sampling, SQN Environmental Section will ensure that DO measurements are taken at depths 0.3, 1, 3, and 5 meters on the inside of the skimmer wall, and on the outside of the skimmer wall at approximately 14 meters below the top of the wall (center of the submerged opening). SQN Environmental Section will ensure that there are visual inspections of the intake forebay for stressed fish at the water surface. Alternately, sampling and visual inspections may be performed by Engineering Services – Central Region as the situation dictates. The organization collecting samples and visuals will report results to Water Management Environmental Compliance in Chattanooga and to the Norris Engineering Laboratory.

The SQN Environmental and Waste Control manager or designee will advise SQN Operations during each morning's shift turnover meeting of the DO levels and predicted trends in the SQN intake forebay when daily DO sampling is initiated.

Aeration system operability will be ensured daily. Aeration effectiveness at several forebay locations will be determined by weekly sampling at 0.3, 1, 3, and 5-meter depths.

Aeration system flow will be initiated whenever any of the following conditions are met:

- If the measured DO at the center of the intake skimmer wall opening (14-meter depth) on the outside of the skimmer wall falls between 2.0 and 2.5 mg/L for 2 consecutive daily samples.
- If the measured DO of any one daily sample falls between 2.0 and 2.5 mg/L and TERRA reflects a prediction of constant or worsening conditions.
- Whenever the measured DO of any daily sample drops to 2.0 mg/L or lower.

Whenever the measured DO at the center of the skimmer wall opening on the outside of the wall increases to above 2.5 mg/L for 2 consecutive daily samples and conditions are predicted to remain stable or improve, aeration sampling will be terminated.

Attachment 1

Organizational Contacts

Water Management Environmental Compliance (Haney Building - Chattanooga)

Neil Woomer	751-7307
Wayne Wilson	751-8961
Don Dycus	751-7322
Jack Milligan	751-7360

Engineering Services - Central Region (Power Service Center - Chickamauga Dam)

Robert Bond	697-4108
Jerry Liner	697-4100
Garry Grant	697-4380
Secretary	697-4263

Engineering Services - Norris Engineering Laboratory

Ming Shiao	632-1886
Walter Harper	632-1882
Switchboard	632-1900

Corporate Environmental Protection (Nuclear)

Diedre Nida	751-8123

Sequoyah Environmental Section

Debby Bodine	843-6700, Pager Number 10496
Lamar Strickland	843-7748, Pager Number 10861
Stephanie Howard	843-6713, Pager Number 60438
Jerry Osborne	843-7630, Pager Number 90091

Sequoyah Operations

Shift Operations Supervisor	843-6211
Jim Baumstark	843-6501