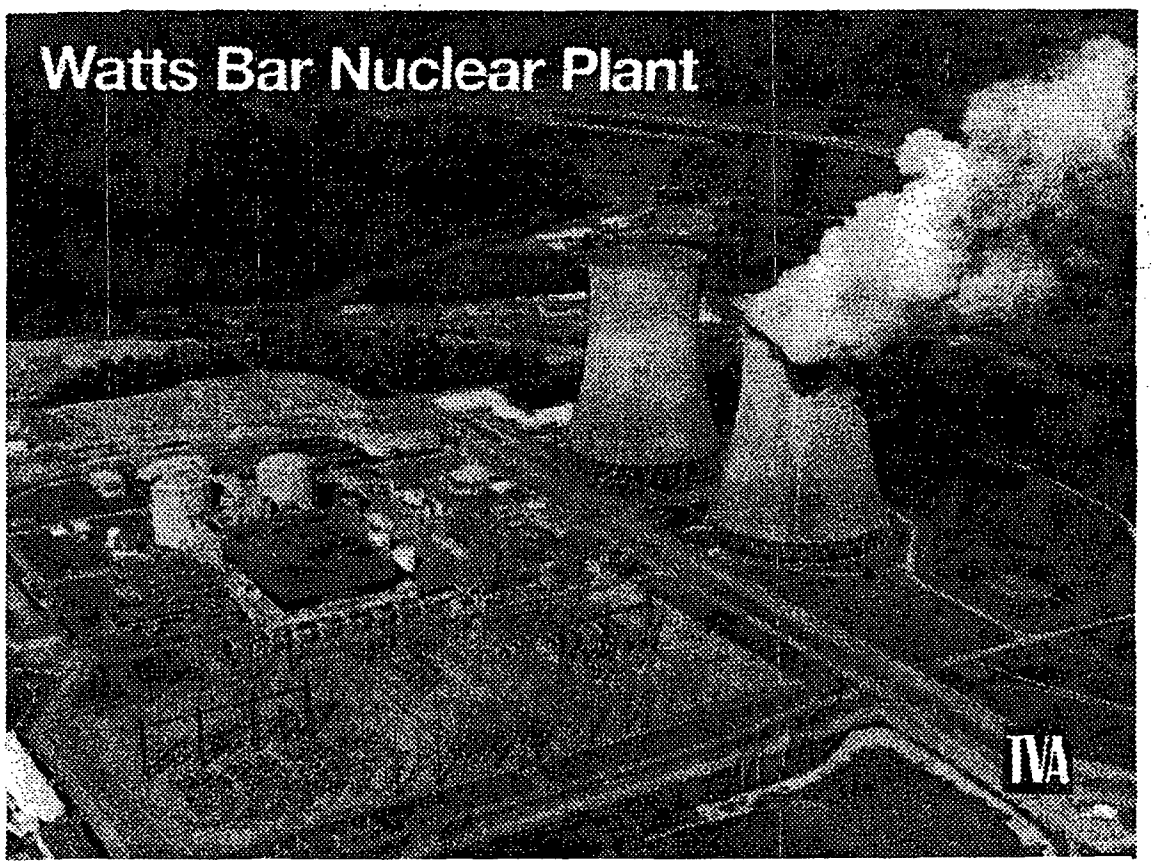
WATTS BAR NUCLEAR PLANT
SUPPLEMENTAL
CONDENSER COOLING WATER PROJECT



Thermal Plume Modeling

Prepared by Walter Harper
Tennessee Valley Authority
Engineering Laboratory
Norris, Tennessee

December 5, 1997

Index No: 444
Title: Watts Bar Nuclear Plant Supplemental Condenser Cooling Water Project EA - August 1998- Thermal Plume Modeling - December 5, 1997

WBN Supplemental Condenser Cooling Water Project

Thermal Plume Modeling

Executive Summary

Project statement

This project would construct and operate a Supplemental Condenser Cooling Water (SCCW) system for the Watts Bar Nuclear Plant. The system would connect existing water intake and discharge piping originally operated as a part of the Watts Bar Fossil Plant to the cooling towers at the Nuclear Plant. This system would increase power production by the Watts Bar Nuclear Plant by reducing main turbine condenser temperature.

The gravity flow SCCW system would operate continuously except during times of chemical water treatment for the Nuclear Plant. Operation of the existing cooling tower was optimized previously at 105% of design capacity, however, warm weather power losses continue due to undersizing of cooling tower capacity to support maximum main turbine generator power and condenser cooling capacity. Without installation of the SCCW system, no increase in generation would be realized.

CORMIX was used to model the mixing of the discharge from the WBF discharge structure into the river. CORMIX is a steady state computer model which only accepts input through keyboard entry. Therefore, it was not feasible to run CORMIX for all possible combinations of river flows and elevations, meteorological conditions and plant operations. Instead, CORMIX was run for a range of river flows, river elevations, ambient river temperatures, discharge flow rates, and plant temperature rises (difference between discharge and intake temperature) which encompassed the maximum and minimum expected values for each parameter. The results of these CORMIX runs were used as the basis for an interpolation scheme by which the instantaneous and average instream river temperature rise due to discharge from the WBF discharge structure was computed.

Conclusions

The proposed SCCW system can be operated without significant risk of non-compliance of the instream thermal limits of 30.5 °C (86.9 °F) maximum discharge temperature, 3 °C (5.4 °F) maximum delta temperature, and ±2 °C (3.6 °F) rate of rise. It would be necessary to operate the bypass system during the months of December, February, March, and April.

The number of predicted non-compliances of the instream temperature rise limit during the months of November and January are relatively small. This indicates that some operation of the bypass would be needed in January and possibly in November, but not on a continuous basis. The conditions under which the bypass would be needed are a combination of low river temperature and higher than normal air temperature. Given reasonably accurate weather forecasts, these conditions can be predicted sufficiently far in advance to turn the bypass on if needed during these months.

There is no significant likelihood of the 85 °F (29.4 °C) WBN intake temperature safety limit being exceeded due to operation of the SCCW system. However, should the intake temperature approach the limit, special WBH operations could be used to reduce the temperature at the WBN intake. If such WBH operations are not feasible, the SCCW system could be shut down, reducing the WBN intake temperature to that of the WBH discharge temperature. No adverse influence on river temperatures at Sequoyah Nuclear Plant is expected from operation of the SCCW system.

Table of Contents

Executive Summary 2

1.0 Introduction 4

2.0 Plant Operating Characteristics 4

2.1 Watts Bar Hydro Plant 4

2.2 Watts Bar Fossil Plant 4

2.3 Watts Bar Nuclear Plant 4
2.3.1 Current Design 4
2.3.2 Proposed Design Modifications 5

3.0 Hydrothermal Analyses 5

3.1 Discharge Through WBF Discharge Structure 5

3.2 Discharge Through WBN Diffuser 6

3.3 Near-Field Effects on River Temperature of Combined Discharges Through WBN Diffuser and WBF Discharge Structure 7
3.3.1 Computer Model Inputs 7
3.3.2 Model Results 9

3.4 Effect of SCCW System Operation on WBN Intake Temperatures 11

3.5 Effect of Watts Bar Nuclear and Fossil Plant Discharges on Sequoyah Nuclear Plant 11

4.0 Conclusions 12

5.0 Tables 13

6.0 Figures 31

7.0 References 43

1.0 Introduction

This evaluation provides details of the computer modeling of the effects of Watts Bar Nuclear Plant (WBN) thermal discharge on Chickamauga Reservoir. The operating characteristics of WBN and Watts Bar Hydro Plant are described. Results of computer simulations of plant operations using dam releases, reservoir elevations, and ambient water and air temperatures for 1976 through 1993 are presented.

2.0 Plant Operating Characteristics

2.1 Watts Bar Hydro Plant

Watts Bar Hydro Plant (WBH) has five units with a total generating capacity of 166.5 MWe. The turbine discharge is approximately 9000 cfs per unit. WBH is normally used for peaking operation which entails storing water during periods of low electrical demand and releasing it during periods of high electrical demand. This usual pattern for peaking operation is low or zero turbine discharge at night and higher discharges during the day.

Hourly WBH discharges have been archived since January 1, 1976. The average annual discharge at the hydro plant for the modeled period is approximately 26,300 cfs. Seasonal and monthly average discharges are shown in Table 1. The normal discharge through each of the five turbines ranges from 7500 to 10,000 cfs. The minimum flow through a single turbine is 3500 cfs, however, for maximum efficiency, the single unit flow is seldom less than 8000 cfs.

The water surface elevation downstream of WBH in the vicinity of WBN is determined by the headwater elevation at Chickamauga Dam and the discharges from WBH and Chickamauga Hydro Plant (CHH).
Normal Chickamauga headwater elevations vary from a minimum pool elevation of 675.0 feet in the winter to a maximum of 683.0 feet in the summer.

2.2 Watts Bar Fossil Plant

Watts Bar Fossil Plant (WBF) is currently mothballed with no scheduled start-up date. Implementation of the proposed plan for supplemental condenser cooling water for WBN would prevent future WBF operation. When operated, the WBF condensers are cooled by a gravity feed cooling water system which withdraws water from Watts Bar Reservoir, through an intake structure located on the upstream face of Watts Bar Dam. The nominal flow rate of the WBF condenser cooling water (CCW) system is 626 cfs (280,968 gpm), with a temperature rise across the condensers of 10 F° (5.56 C°). After passing through the condensers, the cooling water was discharged into the Tennessee River below Watts Bar Dam. This discharge structure is a rectangular culvert seven feet wide by 10 feet high, which expands to a width of 15 feet at the discharge point. The elevation of the top of the culvert outlet is 675 feet, which coincides with the normal minimum pool elevation of Chickamauga Reservoir. At winter reservoir elevations, the culvert acts as an open channel discharge. At higher reservoir elevations, the top of the culvert opening is submerged to a maximum depth of 8 feet.

2.3 Watts Bar Nuclear Plant

2.3.1 Current Design

Watts Bar Nuclear Plant is located on the right bank of the Tennessee River at Tennessee River Mile (TRM) 528. WBN is a two unit plant, however only Unit 1 is currently operational. Unit 1 is rated to produce 1270 MWe of electricity at full load. The plant utilizes a closed cycle heat dissipation system, consisting of one natural draft cooling tower per unit and a blowdown system. Water losses due to blowdown and evaporation are replenished with makeup water supplied via an intake channel and pumping stations at TRM 528.0. The average and maximum makeup rates are 64 cfs (28,725 gpm) and 71.5 cfs (33,348 gpm), respectively.

To maintain the concentration of dissolved solids in the cooling tower basin at approximately twice that found in the Tennessee River, blowdown discharge from the cooling tower is between 21.1 cfs (9470 gpm) and 31.4 cfs (14,093 gpm). All blowdown is either discharged into the Tennessee River through a submerged multiport diffuser system (TRM 527.8) or held for discharge at a later time. The diffuser system consists of two pipes branching from a central conduit at the right bank of Chickamauga Reservoir and extending in a direction perpendicular to Tennessee River flow. Each pipe is controlled by a 54-inch diameter butterfly valve located a short distance downstream of the central conduit wye. A physical description of the diffusers is given in Table 2.

The National Pollutant Discharge Elimination System (NPDES) Permit for WBN stipulates that the diffusers should be operated only when the discharge from WBH is greater than 3500 cfs. To meet this requirement, blowdown from the cooling towers is diverted to a holding pond when WBH is not discharging. When WBH discharge resumes, the stored blowdown water is released through the diffusers. The holding pond discharge rate ranges from 0 to approximately 110 cfs (49,370 gpm), depending on the surface elevation of water in the pond and in the Tennessee River. The combined discharge from the holding pond and cooling towers ranges from 21.1 cfs (9470 gpm) to 138 cfs (61,940 gpm). An overflow weir (elevation 707 ft.) on the south side of the holding pond allows discharge though a surface channel into the Tennessee River (TRM 527.2) should the pond capacity of 190 acre-feet be exceeded due to an extended emergency curtailment of WBH discharge. During normal one unit operation, the pond can accumulate blowdown water for approximately 55 hours before overtopping the overflow weir. The actual time available before overflow varies with plant pump operation, the percentage of cooling tower flow which is lost to evaporation, river elevation, and the initial level of water in the pond. The blowdown system is depicted in Figure 1. A more complete description of the diffuser system and holding pond may be found in Reference 14.

2.3.2 Proposed Design Modifications

The proposed supplemental condenser cooling water (SCCW) system would augment the current makeup water supply system with a supply pipeline from the Watts Bar Fossil Plant (WBF) intake to the Unit 2 tower discharge basin (Figure 2) from where it would be routed to the Unit 1 CCW pumping station. A second discharge pipeline would convey water from the Unit 1 tower basin to the existing WBF discharge structure. In addition, a partial bypass valve and pipeline would be used to divert water from the WBF intake (SCCW supply pipeline) directly to the WBF discharge structure (SCCW discharge pipeline). This would be used in cooler months to reduce the amount of heat discharged through the WBF discharge structure. The total makeup flow rate would be increased to between 274.4 cfs (123,159 gpm) and 439.6 cfs (197,306 gpm), depending on the number of raw cooling water (RCW) and essential raw cooling water (ERCW) pumps in operation, WBH headwater elevation, and the operation of the bypass valve. This would result in an increase of the total blowdown rate to between 232.8 cfs (104,514 gpm) and 398 cfs (178,661 gpm). The blowdown routed to the diffuser/holding pond system would be relatively constant at 44.5 cfs (20000 gpm), with all blowdown in excess of this amount released through the WBF discharge structure.

The WBN diffuser and holding pond system would continue in its present mode of operation. The blowdown discharge through the WBF discharge structure would be continuous, regardless of WBH operation.

3.0 Hydrothermal Analyses

The WBN blowdown discharges from the WBN diffuser system and the WBF discharge culvert were evaluated to determine the near-field effects of the individual and combined discharges on river temperatures in Chickamauga Reservoir.

3.1 Discharge Through WBF Discharge Structure

CORMIX (Cornell Mixing Zone Expert System, version 3.1, References 5,7,8), was used to model the mixing of the discharge from the WBF discharge structure into the river. CORMIX is a steady state computer model which

only accepts input through keyboard entry. Therefore, it was not feasible to run CORMIX for all possible combinations of river flows and elevations, meteorological conditions and plant operations. Instead, CORMIX was run for a range of river flows, river elevations, ambient river temperatures, discharge flow rates, and plant temperature rises (difference between discharge and intake temperature) which encompassed the maximum and minimum expected values for each parameter. The results of these CORMIX runs were used as the basis for an interpolation scheme by which the instantaneous instream river temperature rise due to discharge from the WBF discharge structure was computed (Section 3.3.1.5.7).

A rectangular surface discharge was assumed for all cases. In order to preserve the initial momentum of the flow from the WBF discharge structure, the height and width of the modeled discharge were varied such that the depth of the discharge was equal to the difference between the river elevation and the elevation of the discharge channel bottom (665 feet), with the width adjusted so that the cross sectional area of the channel was equal to that of a 15-foot wide by 10-foot deep rectangle. The modeled discharge channel depth thus varied from 10 feet to 18 feet, with corresponding widths of 15 feet and 8.3 feet.

The maximum instream river temperature rise due to discharge from the WBF discharge structure occurs under conditions of low river flow and high plant temperature rise. In these cases, the plume reached equilibrium conditions within 1000 feet downstream of the discharge.

Results of the CORMIX runs are summarized in Table 3 and Figures 3 through 6.

3.2 Discharge Through WBN Diffuser

The diffuser discharge flow and temperature depend on the reactor power levels of each unit, the flow rates and temperatures of the CCW, ERCW, RCW, and SCCW systems; the surface elevations of the yard holding pond and Chickamauga Reservoir; the ambient wet-bulb and dry-bulb temperatures; and the intake temperature of the ERCW, RCW, and supplemental condenser cooling water systems.

Hourly values of tower blowdown flow and temperature were computed using steam turbo-generator and cooling tower performance calculation methods (Reference 4). One-unit WBN operation was assumed with Unit 1 generating 1230 MWe. In cases where the turbine backpressure limit of 5.5 inches of mercury (in. Hg) would be exceeded, the unit load was reduced to meet the backpressure limit.

The total blowdown flow for the Unit 1 cooling tower was computed as the sum of all ERCW and RCW pump flows and the SCCW flow minus the evaporation from the cooling tower. The smaller of the total blowdown flow or 44.6 cfs (20000 gpm) was routed to the diffuser/holding pond system. All tower blowdown flow in excess of that routed to the diffuser/holding pond system was directed to the WBF discharge structure.

The diffuser discharge was computed with a pipe flow routing program which distributes the flow between diffuser legs by balancing the head between the pond and the river. The program simulates the operation of the yard holding pond in a manner such that flow conservation is maintained for all discharges entering the blowdown system from the cooling towers. It was assumed that both diffuser legs were operated whenever diffuser discharge was permitted.

The heated effluent dilution caused by the interaction between WBN submerged diffusers and the river was computed using an analytical expression (Reference 1) described by Ungate and Howerton (Reference 14).

3.3 Near-Field Effects on River Temperature of Combined Discharges Through WBN Diffuser and WBF Discharge Structure

The thermal effects of the combined WBN discharges on Chickamauga Reservoir depend on the ambient river flow, temperature, and surface elevation, and the discharge flow and temperature through the WBN diffusers and WBF discharge structure. A computer model was used to simulate the thermal effects of WBN under several scenarios for WBN plant operations for the ambient river and atmospheric conditions of the period from January 1, 1976 through October 15, 1993. River flows and elevations, WBN discharge temperatures and flows, and the resulting downstream river temperatures were calculated for each hour of this period.

3.3.1 Computer Model Inputs

3.3.1.1 Meteorological Data

Hourly wet-bulb and dry-bulb temperatures were obtained from National Weather Service meteorological records at Chattanooga airport for January 1, 1976 through October 15, 1993. The Chattanooga airport is the closest airport south (conservative meteorology) of the Watts Bar site. The airport at Knoxville is closer, but is north of the Watts Bar site and located in a zone that historically is cooler than at WBN.

3.3.1.2 Watts Bar and Chickamauga Hydro Releases and Headwater Elevations

Hourly releases from Watts Bar and Chickamauga Hydro Plants, and the headwater elevations at Watts Bar and Chickamauga Dams, were obtained from TVA records for January 1, 1976 through October 15, 1993.

3.3.1.3 Reservoir Flow and Elevations at WBN Site

The discharge flow rate through the WBN diffusers depends on the difference in elevation between the river surface at WBN and the water surface in the WBN holding pond. During periods of discharge from WBH, the river elevation at WBN can be lower than WBH tailwater elevation. Therefore, river flow and river elevations at WBN were calculated on an hourly basis using an explicit one-dimensional unsteady numerical flow routing model (Reference 6). Hourly discharges from WBH and Chickamauga Hydro and the headwater elevation at Chickamauga Dam were used as boundary conditions. The model was calibrated using field measurements of river elevation at WBN for the month of August 1993 (Figure 7).

3.3.1.4 River Temperatures Upstream of the Nuclear Plant Site

WBH release temperatures were generated by TVA's System Temperature (SYSTEMP) model (Reference 2) using the above meteorological data. The SYSTEMP model has previously been used to estimate probable extreme intake temperatures at WBN (Reference 3). An example of computed versus measured WBH release temperatures from that study is shown in Figure 8. Monthly average and extreme temperatures are shown in Table 4. In the absence of SCCW flow, the computed WBH release temperatures were used as the ambient river temperature at WBN. For scenarios with SCCW flow, these temperatures were incremented by the computed river temperature rise due to the flow from the WBF discharge structure (Section 3.3.1.5.7).

3.3.1.5 WBN Operation

3.3.1.5.1 Unit Loads

Unit 1 was assumed to operate at a maximum load of 1230 MWe, unless the computed turbine backpressure exceeded the limit of 5.5 inches of mercury (in. Hg), in which case the unit load was reduced until the turbine backpressure limit was met.

Table of Contents

Executive Summary 2

1.0 PURPOSE OF AND NEED FOR ACTION 5

1.1 Improved Plant Performance 5

1.2 Description of Supplemental CCW System 6

1.3 Public Involvement 6

1.4 Federal and State Permits and Licenses Required 8

1.5 Other Environmental Reviews or Documentation 9

2.0 ALTERNATIVES 10

2.1 The Proposed Action 10
2.1.1 WBF Intake and existing pipeline 11
2.1.2 New supply pipeline 11
2.1.3 New discharge pipeline 11
2.1.4 WBF discharge structure 11

2.2 No Action 12

2.3 Other Actions and Project Variations not Considered in Detail 12
2.3.1 Modification of the existing tower 12
2.3.2 Using both towers for Unit 1 operation 12
2.3.3 Variances to Proposed Action 12

2.4 Comparison of Alternatives 13
2.4.1 Comparison of Construction Impacts 14
2.4.2 Comparison of Operational Impacts 14

3.0 ENVIRONMENTAL IMPACTS 16

3.1 Air Resources 16
3.1.1 Existing Conditions for WBN - NAAQS Attainment 16
3.1.2 Construction Impacts - Fugitive Dust and Vehicle Emissions 16
3.1.3 Operational Impacts 17

3.2 Water Quality 17
3.2.1 Existing Conditions 17
3.2.2 Construction Impacts 18
3.2.3 Operational Impacts 18

3.3 Aquatic Ecology 23
3.3.1 Existing Conditions 23
3.3.2 Construction Impacts 29
3.3.3 Operational Impacts 30
3.3.4 Chemical Impacts 35

3.4 Terrestrial Ecology 36
3.4.1 Existing Conditions 36

3.4.2 Construction Impacts 37
3.4.3 Operational Impacts 38

3.5 Endangered and Threatened Species 38
3.5.1 Existing Conditions 38
3.5.2 Construction Effects 39
3.5.3 Operational Effects 40

3.6 Solid and Hazardous Wastes 40

3.7 Wetlands and Floodplains 40
3.7.1 Field Inspection and Notes 40
3.7.2 Construction Impacts 41
3.7.3 Operational Impacts 41

3.8 Cultural and Archaeological Resources 44
3.8.1 Existing Conditions 44
3.8.2 Construction Impacts 44
3.8.3 Operational Impacts 44

3.9 Socioeconomic Resources 44
3.9.1 Existing Conditions 44
3.9.2 Environmental Justice 44
3.9.3 Impacts 45

3.10 Issues Not Requiring Detailed Analysis 45
3.10.1 Traffic 45
3.10.2 Land Use Conversion 45
3.10.3 Noise 45

3.11 Commitments 45

4.0 LIST OF PREPARERS 46

5.0 LIST OF AGENCIES AND PERSONS CONTACTED 47

6.0 REFERENCES 48

7.0 GLOSSARY 52

8.0 ENCLOSURES 53

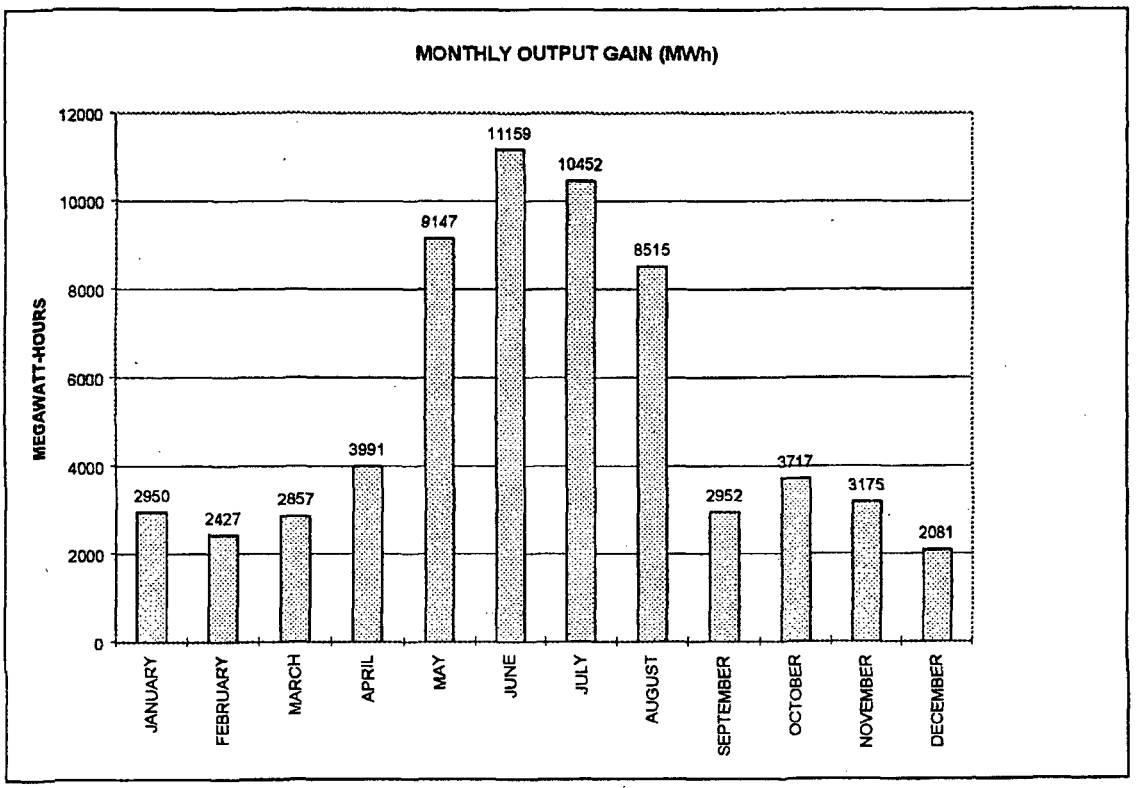
1.0 PURPOSE OF AND NEED FOR ACTION

1.1 Improved Plant Performance

The Condenser Circulating Water (CCW) system for Watts Bar Nuclear Plant (WBN) uses natural draft cooling towers to reject waste heat from the steam cycle. The capability of the towers to cool the CCW is significantly affected by site meteorological conditions. As the ambient temperatures become higher, the tower cooled water temperature also increases. This warmer water from the towers results in a decrease in the net megawatt output of WBN due to an increase in the condenser backpressure above the optimum design. If the temperature of the water to the main condenser could be reduced, the efficiency and output of WBN could be improved. Therefore, it was decided to investigate the feasibility of supplementing tower performance by routing cooler water from upstream of the Watts Bar Dam (WBH) to WBN. This water would mix with and lower the temperature of the water from the towers.

The use of water from WBH to supplement the present CCW would result in approximately 63,400 megawatt hours (MWh) increased output from WBN annually. This corresponds to a net revenue gain of approximately $1,600,000 in fiscal year 1999. This increased capacity would occur predominately in the warm weather months of May through August when the cooling tower cooled water is warmest. Figure 1-1 shows the increase in MWh for each month of an average year. This increase would result from a combination of factors, primarily reduced condenser backpressure with a resultant increase in turbine-generator output. Other less significant contributors would be avoided impacts and costs from reduced operation of some equipment (i.e. turning off of extra pumps) and extension of effective life of other items (e.g. condensate polisher resin beds).

Figure 1-1 Seasonal variation of energy gain under typical weather conditions



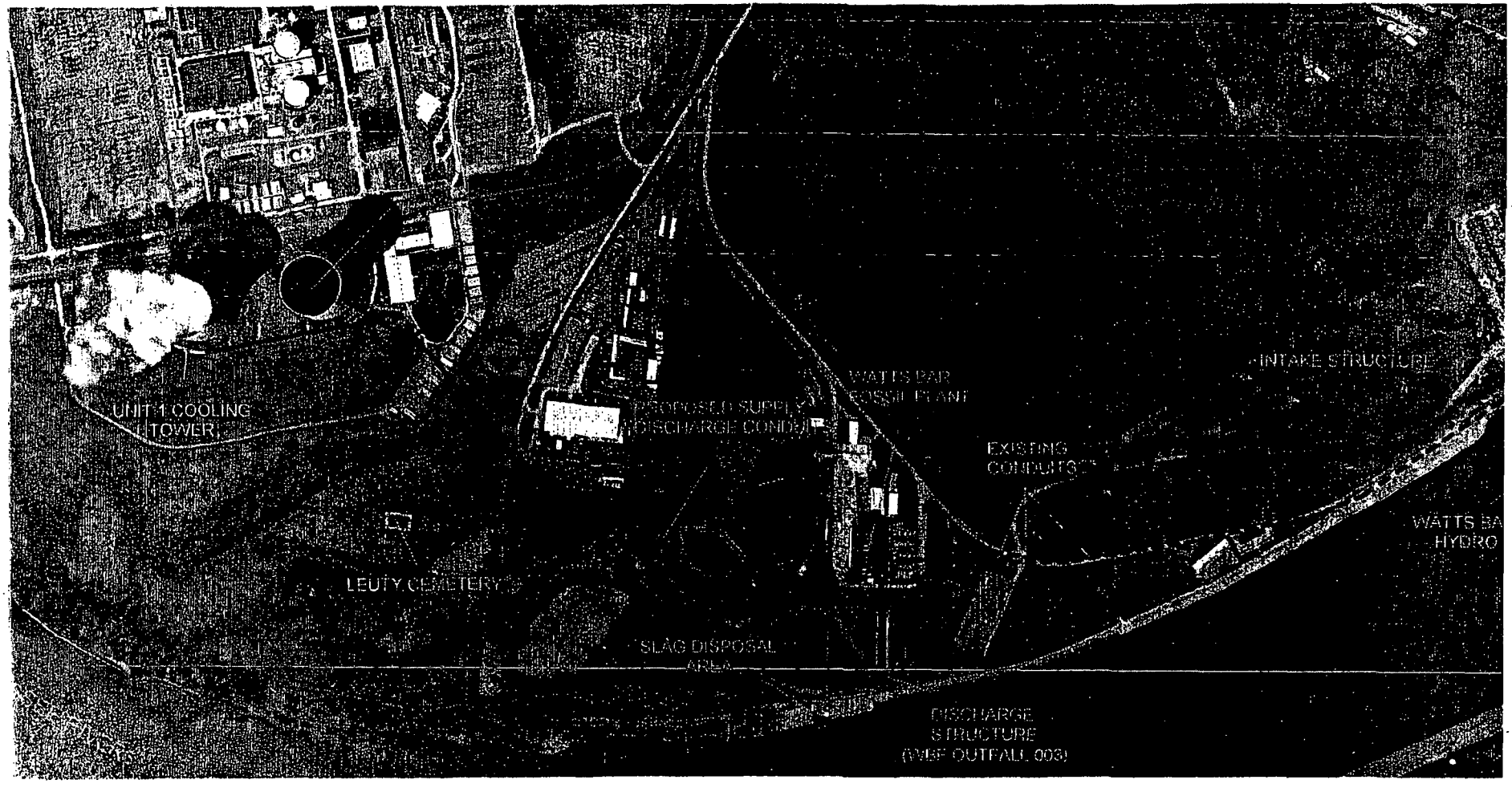
1.2 Description of Supplemental CCW System

The proposed project would provide between 115,000 and 135,000 gallons per minute (gpm) from Watts Bar Reservoir to WBN, depending on the pool elevation, to supplement the cooling capacity of the existing cooling tower. The supplemental flow would normally be continuous during WBN operation. Existing structures supply circulating water for the WBF from the Watts Bar Reservoir. The proposed project would use some of the existing WBF components to take advantage of the gravity flow and eliminate the need for new pumps. This project would use the existing intake structure at WBH, and most of the existing large-diameter pipe from the WBH to WBF to supply supplemental cooling water to the WBN CCW system. New pipe between WBF and WBN cooling towers would be installed. The discharge structure at WBF would also be integrated into the project. See Figure 1-2 for the general location of the project components. The routing of the pipeline is preliminary. Depending upon final soils testing and minimization of excavation, the route may be moved but will remain on the east side of the WBF.

1.3 Public Involvement

TVA determined that the appropriate public involvement for the draft EA was to request comment from involved State of Tennessee and Federal agencies. Neither the environmental or socioeconomic effects of the project are expected to be of public concern. The project construction occurs only on TVA property, and no significant off-site environmental impacts are projected.

Applications for new or modified environmental permits may result in public notices and public meetings at a later time.



WATTS BAR SUPPLE
CCW PROJEC

FIGURE 1-2

1.4 Federal and State Permits and Licenses Required

All required Federal, State, and local regulatory non-radiological environmental permits and approvals were obtained for construction and operation of both WBN and WBF. These include various State permits or licenses for air, water, demolition landfill, underground storage tanks, and hazardous waste generation. Environmental regulatory agencies conduct periodic inspections to verify that these facilities are in compliance with their permits and applicable requirements. In addition, TVA conducts periodic internal audits to provide further assurance of compliance with applicable environmental regulations and TVA environmental policy. Table 1-1 lists the status of existing environmental permits for both WBN and WBF.

Table 1-1 Watts Bar Facilities Existing Permits

Source Description	Permit Number	Renewal Date	Expiration Date
WBN Paint Shop – Air	048011P	07/01/2006	09/01/2006
WBN Sandblast Shop – Air	048010P	07/01/2006	09/01/2006
WBN Cooling Tower 1 – Air	019953P	None	None
WBN Cooling Tower 2 – Air	019954P	None	None
WBN Lube Oil Vapor Extractor 1 – Air	042726P	07/01/99	09/01/99
WBN Lube Oil Vapor Extractor 2 – Air	042725P	07/01/99	09/01/99
WBN Auxiliary Boilers – Air	043216F	07/01/2000	09/01/2000
WBN Hazardous Waste Generator (Fees)	TN2640030035	02/01/98	03/01/98
WBN Landfill (Fees)	721030025	09/30/98	10/17/98
WBN DG Underground Storage Tanks (Fees)	0-610035	01/31/98	03/31/98
WBN General NPDES Storm Water	TNR001343	12/26/2001	12/31/2001
WBN General Construction Storm Water	TNR102716	Per Project	None
WBN NPDES	TN0020168	03/29/98	09/29/98
WBF NPDES	TN00005461	3/31/97	8/1/2000

WBN's existing National Pollution Discharge Elimination System (NPDES) permit authorizes the discharge of process wastewater resulting from the generation of electric power by nuclear fission and associated operations, including steam generator blowdown, cooling tower blowdown, sanitary wastewater, intake screen and strainer backwash, metal cleaning wastewater, miscellaneous flows, and storm water runoff from specific outfalls. WBN will request an expedited special NPDES permit modification from the State of Tennessee in order to begin construction on the SCCW project with subsequent discharge of cooling water through WBF's Outfall 003. As shown in the above table, WBN's permit renewal date of 3/29/98 is approaching, and the WBN permit renewal will include the previously modified special permit which added Outfall 003 at WBF. In turn, the WBF NPDES permit will be revised to eliminate Outfall 003.

In addition to changes in the NPDES permits, it would be necessary for TVA to obtain other state environmental permits for the construction phase of this project. Prior to constructing the new supplemental cooling water discharge and supply pipelines, an erosion control plan would be developed as a part of obtaining and implementing a Tennessee General NPDES Permit for Storm Water Discharges Associated with Construction Activity. An Aquatic Resource Alteration Permit (ARAP) for Utility Line Crossings would be required for pipeline crossings of wet weather conveyances and streams. A Notice of Intent to be covered under the General NPDES Permit for Discharges of Hydrostatic Test Water for testing of the WBF intake and existing pipeline as well as the newly constructed pipelines would also need to be submitted as appropriate.

The proposed project would not involve any jurisdictional wetlands. However, stream crossings may require Corps of Engineers Section 404 permits and ARAP permits. In addition, concurrence would be needed from USFWS and SHPO.

If work needs to be performed on the discharge structure itself, then Corps of Engineers and ARAP permits may be needed for work performed on stream banks or on the discharge structure in water.

No nuclear licensing issues were identified by the team as an impact by the SCCW project. A nuclear safety analysis will be completed as part of the project engineering design change to verify this preliminary conclusion.

The WBN Final Safety Analysis Report (FSAR) section 10.4.5 does commit to meeting all applicable water thermal criteria by dissipating the waste heat directly to the atmosphere by means of a natural draft cooling tower. With the implementation of this project, a portion of the waste heat (up to 20%) would be dissipated in the river. However, as demonstrated by the analysis of this assessment, applicable thermal criteria would still be met. In addition, this project would include provisions to maintain compliance with chemical criteria by control discharges to the same level as those presently in the blowdown leaving the cooling towers. This plan will be revised as appropriate when the SCCW project is implemented.

1.5 Other Environmental Reviews or Documentation

The construction and operational impacts of WBN were assessed by both TVA and NRC in separate EISs (TVA, 1972 and NRC, 1978). Prior to plant startup and receipt of an operating license, and following an extended construction period, TVA prepared a review of its EIS to identify any new issues (TVA, 1995). No substantial new issues were identified by this review. Subsequently, NRC decided to prepare a supplement to their 1978 EIS. The Notice of Availability of the Final Supplemental Statement was published on May 1, 1995 (Federal Register, 1995a). TVA decided to adopt the NRC Final Supplemental EIS, and published its Notice of Adoption on July 10, 1995 and Record of Decision on August 23, 1995 (Federal Register, 1995b and 1995c).

These EISs analyze the operation of the WBN CCW system including the cooling towers. The cooling tower chemical treatment, blowdown concentrations, and thermal effects of the blowdown stream discharge were analyzed.

In 1996, recovery of boiler slag at the Watts Bar Fossil Plant for commercial sale was proposed. The environmental effects of this project were presented in an environmental assessment (TVA, 1996). The proposed route of the pipeline for the WBN SCCW project would pass near and through portions of the WBF site impacted by boiler slag recovery operations identified in that environmental assessment.

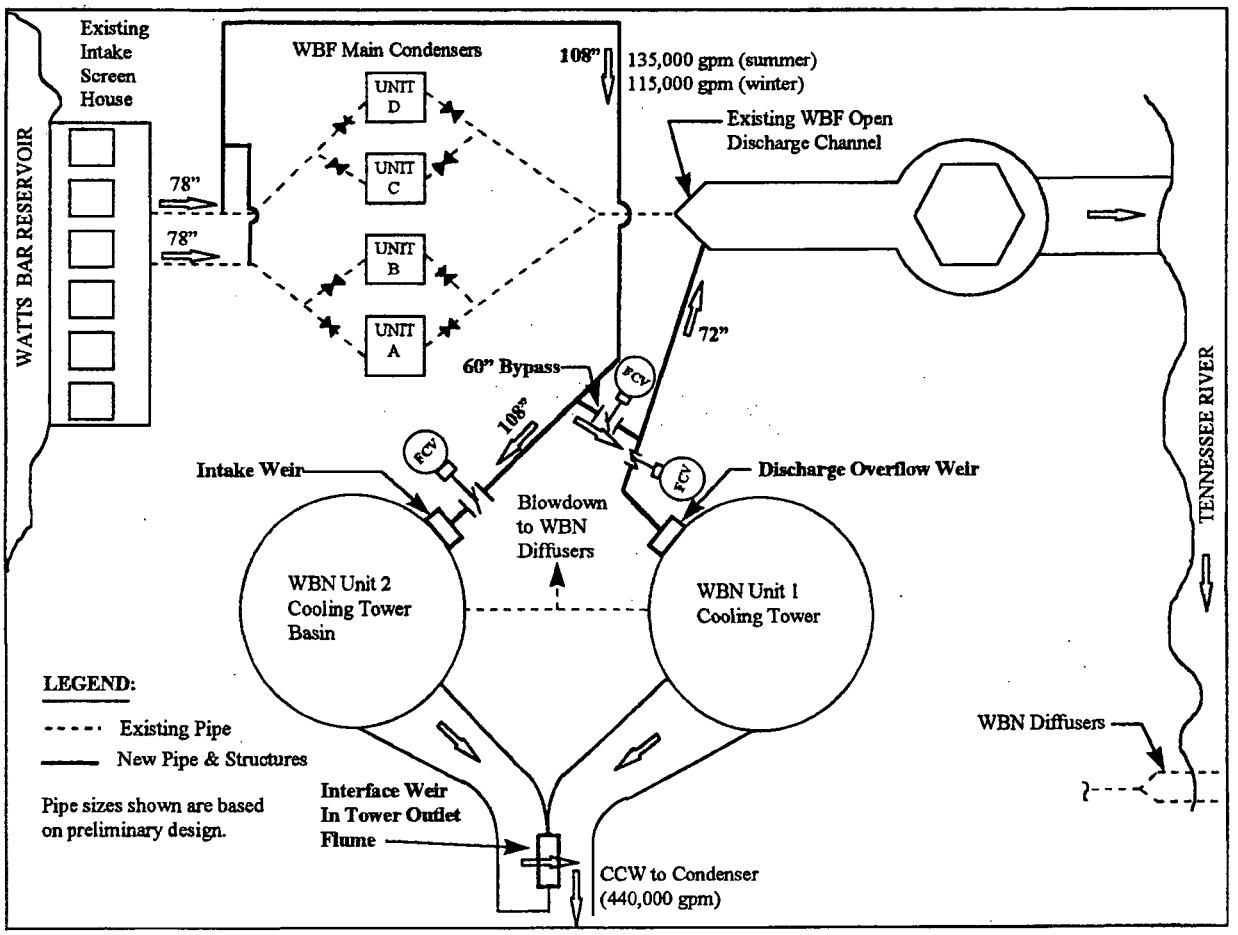
2.0 ALTERNATIVES

WBN has the capacity to generate more electrical power than is presently produced, particularly in the warmer weather months. This inherent capability can be realized if the average cold water temperature of the CCW system can be decreased. Various alternatives were evaluated for achieving the increased output as well as the No Action option.

2.1 The Proposed Action

The proposed action involves providing water from Watts Bar Reservoir to the CCW system at WBN to supplement the performance of the existing cooling tower. The arrangement of the project is schematically shown on Figure 2-1.

Figure 2-1. Conceptual flow diagram of SCCW system.



3.3.1.5.2 CCW Pumps

Four CCW pumps were assumed in operation at all times, unless otherwise noted in the descriptions of the WBN operational scenarios.

3.3.1.5.3 ERCW and RCW Pumps

Two ERCW pumps and two RCW pumps were assumed in operation at all times unless otherwise noted in the descriptions of the WBN operational scenarios. ERCW pump flow rates were assumed to be 21.7 cfs (9,740 gpm) per pump. RCW pump flow rates were assumed to be 10.3 cfs (4,610 gpm) per pump. These flow rates assume 10 percent degradation from design capacity as indicated in the ERCW Design Criteria and RCW System Description (References 12,13). ERCW and RCW system intake temperatures were assumed equal to the ambient river temperature as described in Section 3.3.1.4.

3.3.1.5.4 SCCW Flow

The SCCW system intake flow (WBF intake to Unit 2 tower basin) was computed from the following equation (Reference 10).

$$\text{Eq.1} \qquad flow = 133000gpm\sqrt{\frac{lake_level - 729ft}{740.5ft - 729ft}}$$

FLOW is the flow through the WBF intake, and LAKE_LEVEL is the Watts Bar Reservoir elevation (ft). Based on recorded WBH headwater elevations for the period from January 1, 1976 through October 15, 1993, the SCCW system intake flow rate ranged from 210.4 cfs (94453 gpm) to 365.3 cfs (163,973 gpm). These flows correspond to WBH headwater elevations of 734.8 ft and 746.8 ft, respectively.

229
-359

3.3.1.5.5 Cooling Tower Performance

The Unit 1 cooling tower capability was assumed to be 105 percent of design capability, based on performance testing after modifications made during the 1996 mid-cycle outage (Reference 11).

3.3.1.5.6 Condenser Cleanliness

The Unit 1 condenser cleanliness factor was assumed to be 85 percent.

3.3.1.5.7 Instream Temperature Rise Due to Flow Through WBF Discharge Channel

CORMIX runs were made for all combinations of the following:
River flows:

- 1000 cfs - minimum value for which CORMIX would run
- 4000 cfs - minimum April instantaneous WBH release
- 8000 cfs - nominal WBH single unit release
- 46000 cfs - maximum WBH turbine release

River surface elevations:

- 675 ft - minimum winter pool for Chickamauga Reservoir
- 683 ft - maximum summer pool for Chickamauga Reservoir

River temperatures (WBH discharge temperature):

- 39.2 °F - minimum value for which CORMIX can be run
- 60.0 °F - approximate mean value of river temperature data
- 83.0 °F - maximum value from river temperature data

Discharge flow:

334.5 cfs - maximum expected flow from WBF intake to CCW inlet
269.6 cfs - minimum expected discharge from cooling tower to WBF discharge structure

Plant Temperature Rise (difference between discharge and ambient river temperatures):

5.4 °F - state instream temperature rise limit
11.7 °F - approximate median temperature rise computed by WBN plant model.
20.7 °F - intermediate value for improved interpolation
43.2 °F - maximum plant temperature rise computed by WBN plant model.

The results of these CORMIX runs were incorporated into a five dimensional matrix in the WBN plant model. For each hour in the simulation period, the instream temperature rise below the WBF discharge structure was determined by interpolation using the ambient river temperature, SCCW flow, and computed river flow and elevation and plant temperature rise.

For river flows less than 1000 cfs, 1000 cfs is used as the river flow in the interpolation process. Field studies of WBF operation (Reference 4) indicated that for prolonged periods of low or zero river flow, the temperature in the vicinity of the WBF discharge channel reached an equilibrium level, after which the heated area expanded downstream with no further increase in temperature. The same process is expected to occur with the proposed discharge, although the equilibrium temperature may differ due to the differences in discharge temperature and flow rate.

3.3.2 Model Results

Four operational scenarios were investigated. For all scenarios, hourly WBN discharge temperature and flow, and downstream river temperature, temperature rise, and rate of change were calculated for the period from January 1, 1976 through October 15, 1993. The 24 hour running average values were then computed from the hourly values. The downstream temperature, temperature rise, and rate of change were computed based on the combined effects of the SCCW and WBN diffuser discharges. WBN was operated under the current diffuser discharge restrictions (no WBN diffuser discharge when WBH discharge is less than 3,500 cfs). During periods when the WBH discharge is below this level, cooling tower blowdown flow is routed into the yard holding pond. The blowdown rate to the diffuser/holding pond system was fixed at 44.6 cfs (20000 gpm), so the same maximum pond elevation of 703.96 feet occurred under all scenarios. The pond never reached the 707.0 ft elevation of the overflow weir, therefore there was no discharge from the overflow weir for any of the scenarios.

The maximum upstream river temperature for all scenarios was 82.5°F (28.1 C°) on July 28, 1993. The maximum downstream river temperature of 83.7°F (28.7 C°) for all scenarios occurred on the same date.

Model results for each scenario are given below.

3.3.2.1 Scenario 1

Under Scenario 1, the full SCCW flow given Equation 1 was routed to the Unit 2 tower basin. Two ERCW pumps, two RCW pumps, and four CCW pumps were in service at all times.

The maximum diffuser discharge of 129 cfs (57,900 gpm), a combination of 43.5 cfs (19,524 gpm) blowdown from the towers and 85.5 cfs (38,375 gpm) flow from the yard holding pond, occurred on September 28, 1988. The maximum total discharge from the plant occurred at the same time, with an additional 280.3 cfs (125,807 gpm) being discharged through the WBF discharge structure for a total discharge rate of 409.3 cfs (183,707 gpm).

The maximum 24-hour averaged downstream river temperature of 83.5°F (28.6 C°) occurred on July 28, 1993. The maximum 24-hour averaged downstream river temperature rise was 7.1 F° (3.9 C°) on March 4, 1988. The

maximum discharge temperature was 96.3°F (35.7 C°) on July 13, 1980. A monthly summary of the results for Scenario 1 is shown in Table 5.

As shown in Figure 9, the instream temperature rise exceeded 5.4 F° (3.0 C°) for 1858 hours (1.2 percent) of the simulation period, most often during in the month of February.

3.3.2.2 Scenario 2

Under Scenario 2, the full SCCW flow given by Equation 1 was routed to the Unit 2 tower basin. Two ERCW pumps and two RCW pumps were in service at all times. Four CCW pumps were in service except during January and February, when the number of CCW pumps was reduced to three.

The maximum diffuser discharge of 129 cfs (57,900 gpm), a combination of 43.5 cfs (19,524 gpm) blowdown from the towers and 85.5 cfs (38,375 gpm) flow from the yard holding pond, occurred on September 28, 1988. The maximum total discharge from the plant occurred at the same time, with an additional 280.3 cfs (125,807 gpm) being discharged through the WBF discharge structure for a total discharge rate of 409.3 cfs (183,707 gpm).

The maximum 24-hour averaged downstream river temperature of 83.5°F (28.6 C°) occurred on July 28, 1993. The maximum 24-hour averaged downstream river temperature rise was 7.1 F° (3.9 C°) on March 4, 1988. The maximum discharge temperature was 96.3°F (35.7 C°) on July 13, 1980. A monthly summary of the results for Scenario 2 is shown in Table 6.

Decreasing the number of CCW pumps during January and February substantially reduced the number of times the 24-hour averaged instream temperature rise exceeded 5.4 F° during those months (Figure 10); however it still exceeded 5.4 F° for 1316 hours (0.8 percent) of the simulation period, with February and March having the most occurrences.

3.3.2.3 Scenario 3

Under Scenario 3, 40 percent of the SCCW flow given by Equation 1 was diverted directly to the WBF discharge structure during the months of November through April. The remaining flow was routed to the Unit 2 cooling tower basin. Four CCW pumps were used except during January when the number of CCW pumps was reduced to three.

The maximum diffuser discharge of 129 cfs (57,900 gpm), a combination of 43.5 cfs (19,524 gpm) blowdown from the towers and 85.5 cfs (38,375 gpm) flow from the yard holding pond, occurred on September 28, 1988. The maximum total discharge from the plant occurred at the same time, with an additional 280.3 cfs (125,807 gpm) being discharged through the WBF discharge structure for a total discharge rate of 409.3 cfs (183,707 gpm).

The maximum 24-hour averaged downstream river temperature of 83.5°F (28.6 C°) occurred on July 28, 1993. The maximum 24-hour averaged downstream river temperature rise was 5.3 F° (2.9 C°) on May 2, 1983. The maximum discharge temperature was 96.3°F (35.7 C°) on July 13, 1980. A monthly summary of the results for Scenario 3 is shown in Table 7.

With the operation of the bypass, there were no instances of the 24-hour averaged instream temperature rise exceeding 5.4 F° (3.0 C°) (Figure 11).

3.3.2.4 Scenario 4

WBN operations for Scenario 4 were the same as for Scenario 3, with the addition of a third RCW pump during the month of May.

The maximum diffuser discharge of 129 cfs (57,900 gpm), a combination of 43.5 cfs (19,524 gpm) blowdown from the towers and 85.5 cfs (38,375 gpm) flow from the yard holding pond, occurred on September 28, 1988. The maximum total discharge from the plant occurred on May 27, 1985, with a diffuser discharge of 122 cfs (54,757 gpm) an additional 288.3 cfs (129,398 gpm) being discharged through the WBF discharge structure for a total discharge rate of 410.3 cfs (184,155 gpm).

The maximum 24-hour averaged downstream river temperature of 83.5°F (28.6 C°) occurred on July 28, 1993. The maximum 24-hour averaged downstream river temperature rise was 4.8 F° (2.7 C°) on May 2, 1983. The maximum discharge temperature was 96.3°F (35.7 C°) on July 13, 1980. A monthly summary of the results for Scenario 4 is shown in Table 8.

The additional RCW pump reduced the maximum value of the 24-hour averaged instream temperature rise for May from 5.3 F° to 4.8 F°, with no occurrences of the rise exceeding 5.4 F° (Figure 12).

3.4 Effect of SCCW System Operation on WBN Intake Temperatures

The design limit on the intake temperature for the WBN ERCW system is 85 °F (29.4 °C), above which the plant is required to initiate shut-down protocol for safety reasons. Since the WBF discharge structure is upstream of the WBN RCW and ERCW system intakes, intake temperatures at WBN would be increased due to the operation of the SCCW system.

WBN ERCW intake temperatures were computed for the simulations by adding the instream temperature rise due to the SCCW system discharge at the end of the 1000-foot mixing zone to the WBH discharge temperature. No further cooling or mixing was assumed to occur between the end of the mixing zone and the WBN intake structure, which is approximately 4000 feet further downstream. Nor was any allowance made for thermal stratification which would provide cooler water at the WBN intake. The maximum computed intake temperature which occurred under all of the four scenarios was 83.7 °F (28.7 °C) on July 28, 1993. The WBH discharge temperature at this time was 82.5 °F (28.1 °C).

Under a combination of extremely high ambient river and air temperatures and low or zero WBH discharge flow, it would be possible for the intake temperature to exceed the limit due to the influence of the SCCW system discharge. However, such a combination of conditions is unlikely, since the normal summer peaking operation of WBH would provide adequate river flow during periods of high air temperatures to prevent its occurrence. Should these conditions occur, increasing the WBH discharge would normally provide sufficient additional dilution of the flow from the WBF discharge structure to prevent the WBN intake temperature from reaching 85 °F. In the event that increased discharge from WBH is not possible, curtailing the SCCW flow would reduce the WBN intake temperature to that of the WBH discharge. If the WBH discharge temperature approaches the WBN intake limit, the only recourse would be to shut down WBN operation.

3.5 Effect of Watts Bar Nuclear and Fossil Plant Discharges on Sequoyah Nuclear Plant

Sequoyah Nuclear Plant (SQN), located about 45 river miles downstream of the Watts Bar facilities, has intake temperature limits of 83.0 °F when the Chickamauga Reservoir elevation is at or below 680 feet, and 84.5 °F otherwise. In 1993, a reservoir water quality model was used to determine the potential effects of the Watts Bar facilities on SQN intake temperatures (Reference 9). It was determined that there would be no adverse effects on SQN intake temperatures due to the combined operation of two units at Watts Bar Nuclear Plant and Watts Bar Fossil Plant.

River temperatures are high enough to warrant concern about exceeding the SQN intake temperature limit only during the months of July through September. When operating, WBF discharged heat into the Tennessee River at a rate of 1.4×10^9 BTU/hr. For the proposed one-unit WBN operation with SCCW flow, the maximum daily averaged rate of heat discharged through the WBF discharge structure during the months of July through September is 1.35×10^9 BTU/hr (Table 7). Since this is less than the rate of heat discharged by WBF, no adverse effects on SQN intake temperatures should result from the operation of the SCCW flow at WBN.

4.0 Conclusions

Based on the above analyses, the proposed SCCW system can be operated without significant risk of violation of the proposed instream thermal limits. It would be necessary to operate the bypass system during the months of December, February, March, and April.

The number of predicted violations of the instream temperature rise limit during the months of November and January are relatively small. This indicates that some operation of the bypass would be needed in January and possibly in November, but not on a continuous basis. The conditions under which the bypass would be needed are a combination of low river temperature and higher than normal air temperature. Given reasonably accurate weather forecasts, these conditions can be predicted sufficiently far in advance to turn the bypass on if needed during these months.

There is no significant likelihood of the 85 °F (29.4 °C) WBN intake temperature safety limit being exceeded due to operation of the SCCW system. However, should the intake temperature approach the limit, special hydro operations could be used to reduce the temperature at the WBN intake. If such hydro operations are not feasible, the SCCW system could be shut down, reducing the WBN intake temperature to that of the WBH discharge temperature.

No adverse influence on river temperatures at Sequoyah Nuclear Plant is expected from operation of the SCCW system.

5.0 Tables

Table 1 Average WBH Discharges From 1/01/1976 Through 10/15/1993

Month	Discharge (cfs)
January	36146
February	33746
March	30855
April	18411
May	20387
June	22833
July	24155
August	25546
September	22400
October	20550
November	25349
December	35324

Season	Discharge (cfs)
Winter	35108
Spring	23270
Summer	24193
Fall	22715

Table 2

Dimensions of Constructed Diffusers
Watts Bar Nuclear Plant

		Upstream Leg	Downstream Leg	Total
DIFFUSER	Pipe Length (ft) (unpaved corrugated steel pipe)	80.0	160.0	240.0
	Pipe Diameter (ft)	3.5	4.5	
	Port Diameter (in)	1.0	1.0	
	Number of Ports Per Corrugation	2	2	
	Port Spacing Normal to Corrugation (in)	3.0	3.0	
	Port Spacing Parallel to Corrugation (in)	3.0	3.0	
	Friction Factor	0.0948	0.0841	
APPROACH PIPE	Pipe Length (ft) (paved corrugated steel pipe)	447.0	297.0	744.0
	Pipe Diameter (ft)	3.5	4.5	
	Friction Factor	0.0191	0.0148	

Table 3

Results of CORMIX Runs for WBN Blowdown Discharge Through WBF Discharge Structure					
RIVER ELEV (FT)	RIVER FLOW (CFS)	RIVER TEMP (°F)	DISCH FLOW (CFS)	DISCH TEMP (°F)	ΔT @ 1000 FT (F°)
675	988.8	39.2	334.5	44.6	1.4
675	988.8	39.2	334.5	50.9	3
675	988.8	39.2	334.5	59.9	5.2
675	988.8	39.2	334.5	82.4	10.9
675	988.8	39.2	269.6	44.6	1.2
675	988.8	39.2	269.6	50.9	2.6
675	988.8	39.2	269.6	59.9	4.4
675	988.8	39.2	269.6	82.4	9.3
675	3990.4	39.2	334.5	44.6	1.5
675	3990.4	39.2	334.5	50.9	2.5
675	3990.4	39.2	334.5	59.9	3.5
675	3990.4	39.2	334.5	82.4	7.5
675	3990.4	39.2	269.6	44.6	1.5
675	3990.4	39.2	269.6	50.9	2.8
675	3990.4	39.2	269.6	59.9	3.1
675	3990.4	39.2	269.6	82.4	6.9
675	7980.8	39.2	334.5	44.6	1.3
675	7980.8	39.2	334.5	50.9	2.6
675	7980.8	39.2	334.5	59.9	3.6
675	7980.8	39.2	334.5	82.4	6.6
675	7980.8	39.2	269.6	44.6	1.1
675	7980.8	39.2	269.6	50.9	2.6
675	7980.8	39.2	269.6	59.9	3.2
675	7980.8	39.2	269.6	82.4	6.9
675	45907.4	39.2	334.5	44.6	1
675	45907.4	39.2	334.5	50.9	2
675	45907.4	39.2	334.5	59.9	1.8
675	45907.4	39.2	334.5	82.4	4.3
675	45907.4	39.2	269.6	44.6	0.9
675	45907.4	39.2	269.6	50.9	1.7
675	45907.4	39.2	269.6	59.9	4.5
675	45907.4	39.2	269.6	82.4	4
683	988.8	39.2	334.5	44.6	1.4
683	988.8	39.2	334.5	50.9	2.9
683	988.8	39.2	334.5	59.9	5.2
683	988.8	39.2	334.5	82.4	10.9
683	988.8	39.2	269.6	44.6	1.2
683	988.8	39.2	269.6	50.9	2.5
683	988.8	39.2	269.6	59.9	4.4
683	988.8	39.2	269.6	82.4	9.3
683	3990.4	39.2	334.5	44.6	1
683	3990.4	39.2	334.5	50.9	2.9

Results of CORMIX Runs for WBN Blowdown Discharge Through WBF Discharge Structure					
RIVER ELEV (FT)	RIVER FLOW (CFS)	RIVER TEMP (°F)	DISCH FLOW (CFS)	DISCH TEMP (°F)	ΔT @ 1000 FT (F°)
683	3990.4	39.2	334.5	59.9	3.4
683	3990.4	39.2	334.5	82.4	4.8
683	3990.4	39.2	269.6	44.6	0.9
683	3990.4	39.2	269.6	50.9	1.7
683	3990.4	39.2	269.6	59.9	3
683	3990.4	39.2	269.6	82.4	6.3
683	7980.8	39.2	334.5	44.6	1.2
683	7980.8	39.2	334.5	50.9	2.4
683	7980.8	39.2	334.5	59.9	2.8
683	7980.8	39.2	334.5	82.4	3.8
683	7980.8	39.2	269.6	44.6	1
683	7980.8	39.2	269.6	50.9	1.6
683	7980.8	39.2	269.6	59.9	2.9
683	7980.8	39.2	269.6	82.4	11.8
683	45907.4	39.2	334.5	44.6	0.8
683	45907.4	39.2	334.5	50.9	1.2
683	45907.4	39.2	334.5	59.9	2.3
683	45907.4	39.2	334.5	82.4	4.7
683	45907.4	39.2	269.6	44.6	0.8
683	45907.4	39.2	269.6	50.9	1.1
683	45907.4	39.2	269.6	59.9	2.2
683	45907.4	39.2	269.6	82.4	6.5
675	988.8	60	334.5	65.4	1.4
675	988.8	60	334.5	71.7	3
675	988.8	60	334.5	80.7	5.2
675	988.8	60	334.5	103.2	10.9
675	988.8	60	269.6	65.4	1.2
675	988.8	60	269.6	71.7	2.5
675	988.8	60	269.6	80.7	4.4
675	988.8	60	269.6	103.2	9.3
675	3990.4	60	334.5	65.4	1.4
675	3990.4	60	334.5	71.7	2
675	3990.4	60	334.5	80.7	3.5
675	3990.4	60	334.5	103.2	5.9
675	3990.4	60	269.6	65.4	1.7
675	3990.4	60	269.6	71.7	1.8
675	3990.4	60	269.6	80.7	3.2
675	3990.4	60	269.6	103.2	8.8
675	7980.8	60	334.5	65.4	1.3
675	7980.8	60	334.5	71.7	2.1
675	7980.8	60	334.5	80.7	3.2
675	7980.8	60	334.5	103.2	6.5
675	7980.8	60	269.6	65.4	1.4
675	7980.8	60	269.6	71.7	2
675	7980.8	60	269.6	80.7	3.3

Results of CORMIX Runs for WBN Blowdown Discharge Through WBF Discharge Structure					
RIVER ELEV (FT)	RIVER FLOW (CFS)	RIVER TEMP (°F)	DISCH FLOW (CFS)	DISCH TEMP (°F)	ΔT @ 1000 FT (F°)
675	7980.8	60	269.6	103.2	11.8
675	45907.4	60	334.5	65.4	0.8
675	45907.4	60	334.5	71.7	1
675	45907.4	60	334.5	80.7	2
675	45907.4	60	334.5	103.2	4.4
675	45907.4	60	269.6	65.4	0.7
675	45907.4	60	269.6	71.7	0.9
675	45907.4	60	269.6	80.7	1.8
675	45907.4	60	269.6	103.2	5.4
683	988.8	60	334.5	65.4	1.4
683	988.8	60	334.5	71.7	3
683	988.8	60	334.5	80.7	5.2
683	988.8	60	334.5	103.2	10.9
683	988.8	60	269.6	65.4	1.2
683	988.8	60	269.6	71.7	2.5
683	988.8	60	269.6	80.7	4.4
683	988.8	60	269.6	103.2	9.3
683	3990.4	60	334.5	65.4	0.9
683	3990.4	60	334.5	71.7	1.9
683	3990.4	60	334.5	80.7	2.5
683	3990.4	60	334.5	103.2	3.3
683	3990.4	60	269.6	65.4	0.8
683	3990.4	60	269.6	71.7	1.4
683	3990.4	60	269.6	80.7	4
683	3990.4	60	269.6	103.2	3.4
683	7980.8	60	334.5	65.4	0.8
683	7980.8	60	334.5	71.7	1.5
683	7980.8	60	334.5	80.7	2
683	7980.8	60	334.5	103.2	10.3
683	7980.8	60	269.6	65.4	0.8
683	7980.8	60	269.6	71.7	1.6
683	7980.8	60	269.6	80.7	6.3
683	7980.8	60	269.6	103.2	9.9
683	45907.4	60	334.5	65.4	0.6
683	45907.4	60	334.5	71.7	1.3
683	45907.4	60	334.5	80.7	2.3
683	45907.4	60	334.5	103.2	6.9
683	45907.4	60	269.6	65.4	0.6
683	45907.4	60	269.6	71.7	1.3
683	45907.4	60	269.6	80.7	3.2
683	45907.4	60	269.6	103.2	6.5
675	988.8	83	334.5	88.4	1.4
675	988.8	83	334.5	94.7	3
675	988.8	83	334.5	103.7	5.2
675	988.8	83	334.5	126.2	10.9

Results of CORMIX Runs for WBN Blowdown Discharge Through WBF Discharge Structure					
RIVER ELEV (FT)	RIVER FLOW (CFS)	RIVER TEMP (°F)	DISCH FLOW (CFS)	DISCH TEMP (°F)	ΔT @ 1000 FT (F°)
675	988.8	83	269.6	88.4	1.2
675	988.8	83	269.6	94.7	2.5
675	988.8	83	269.6	103.7	4.4
675	988.8	83	269.6	126.2	9.3
675	3990.4	83	334.5	88.4	2.1
675	3990.4	83	334.5	94.7	2
675	3990.4	83	334.5	103.7	3.6
675	3990.4	83	334.5	126.2	7.1
675	3990.4	83	269.6	88.4	0.8
675	3990.4	83	269.6	94.7	3.3
675	3990.4	83	269.6	103.7	3.3
675	3990.4	83	269.6	126.2	7.3
675	7980.8	83	334.5	88.4	2.2
675	7980.8	83	334.5	94.7	1.9
675	7980.8	83	334.5	103.7	3.2
675	7980.8	83	334.5	126.2	12
675	7980.8	83	269.6	88.4	0.8
675	7980.8	83	269.6	94.7	1.9
675	7980.8	83	269.6	103.7	3.3
675	7980.8	83	269.6	126.2	11.3
675	45907.4	83	334.5	88.4	0.7
675	45907.4	83	334.5	94.7	1.1
675	45907.4	83	334.5	103.7	2.1
675	45907.4	83	334.5	126.2	6.2
675	45907.4	83	269.6	88.4	0.4
675	45907.4	83	269.6	94.7	1
675	45907.4	83	269.6	103.7	1.9
675	45907.4	83	269.6	126.2	5.6
683	988.8	83	334.5	88.4	1.4
683	988.8	83	334.5	94.7	3
683	988.8	83	334.5	103.7	5.2
683	988.8	83	334.5	126.2	10.9
683	988.8	83	269.6	88.4	1.2
683	988.8	83	269.6	94.7	2.5
683	988.8	83	269.6	103.7	4.4
683	988.8	83	269.6	126.2	9.3
683	3990.4	83	334.5	88.4	0.9
683	3990.4	83	334.5	94.7	1.5
683	3990.4	83	334.5	103.7	2.7
683	3990.4	83	334.5	126.2	3.3
683	3990.4	83	269.6	88.4	0.8
683	3990.4	83	269.6	94.7	1.2
683	3990.4	83	269.6	103.7	3
683	3990.4	83	269.6	126.2	2.7
683	7980.8	83	334.5	88.4	0.7

Results of CORMIX Runs for WBN Blowdown Discharge Through WBF Discharge Structure					
RIVER ELEV (FT)	RIVER FLOW (CFS)	RIVER TEMP (°F)	DISCH FLOW (CFS)	DISCH TEMP (°F)	ΔT @ 1000 FT (F°)
683	7980.8	83	334.5	94.7	1.5
683	7980.8	83	334.5	103.7	5.9
683	7980.8	83	334.5	126.2	9.2
683	7980.8	83	269.6	88.4	0.8
683	7980.8	83	269.6	94.7	1
683	7980.8	83	269.6	103.7	5.6
683	7980.8	83	269.6	126.2	8.9
683	45907.4	83	334.5	88.4	0.6
683	45907.4	83	334.5	94.7	1.3
683	45907.4	83	334.5	103.7	3.3
683	45907.4	83	334.5	126.2	6.8
683	45907.4	83	269.6	88.4	0.6
683	45907.4	83	269.6	94.7	1.2
683	45907.4	83	269.6	103.7	3.1
683	45907.4	83	269.6	126.2	6.4

Table 4

Monthly Average and Extreme Ambient River Temperatures (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	34.8	35.1	37.6	48.6	57.7	62.5	66.1	70.7	67.4	58.1	47.6	39.6
Avg	42.0	41.9	47.7	56.7	64.5	70.7	74.9	76.5	75.0	68.0	58.8	48.7
Max	51.7	51.0	56.1	65.1	71.9	78.8	82.5	81.7	81.1	76.7	67.9	59.2

Table 5

Summary of Results - Scenario 1
January 1, 1976 - October 15, 1993

1230 MWe Generation
Supplemental CCW Flow
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
January													
Min	-10	-11	36.5	42.8	1.2	34.8	37.4	0.9	-1.3	698	0	188.3	1.36E+08
Max	71	63	55.7	77.9	39.9	51.7	55.2	6.9	1.5	702.9	122	288.8	1.82E+09
Avg	37.5	33.9	45.1	62.7	20.7	42	45.3	3.2	-0.01	698.1	43.6	213.3	9.89E+08
February													
Min	9	7	37.3	51.8	3.2	35.1	37.9	1	-1.7	698	0	188.7	2.53E+08
Max	79	67	55.1	79.3	42.1	51	54.6	7	2	702.2	118	295.4	1.92E+09
Avg	42.5	37.9	45.5	65	23.2	41.9	45.6	3.8	0	698.1	43.7	211.1	1.10E+09
March													
Min	10	8	40	52.3	3.4	37.6	40.9	0.9	-2	698	0	189.2	3.22E+08
Max	85	73	61.5	81.8	39.4	56.1	60.8	7.1	1.7	703	124	282.8	1.82E+09
Avg	51.2	45.3	51.2	69.3	21.7	47.7	51.2	3.6	0.01	698.2	43.7	213.5	1.04E+09
April													
Min	26	25	50.5	60.1	-0.1	48.6	51.2	0.9	-2.2	698	0	193.2	1.68E+08
Max	91	73	69	83.1	31.5	65.1	67.7	6	2.4	702.1	118	322	1.74E+09
Avg	59.8	52.4	59.8	73.7	17	56.7	59.8	3.3	0.01	698.4	43.4	252.2	9.60E+08
May													
Min	38	36	59.1	68.5	-1.1	57.7	59.9	0.8	-3	698	0	219.3	1.77E+08
Max	93	78	75.2	87.2	28.7	71.9	74.4	5.3	2.9	703.5	126	343.2	1.61E+09
Avg	67.3	61.1	67.1	78.7	14.2	64.5	67.1	2.7	0.01	698.5	43.3	275.5	8.81E+08
June													

Summary of Results - Scenario 1
January 1, 1976 - October 15, 1993

1230 MWe Generation
Supplemental CCW Flow
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
Min	47	46	63.3	72.4	-1.2	62.5	63.6	0.9	-2.6	698	0	249.2	2.39E+08
Max	101	81	80.2	89.4	24.4	78.8	80	4.2	1.6	702.7	122	327.7	1.48E+09
Avg	75.1	68.3	72.8	83.3	12.6	70.7	72.8	2.1	0.01	698.5	43.3	276.6	7.86E+08
July													
Min	57	56	68.3	78	-3.4	66.1	68.5	0.8	-2.1	698	0	254.6	1.02E+07
Max	105	85	83.7	91	24.2	82.5	83.5	3.4	1.6	701.8	116	304.5	1.35E+09
Avg	79	72	76.5	85.7	10.8	74.9	76.5	1.6	0	698.4	43.4	275.7	6.69E+08
August													
Min	54	53	71.9	76.6	-4.7	70.7	72.4	0.7	-1.7	698	0	262.2	-6.04E+07
Max	104	84	82.9	89.4	18.9	81.7	82.8	2.4	1.3	701.2	112	293.4	9.90E+08
Avg	77.5	71	77.7	85	8.5	76.5	77.7	1.2	0	698.3	43.4	274.8	5.23E+08
September													
Min	41	40	68.2	69.6	-9.9	67.4	68.4	0.6	-1.8	698	0	263.2	-4.21E+08
Max	99	79	82.3	88.1	17.6	81.1	82	2.4	1	704	129	298.6	8.90E+08
Avg	71	65.5	76.1	81.5	6.4	75	76.2	1.1	-0.01	698.5	43.3	276.1	3.95E+08
October													
Min	26	25	59.2	62.1	-10.5	58.1	59.4	0.6	-1.7	698	0	242.2	-4.61E+08
Max	89	76	78.3	86.2	20.8	76.7	78	3.1	1.1	701.7	116	317.3	1.12E+09
Avg	59	53.8	69.3	74.3	6.2	68	69.4	1.3	-0.01	698.3	43.3	266.8	3.63E+08
November													
Min	16	16	48.4	55.3	-8.8	47.6	48.9	0.6	-1.2	698	0	207.4	-3.33E+08
Max	81	70	70.5	82.7	32	67.9	69.7	5.8	1.4	701	110	286.3	1.43E+09
Avg	50.3	45.9	60.6	69.6	10.7	58.8	60.8	1.9	-0.01	698.2	43.4	237.7	5.64E+08
December													

Summary of Results - Scenario 1
January 1, 1976 - October 15, 1993

1230 MWe Generation
Supplemental CCW Flow
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
Min	-2	-2	41	46.5	-2.1	39.6	41.4	0.7	-1.4	698	0	191.4	8.96E+06
Max	77	69	61.8	80.9	37.8	59.2	61.9	6.5	1.9	701.7	114	314.5	1.60E+09
Avg	41.6	37.8	51.2	64.9	16.2	48.7	51.4	2.5	-0.01	698.2	43.6	215.1	7.74E+08

Table 6

Summary of Results - Scenario 2
January 1, 1976 - October 15, 1993

1230 MWe Generation
Supplemental CCW Flow
3 CCW *Pumps: Jan - Feb*
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
January													
Min	-10	-11	36.1	40.6	-1	34.8	37	0.8	-1.3	698	0	188.3	3.53E+07
Max	71	63	55.2	77.1	38	51.7	55	6.5	1.5	702.9	122	288.8	1.73E+09
Avg	37.5	33.9	44.8	60.8	18.7	42	45	2.9	-0.01	698.1	43.6	213.3	8.95E+08
February													
Min	9	7	36.9	49.7	1.1	35.1	37.5	0.9	-1.6	698	0	188.7	1.54E+08
Max	79	67	54.7	77.4	40.2	51	54.1	6.6	1.9	702.2	118	295.4	1.80E+09
Avg	42.5	37.9	45.2	63.1	21.2	41.9	45.2	3.4	0	698.1	43.7	211.1	1.01E+09
March													
Min	10	8	40	52.3	3.4	37.6	40.9	0.9	-2	698	0	189.2	3.22E+08
Max	85	73	61.5	81.8	39.4	56.1	60.8	7.1	1.7	703	124	282.8	1.82E+09
Avg	51.2	45.3	51.2	69.3	21.7	47.7	51.2	3.6	0.01	698.2	43.7	213.5	1.04E+09
April													
Min	26	25	50.5	60.1	-0.1	48.6	51.2	0.9	-2.2	698	0	193.2	1.68E+08
Max	91	73	69	83.1	31.5	65.1	67.7	6	2.4	702.1	118	322	1.74E+09
Avg	59.8	52.4	59.8	73.7	17	56.7	59.8	3.3	0.01	698.4	43.4	252.2	9.60E+08
May													
Min	38	36	59.1	68.5	-1.1	57.7	59.9	0.8	-3	698	0	219.3	1.77E+08
Max	93	78	75.2	87.2	28.7	71.9	74.4	5.3	2.9	703.5	126	343.2	1.61E+09
Avg	67.3	61.1	67.1	78.7	14.2	64.5	67.1	2.7	0.01	698.5	43.3	275.5	8.81E+08
June													
Min	47	46	63.3	72.4	-1.2	62.5	63.6	0.9	-2.6	698	0	249.2	2.39E+08
Max	101	81	80.2	89.4	24.4	78.8	80	4.2	1.6	702.7	122	327.7	1.48E+09
Avg	75.1	68.3	72.8	83.3	12.6	70.7	72.8	2.1	0.01	698.5	43.3	276.6	7.86E+08

Summary of Results - Scenario 2
January 1, 1976 - October 15, 1993

1230 MWe Generation
Supplemental CCW Flow
3 CCW Pumps: Jan - Feb
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
July													
Min	57	56	68.3	78	-3.4	66.1	68.5	0.8	-2.1	698	0	254.6	1.02E+07
Max	105	85	83.7	91	24.2	82.5	83.5	3.4	1.6	701.8	116	304.5	1.35E+09
Avg	79	72	76.5	85.7	10.8	74.9	76.5	1.6	0	698.4	43.4	275.7	6.69E+08
August													
Min	54	53	71.9	76.6	-4.7	70.7	72.4	0.7	-1.7	698	0	262.2	-6.04E+07
Max	104	84	82.9	89.4	18.9	81.7	82.8	2.4	1.3	701.2	112	293.4	9.90E+08
Avg	77.5	71	77.7	85	8.5	76.5	77.7	1.2	0	698.3	43.4	274.8	5.23E+08
September													
Min	41	40	68.2	69.6	-9.9	67.4	68.4	0.6	-1.8	698	0	263.2	-4.21E+08
Max	99	79	82.3	88.1	17.6	81.1	82	2.4	1	704	129	298.6	8.90E+08
Avg	71	65.5	76.1	81.5	6.4	75	76.2	1.1	-0.01	698.5	43.3	276.1	3.95E+08
October													
Min	26	25	59.2	62.1	-10.5	58.1	59.4	0.6	-1.7	698	0	242.2	-4.61E+08
Max	89	76	78.3	86.2	20.8	76.7	78	3.1	1.1	701.7	116	317.3	1.12E+09
Avg	59	53.8	69.3	74.3	6.2	68	69.4	1.3	-0.01	698.3	43.3	266.8	3.63E+08
November													
Min	16	16	48.4	55.3	-8.8	47.6	48.9	0.6	-1.2	698	0	207.4	-3.33E+08
Max	81	70	70.5	82.7	32	67.9	69.7	5.8	1.4	701	110	286.3	1.43E+09
Avg	50.3	45.9	60.6	69.6	10.7	58.8	60.8	1.9	-0.01	698.2	43.4	237.7	5.64E+08
December													
Min	-2	-2	41	46.5	-2.1	39.6	41.4	0.7	-1.4	698	0	191.4	8.96E+06
Max	77	69	61.8	80.9	37.8	59.2	61.9	6.5	1.9	701.7	114	314.5	1.60E+09
Avg	41.6	37.8	51.2	64.9	16.2	48.7	51.4	2.5	-0.01	698.2	43.6	215.1	7.74E+08

Table 7

Summary of Results - Scenario 3
January 1, 1976 - October 15, 1993
1230 MWe Generation
Supplemental CCW Flow
3 CCW Pumps: Jan - Feb
Bypass Flow Nov - April
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
January													
Min	-10	-11	35.7	40.6	-1	34.8	36.1	0.7	-1.3	698	0	188.3	1.96E+07
Max	71	63	52.8	77.1	38	51.7	52.7	3.8	1.4	702.9	122	288.8	9.69E+08
Avg	37.5	33.9	43.5	60.8	18.7	42	43.7	1.6	-0.01	698.1	43.6	213.3	5.00E+08
February													
Min	9	7	36.2	49.7	1.1	35.1	36.6	0.8	-1.6	698	0	188.7	8.66E+07
Max	79	67	52.8	77.4	40.2	51	52.7	3.8	1.7	702.2	118	295.4	1.03E+09
Avg	42.5	37.9	43.7	63.1	21.3	41.9	43.7	2	0.01	698.1	43.7	211.1	5.62E+08
March													
Min	10	8	38.9	52.3	3.4	37.6	39.4	0.8	-1.2	698	0	189.2	1.80E+08
Max	85	73	59.1	81.8	39.4	56.1	58.5	4	1.5	703	124	282.8	1.03E+09
Avg	51.2	45.3	49.6	69.3	21.7	47.7	49.6	2	0.01	698.2	43.7	213.5	5.80E+08
April													
Min	26	25	49.6	60.1	-0.1	48.6	49.8	0.6	-1.3	698	0	193.2	9.56E+07
Max	91	73	66.4	83.1	31.5	65.1	66.3	3.2	1.4	702.1	118	322	9.94E+08
Avg	59.8	52.4	58.2	73.7	17.1	56.7	58.3	1.7	0.01	698.4	43.4	252.2	5.43E+08
May													
Min	38	36	59.1	68.5	-1.1	57.7	59.2	0.8	-3	698	0	219.3	1.77E+08
Max	93	78	75.2	87.2	28.7	71.9	74.4	5.3	3.5	703.5	126	343.2	1.61E+09
Avg	67.3	61.1	67.1	78.7	14.2	64.5	67.1	2.7	0.01	698.5	43.3	275.5	8.74E+08
June													
Min	47	46	63.3	72.4	-1.2	62.5	63.6	0.9	-2.6	698	0	249.2	2.39E+08
Max	101	81	80.2	89.4	24.4	78.8	80	4.2	1.6	702.7	122	327.7	1.48E+09
Avg	75.1	68.3	72.8	83.3	12.6	70.7	72.8	2.1	0.01	698.5	43.3	276.6	7.86E+08

Summary of Results - Scenario 3
January 1, 1976 - October 15, 1993
1230 MWe Generation
Supplemental CCW Flow
3 CCW Pumps: Jan - Feb
Bypass Flow Nov - April
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
July													
Min	57	56	68.3	75	-3.4	66.1	68.5	0.8	-2.1	698	0	254.6	1.02E+07
Max	105	85	83.7	96.3	24.2	82.5	83.5	3.4	1.6	701.8	116	304.5	1.35E+09
Avg	79	72	76.5	85.7	10.8	74.9	76.5	1.6	0	698.4	43.4	275.7	6.69E+08
August													
Min	54	53	71.9	73.2	-4.7	70.7	72.4	0.7	-1.7	698	0	262.2	-6.04E+07
Max	104	84	82.9	94.4	18.9	81.7	82.8	2.4	1.3	701.2	112	293.4	9.90E+08
Avg	77.5	71	77.7	85	8.5	76.5	77.7	1.2	0	698.3	43.4	274.8	5.23E+08
September													
Min	41	40	68.2	65.8	-9.9	67.4	68.4	0.6	-1.8	698	0	263.2	-4.21E+08
Max	99	79	82.3	92	17.6	81.1	82	2.4	1	704	129	298.6	8.90E+08
Avg	71	65.5	76.1	81.4	6.4	75	76.2	1.1	-0.01	698.5	43.3	276.1	3.95E+08
October													
Min	26	25	59.2	57.5	-10.5	58.1	59.4	0.6	-1.7	698	0	242.2	-4.61E+08
Max	89	76	78.3	89.3	20.8	76.7	78	3.1	1.1	701.7	116	317.3	1.12E+09
Avg	59	53.8	69.3	74.2	6.2	68	69.4	1.3	-0.01	698.3	43.3	266.8	3.63E+08
November													
Min	16	16	48.4	53	-8.8	47.6	48.6	0.6	-1.4	698	0	207.4	-1.90E+08
Max	81	70	69.4	84.9	32	67.9	69.7	3.1	1.2	701	110	286.3	8.61E+08
Avg	50.3	45.9	59.9	69.5	10.7	58.8	60.2	1.2	-0.01	698.2	43.4	237.7	3.22E+08
December													
Min	-2	-2	40.7	44.8	-2.1	39.6	40.9	0.7	-1.2	698	0	191.4	4.67E+06
Max	77	69	60.6	84.1	37.8	59.2	60.7	3.7	1.5	701.7	114	314.5	9.09E+08
Avg	41.6	37.8	50.1	64.9	16.2	48.7	50.3	1.5	-0.01	698.2	43.6	215.1	4.33E+08

Table 8

Summary of Results - Scenario 4
January 1, 1976 - October 15, 1993
1230 MWe Generation
Supplemental CCW Flow
3 CCW Pumps: Jan - Feb 3 RCW Pumps: May
Bypass Flow Nov - April
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
January													
Min	-10	-11	35.7	40.6	-1	34.8	36.1	0.7	-1.3	698	0	188.3	1.96E+07
Max	71	63	52.8	77.1	38	51.7	52.7	3.8	1.4	702.9	122	288.8	9.69E+08
Avg	37.5	33.9	43.5	60.8	18.7	42	43.7	1.6	-0.01	698.1	43.6	213.3	5.00E+08
February													
Min	9	7	36.2	49.7	1.1	35.1	36.6	0.8	-1.6	698	0	188.7	8.66E+07
Max	79	67	52.8	77.4	40.2	51	52.7	3.8	1.7	702.2	118	295.4	1.03E+09
Avg	42.5	37.9	43.7	63.1	21.3	41.9	43.7	2	0.01	698.1	43.7	211.1	5.62E+08
March													
Min	10	8	38.9	52.3	3.4	37.6	39.4	0.8	-1.2	698	0	189.2	1.80E+08
Max	85	73	59.1	81.8	39.4	56.1	58.5	4	1.5	703	124	282.8	1.03E+09
Avg	51.2	45.3	49.6	69.3	21.7	47.7	49.6	2	0.01	698.2	43.7	213.5	5.80E+08
April													
Min	26	25	49.6	60.1	-0.1	48.6	49.8	0.6	-1.3	698	0	193.2	9.56E+07
Max	91	73	66.4	83.1	31.5	65.1	66.3	3.2	1.4	702.1	118	322	9.94E+08
Avg	59.8	52.4	58.2	73.7	17.1	56.7	58.3	1.7	0.01	698.4	43.4	252.2	5.43E+08
May													
Min	38	36	59.1	68.5	-1.1	57.7	59.2	0.8	-2.7	698	0	229.6	1.83E+08
Max	93	78	75.1	87.2	28.7	71.9	74.4	4.8	3	703.5	126	353.5	1.66E+09
Avg	67.3	61.1	67	78.7	14.2	64.5	67	2.6	0.01	698.5	43.3	285.8	9.06E+08
June													

Summary of Results - Scenario 4
January 1, 1976 - October 15, 1993
1230 MWe Generation
Supplemental CCW Flow
3 CCW Pumps: Jan - Feb 3 RCW Pumps: May
Bypass Flow Nov - April
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
Min	47	46	63.3	72.4	-1.2	62.5	63.5	0.9	-2.6	698	0	249.2	2.39E+08
Max	101	81	80.2	89.4	24.4	78.8	80	4.1	1.6	702.7	122	327.7	1.48E+09
Avg	75.1	68.3	72.8	83.3	12.6	70.7	72.8	2.1	0.01	698.5	43.3	276.6	7.87E+08
July													
Min	57	56	68.3	78	-3.4	66.1	68.5	0.8	-2.1	698	0	254.6	1.03E+07
Max	105	85	83.7	91	24.2	82.5	83.5	3.4	1.6	701.8	116	304.5	1.35E+09
Avg	79	72	76.5	85.7	10.8	74.9	76.5	1.6	0	698.4	43.4	275.7	6.69E+08
August													
Min	54	53	71.9	76.6	-4.7	70.7	72.4	0.7	-1.7	698	0	262.2	-6.04E+07
Max	104	84	82.9	89.4	18.9	81.7	82.8	2.4	1.3	701.2	112	293.4	9.90E+08
Avg	77.5	71	77.7	85	8.5	76.5	77.7	1.2	0	698.3	43.4	274.8	5.23E+08
September													
Min	41	40	68.2	69.6	-9.9	67.4	68.4	0.6	-1.8	698	0	263.2	-4.21E+08
Max	99	79	82.3	88.1	17.6	81.1	82	2.4	1	704	129	298.6	8.90E+08
Avg	71	65.5	76.1	81.5	6.4	75	76.2	1.1	-0.01	698.5	43.3	276.1	3.95E+08
October													
Min	26	25	59.2	62.1	-10.5	58.1	59.4	0.6	-1.7	698	0	242.2	-4.61E+08
Max	89	76	78.3	86.2	20.8	76.7	78	3.1	1.1	701.7	116	317.3	1.12E+09
Avg	59	53.8	69.3	74.3	6.2	68	69.4	1.3	-0.01	698.3	43.3	266.8	3.63E+08
November													
Min	16	16	48.4	55.3	-8.8	47.6	48.6	0.6	-1.4	698	0	207.4	-1.90E+08
Max	81	70	69.4	82.7	32	67.9	69.7	3.1	1.2	701	110	286.3	8.61E+08
Avg	50.3	45.9	59.9	69.6	10.7	58.8	60.2	1.2	-0.01	698.2	43.4	237.7	3.22E+08

Summary of Results - Scenario 4
January 1, 1976 - October 15, 1993
1230 MWe Generation
Supplemental CCW Flow
3 CCW Pumps: Jan - Feb 3 RCW Pumps: May
Bypass Flow Nov - April
24-Hour Averaging

	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Intake Temp (°F)	Discharge Temp (°F)	Plant Temp Rise (F°)	River Temp				Pond Elevation (ft)	Diffuser Discharge (cfs)	SCCW	
						Ambient (°F)	Downstream (°F)	Rise (F°)	Rate (F°/hr)			Discharge (cfs)	Heat (BTU/hr)
December													
Min	-2	-2	40.7	46.5	-2.1	39.6	40.9	0.7	-1.2	698	0	191.4	4.68E+06
Max	77	69	60.6	80.9	37.8	59.2	60.7	3.7	1.5	701.7	114	314.5	9.09E+08
Avg	41.6	37.8	50.1	64.9	16.2	48.7	50.3	1.5	-0.01	698.2	43.6	215.1	4.33E+08

6.0 Figures

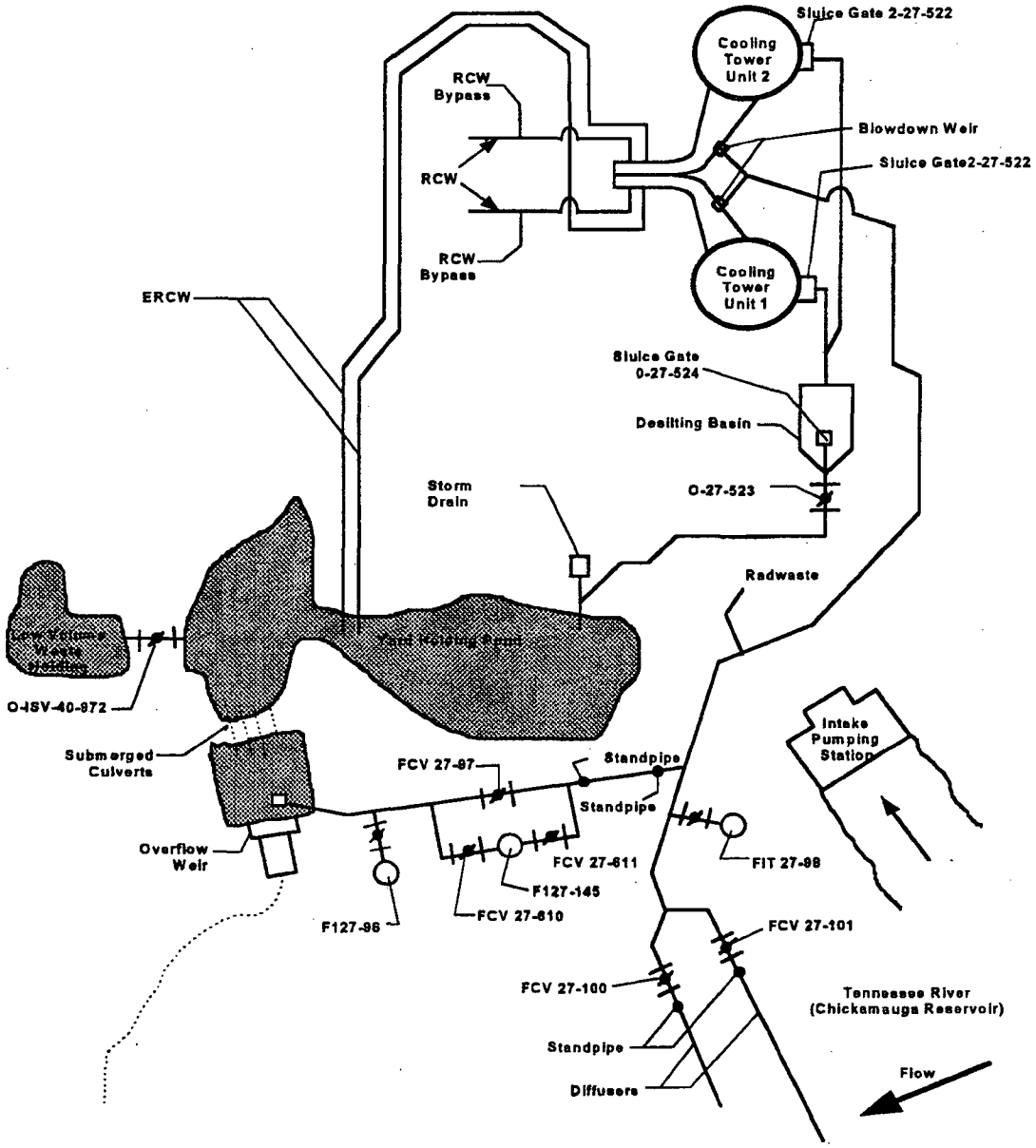
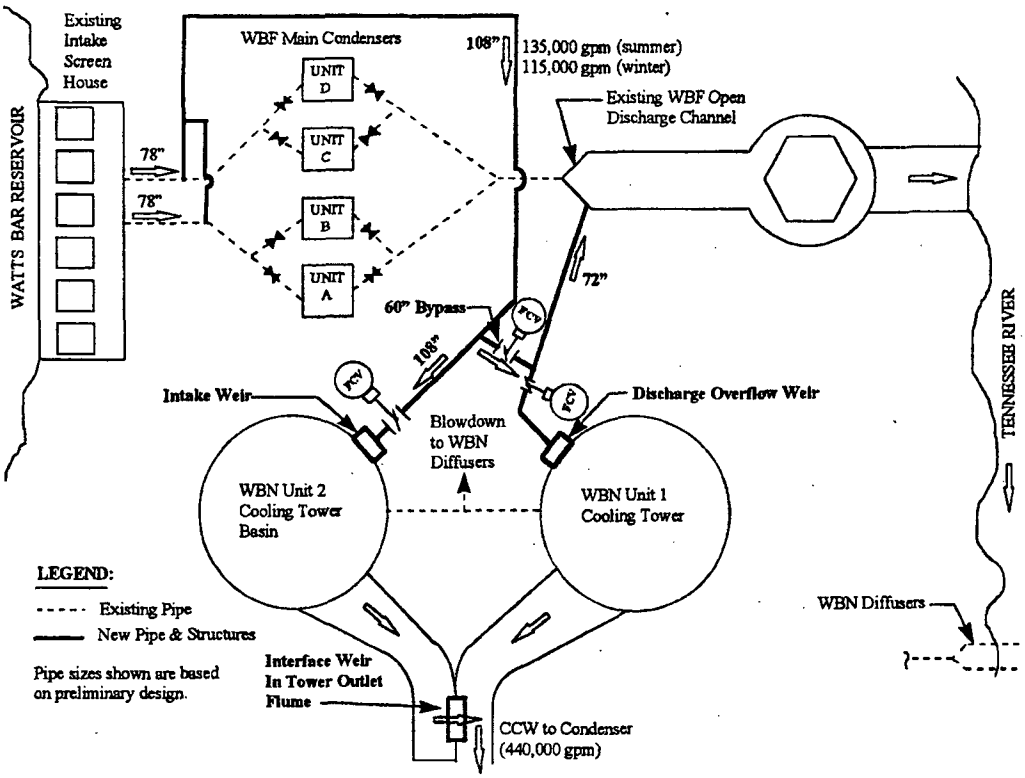


Figure 1. WBN Cooling Tower Blowdown System

Figure 2. Conceptual Flow Diagram of WBN SCCW System



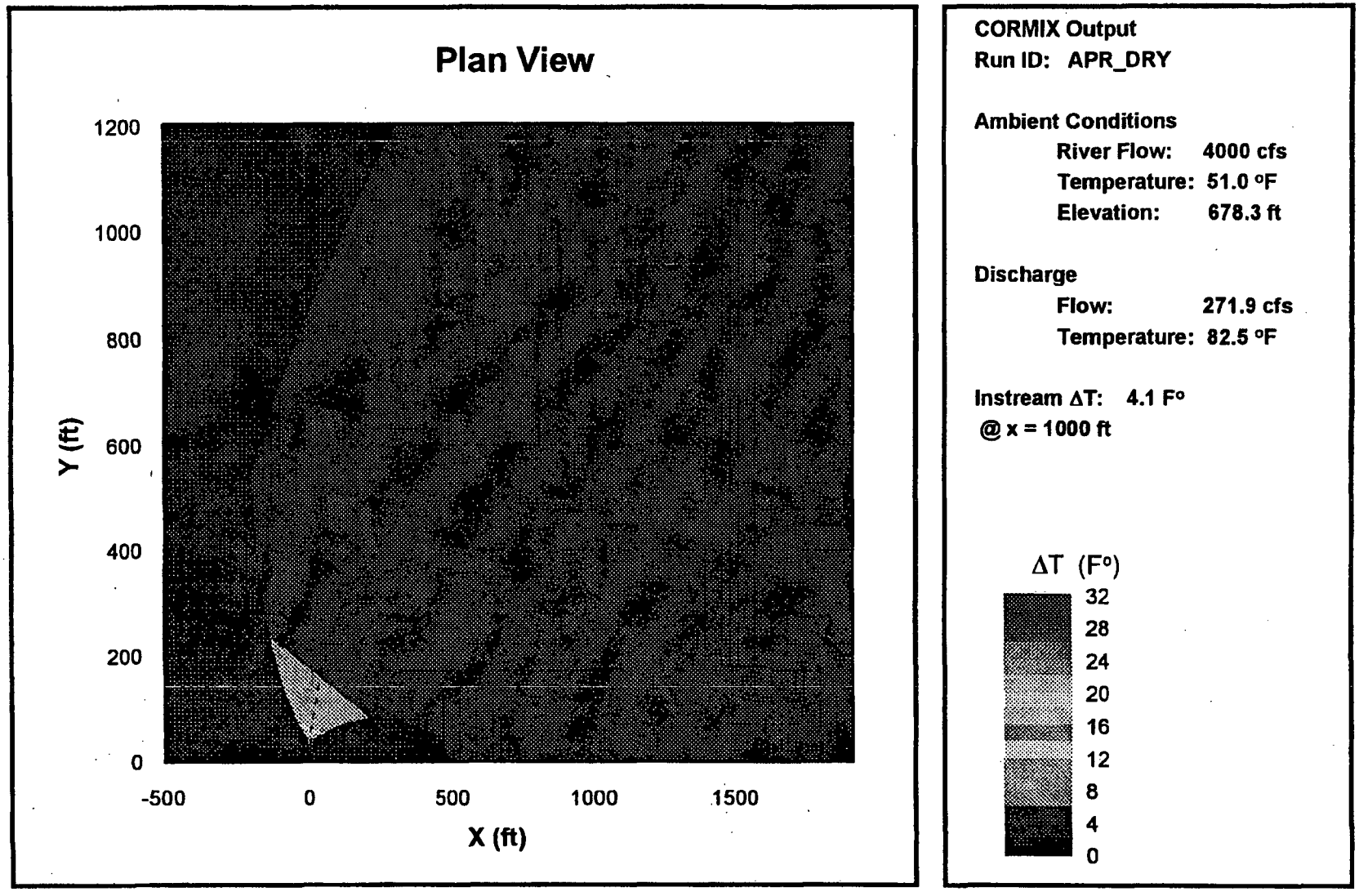


Figure 3. Plan View of CORMIX Results for Instream ΔT for Worst Case April Conditions

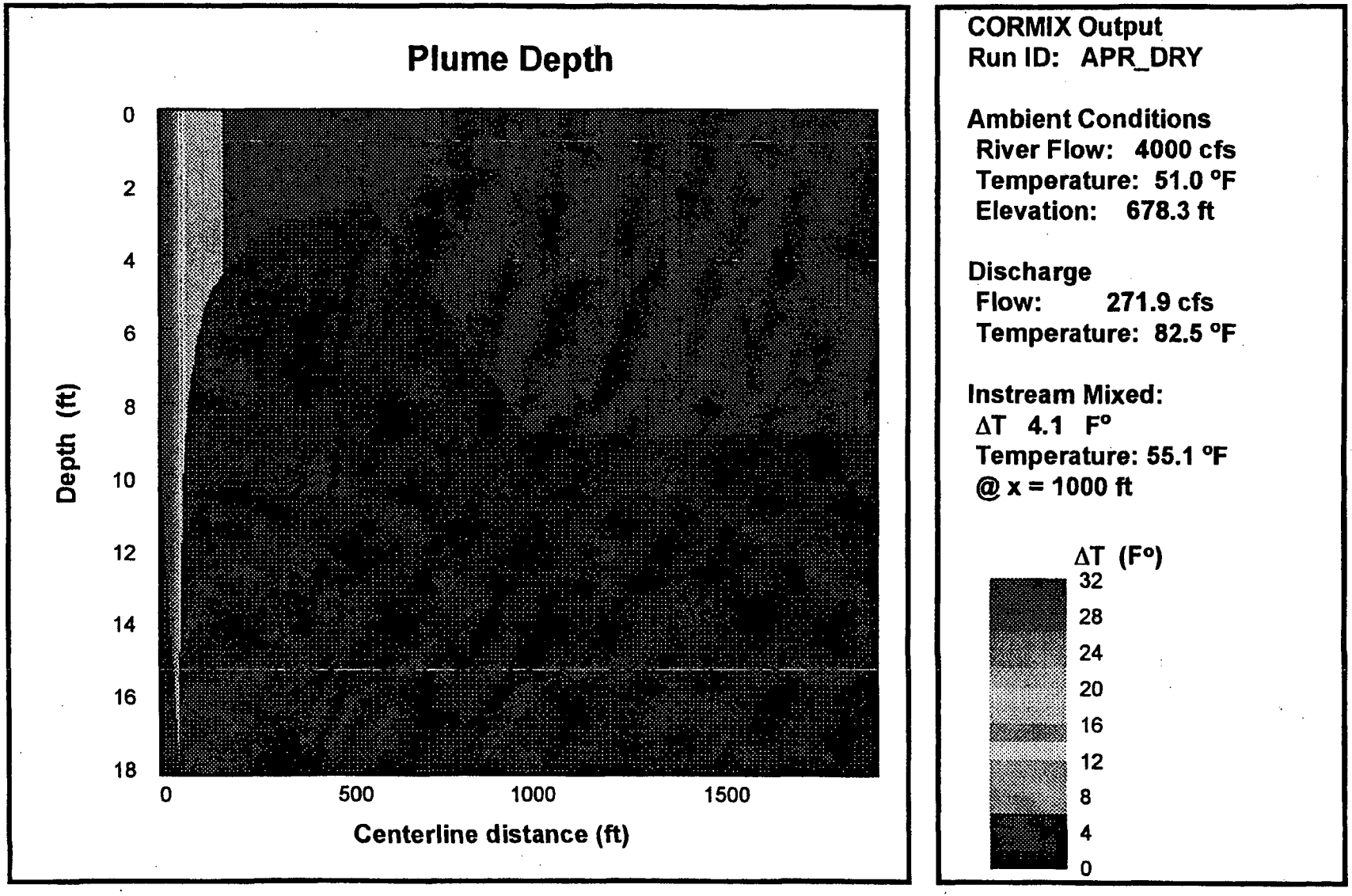


Figure 4. Side View of CORMIX Results for Instream ΔT for Worst Case April Conditions

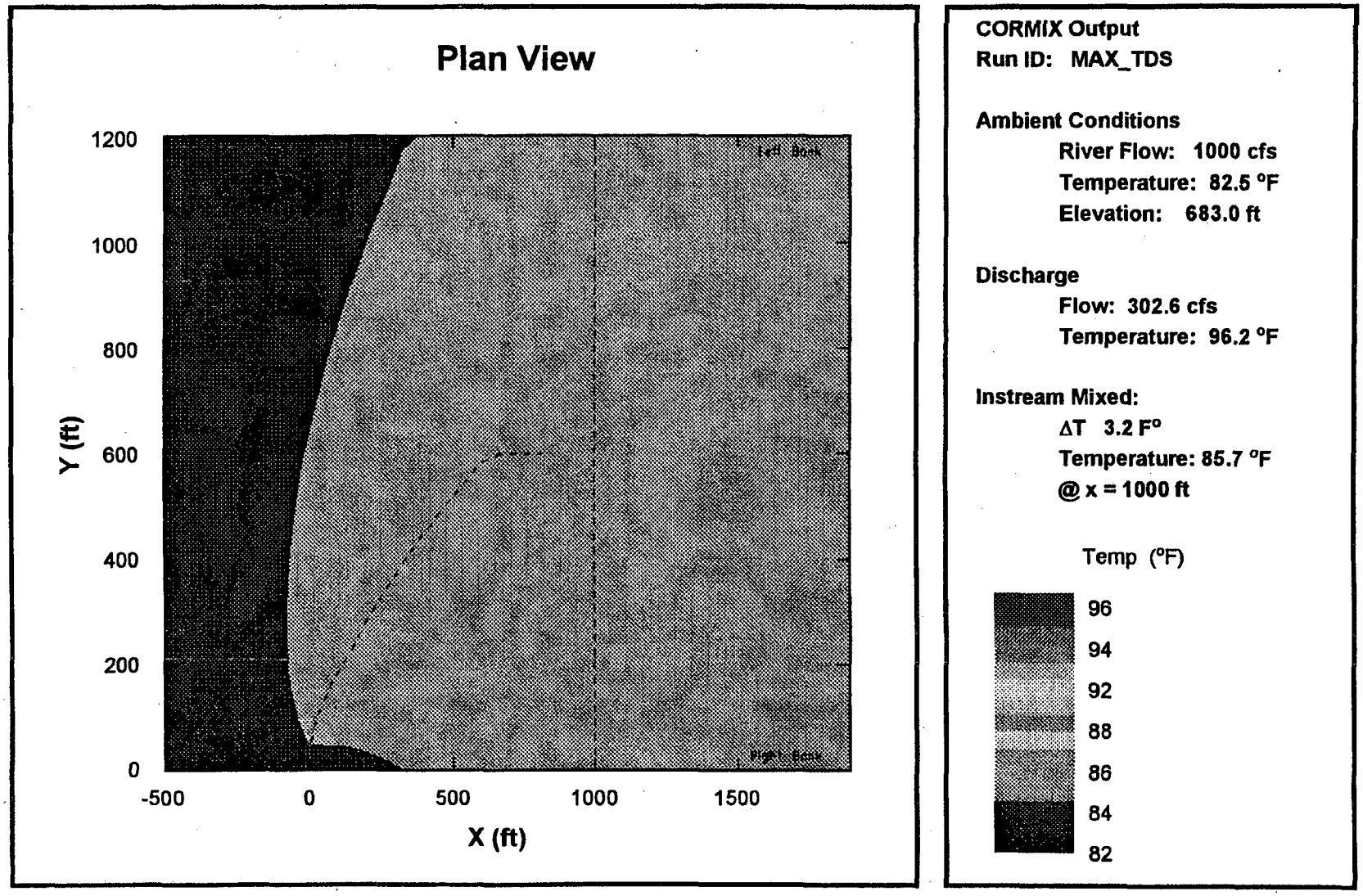
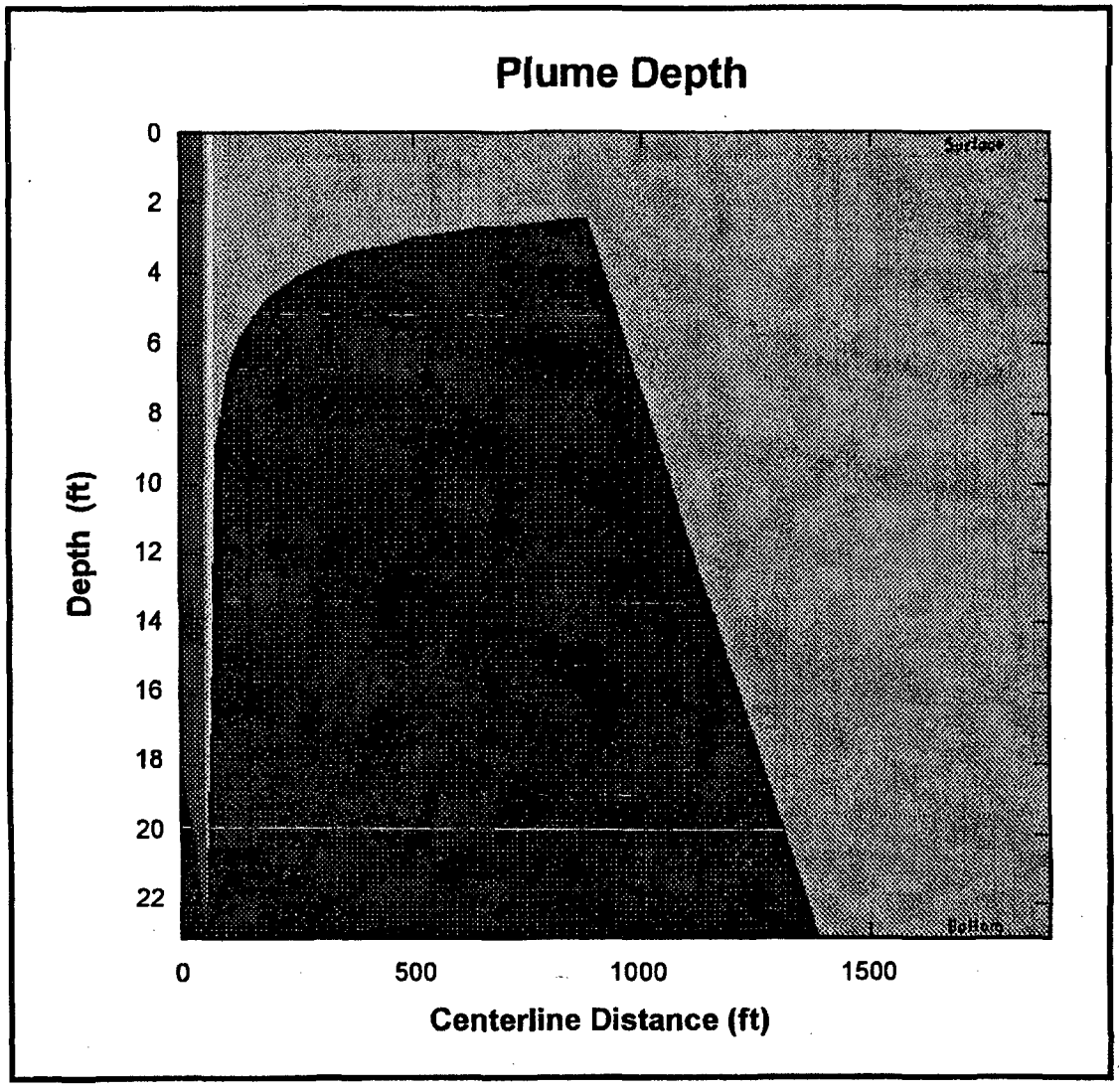


Figure 5. Plan View of CORMIX Results for Downstream Temperature for Worst Case Conditions



CORMIX Output
Run ID: MAX_TDS

Ambient Conditions
River Flow: 1000 cfs
Temperature: 82.5 °F
Elevation: 683.0 ft

Discharge
Flow: 302.6 cfs
Temperature: 96.2 °F

Instream Mixed:
ΔT 3.2 F°

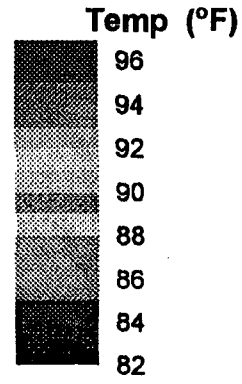
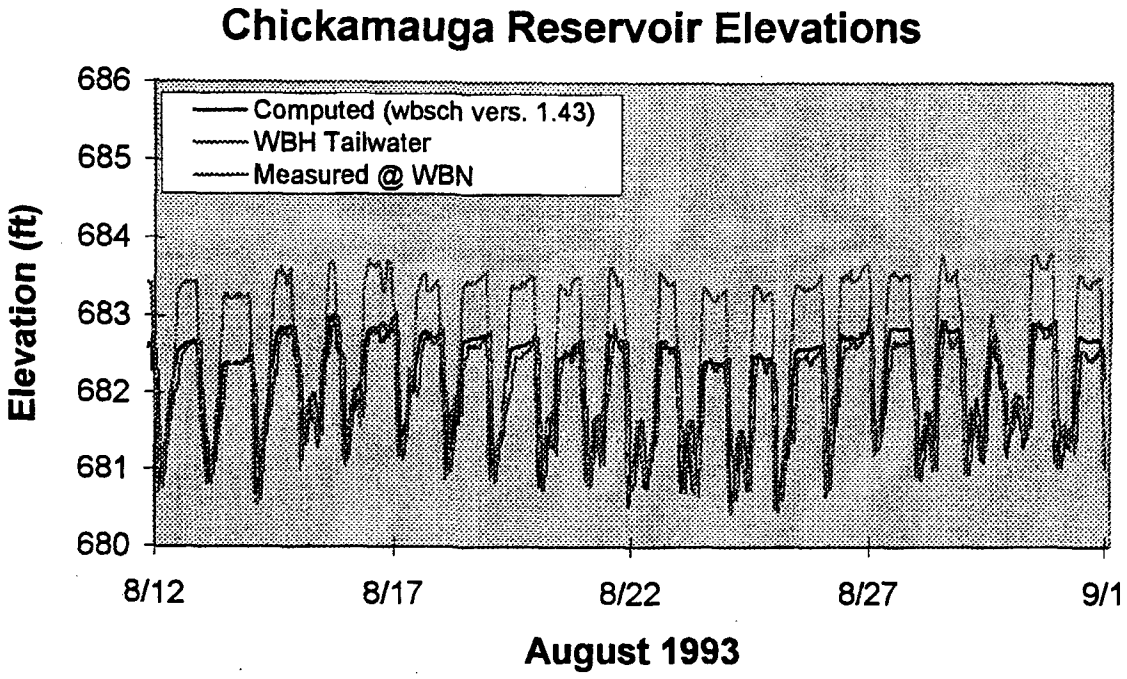


Figure 6. Side View of CORMIX Results for Downstream Temperature for Worst Case Conditions



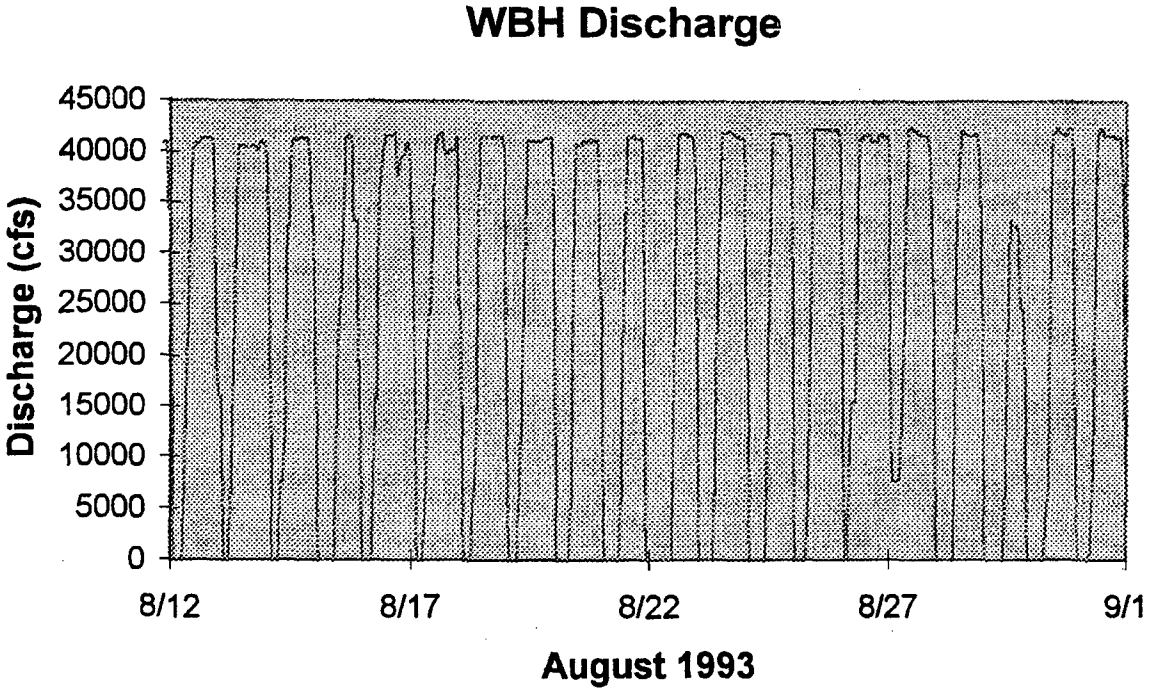


Figure 7. Measured and Computed River Elevations in the Vicinity of WBN, and WBH Discharges During August 1993

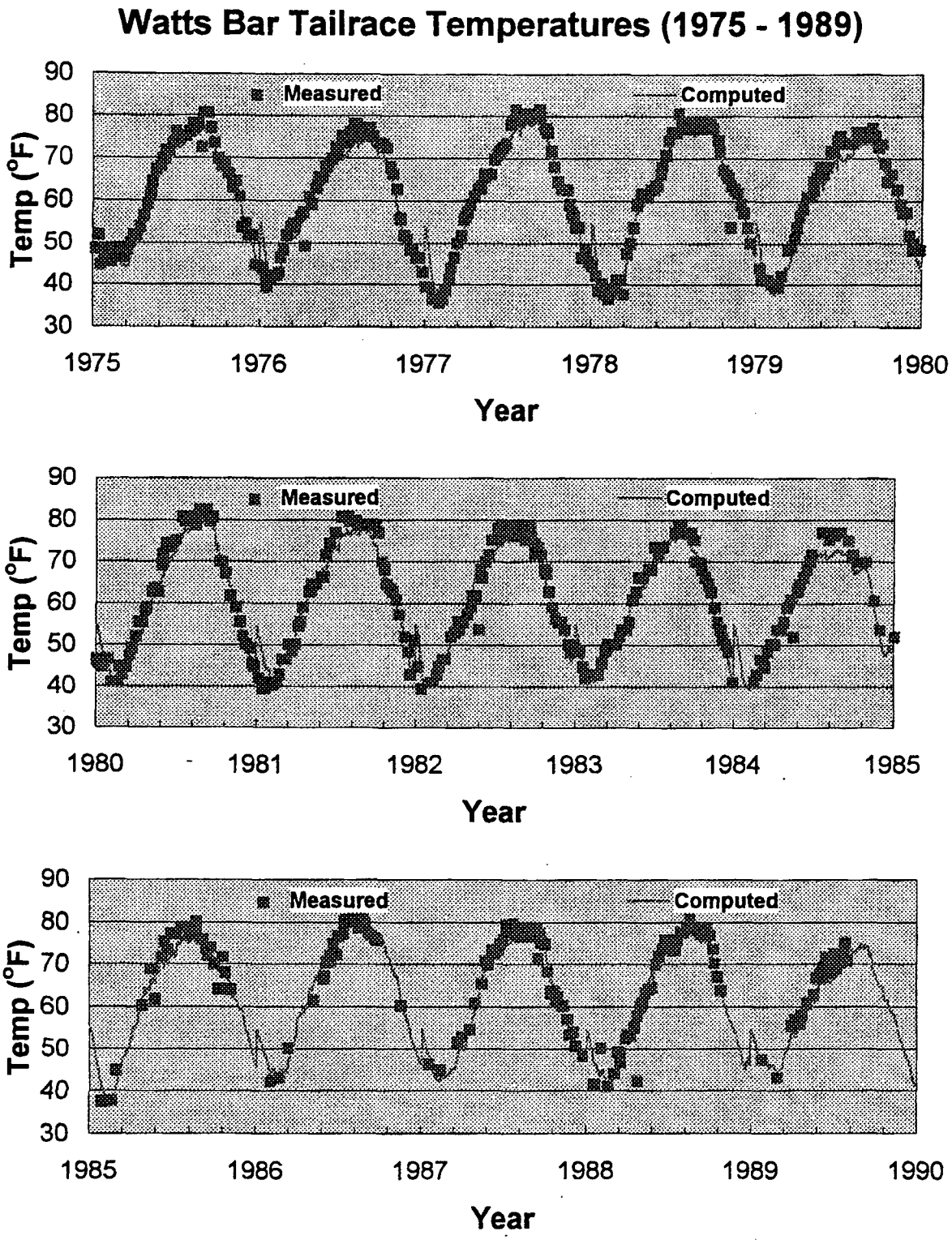


Figure 8. Measured and Computed WBH Tailrace Temperatures, 1975-1989 (Alavian and Potter, 1992)

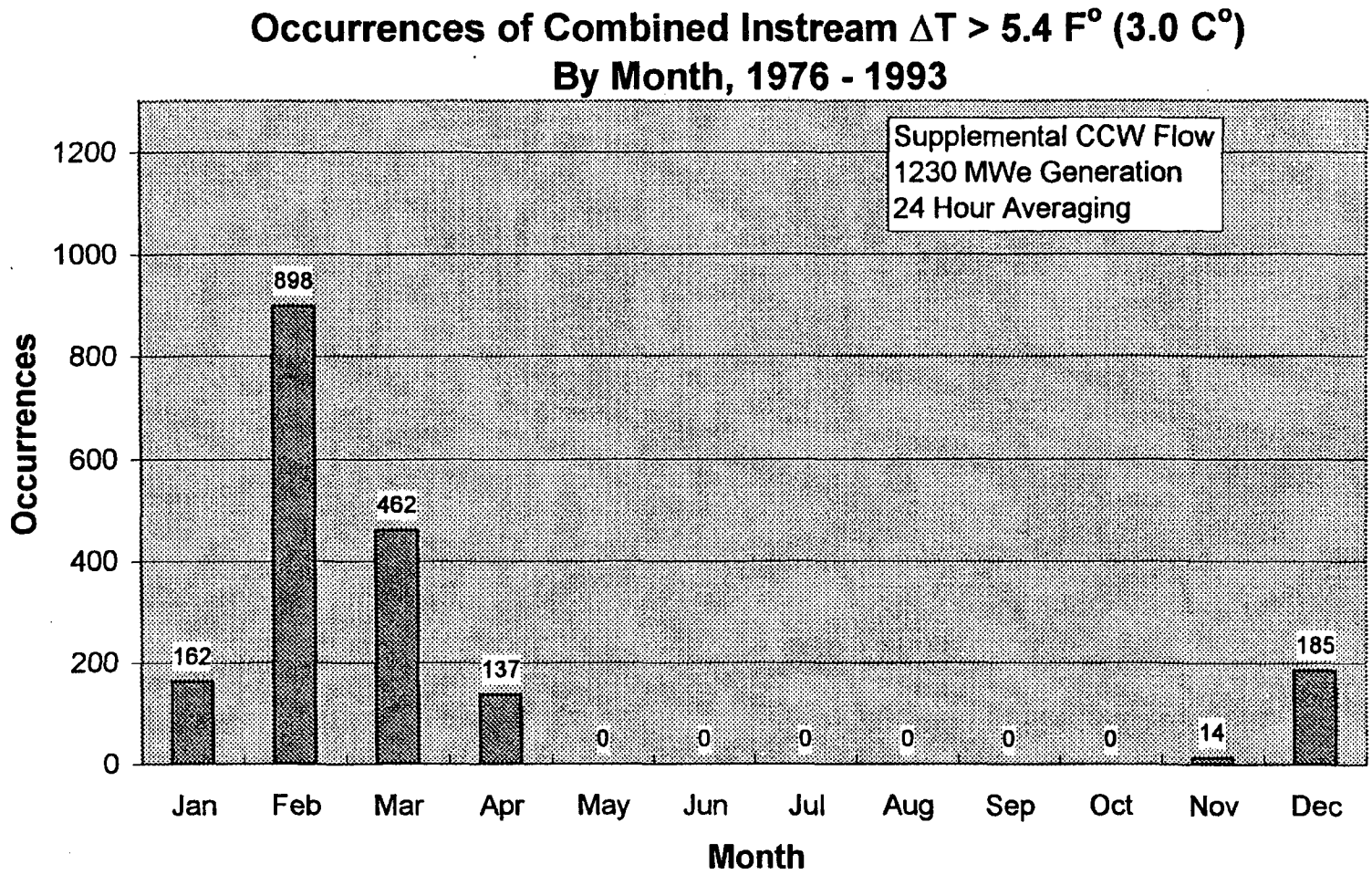


Figure 9. Total Number of Occurrences of 24-Hour Averaged Instream River Temperature Rise Greater Than 5.4 F° (3.0 C°) with Full Supplemental CCW Flow

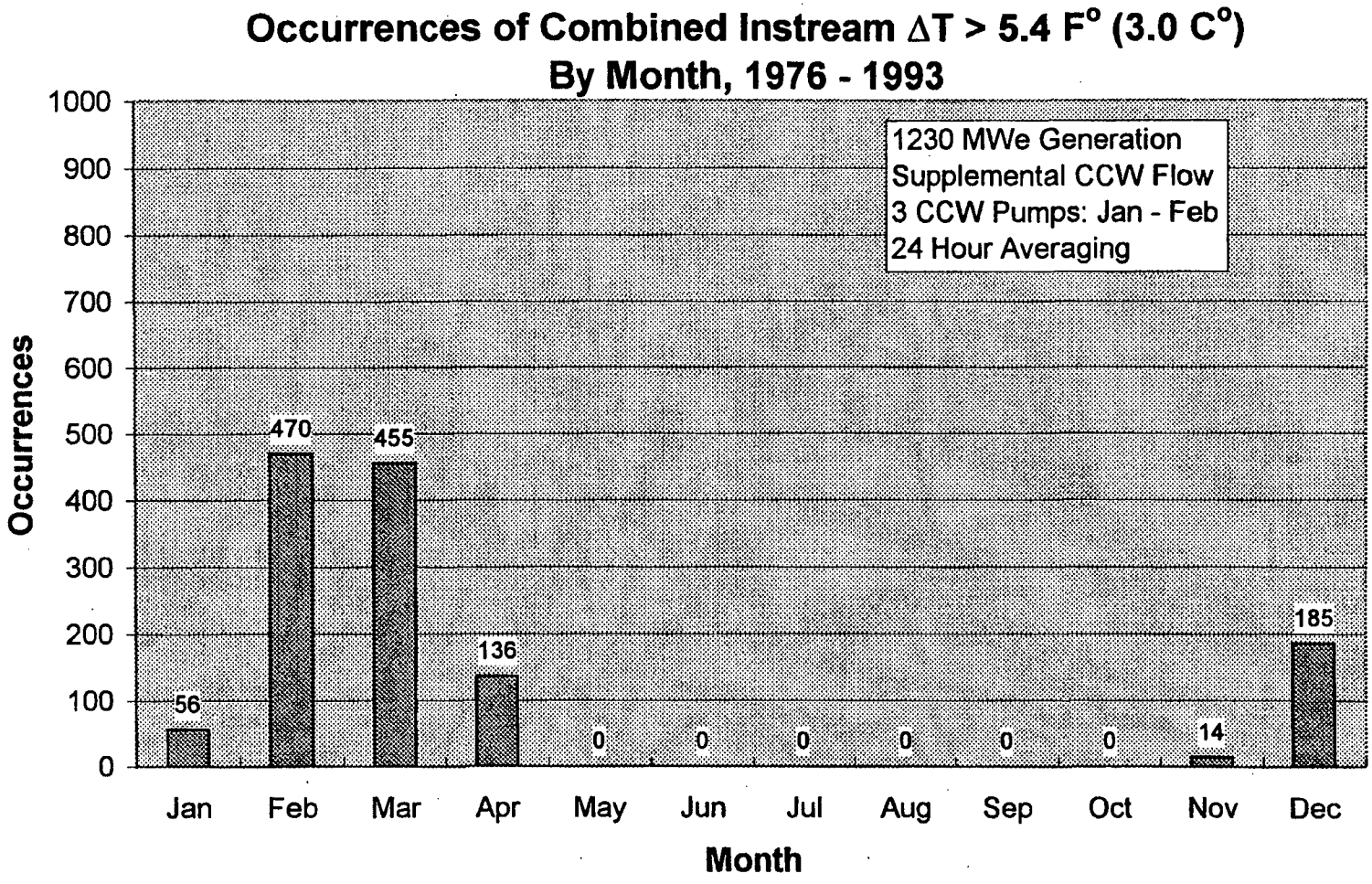


Figure 10. Total Number of Occurrences of Instream River Temperature Rise Greater Than 5.4 F° (3.0 C°) with Supplemental CCW Flow and CCW Pumps Reduced to Three in January and February

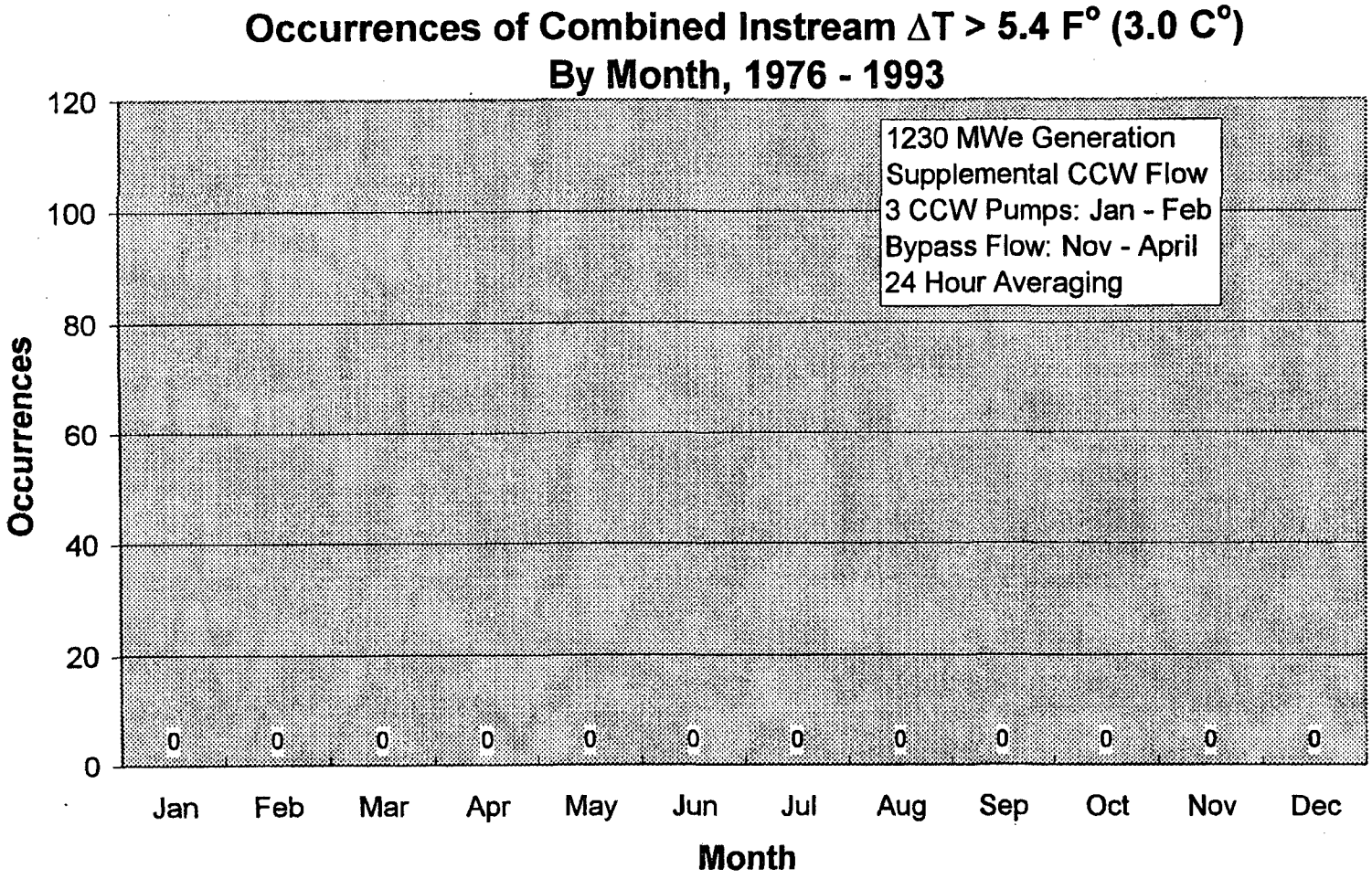


Figure 11. Total Number of Occurrences of Instream River Temperature Rise Greater Than 5.4 F° (3.0 C°) with 40 Percent Bypass of Supplemental CCW Flow Between November and April, and CCW Pumps Reduced to Three in January and February

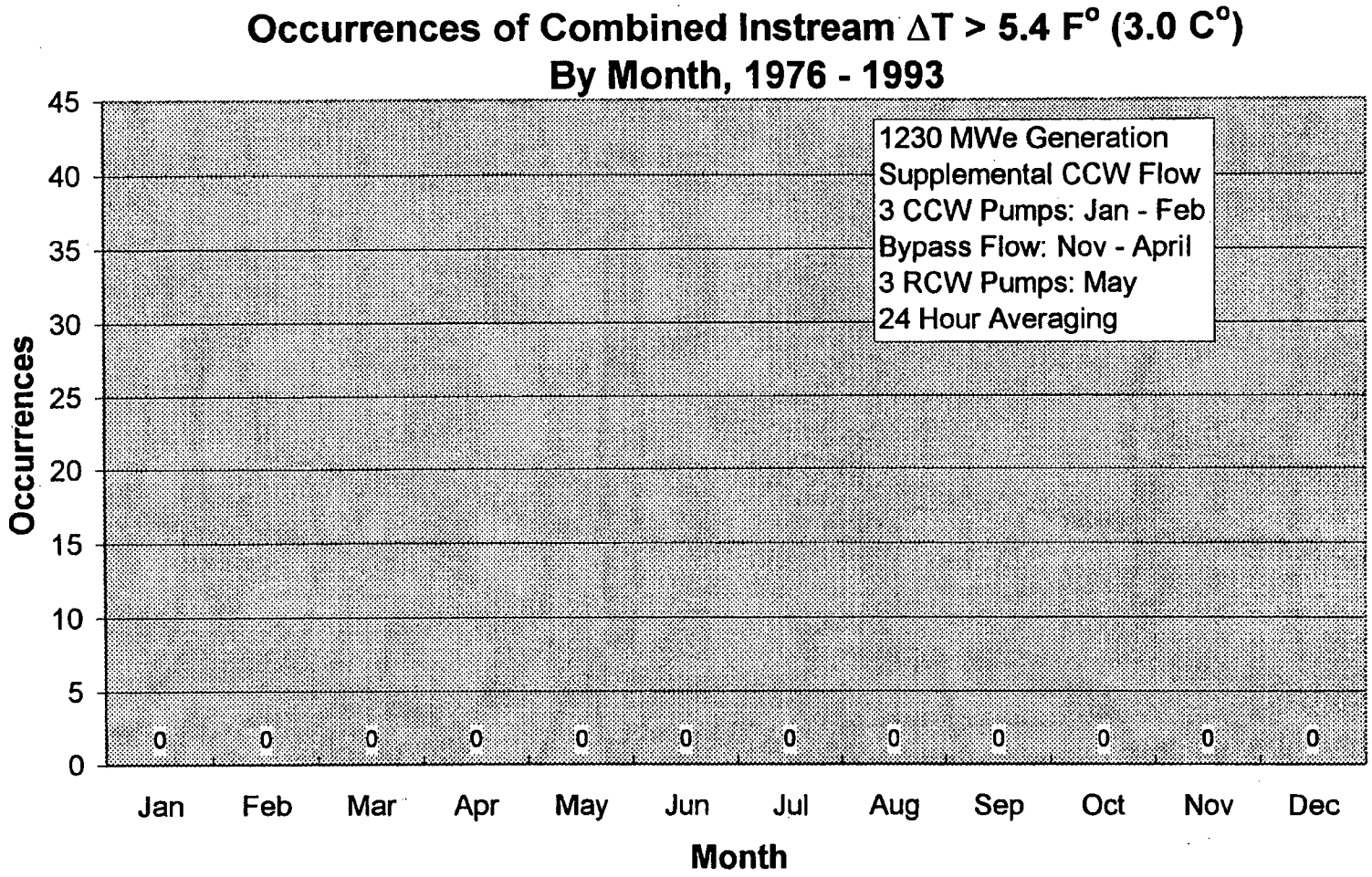


Figure 12. Total Number of Occurrences of Instream River Temperature Rise Greater Than 5.4 F° (3.0 C°) with 40 Percent Bypass of Supplemental CCW Flow Between November and April, CCW Pumps Reduced to Three in January and February, and RCW Pumps Increased to Three in May

7.0 References

1. Adams, E. E. 1972. "Submerged Multiport Diffusers in Shallow Water With Current," Masters Thesis, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

2. Alavian, V., and P. Ostrowski, Jr. 1991. "Modeling Longitudinal Temperature Distribution in TVA Reservoir System," Proceedings of the 1991 National Conference on Hydraulic Engineering, ASCE, Edited by R. M. Shane, Nashville, Tennessee, July 29 - August 2, 1991, pp. 583-588.

3. Alavian, V., and K. W. Potter. 1992. "Analysis of Extreme Water Temperature at Intake of Watts Bar Nuclear Plant," Tennessee Valley Authority, Engineering Laboratory Report No. WR28-1-85-135, Norris, Tennessee.

4. Benton, D. J. 1992. "Results of Analysis of the Watts Bar Nuclear Plant Heat Rejection System," Tennessee Valley Authority, Engineering Laboratory Report No. WR28-2-85-136, Norris, Tennessee.

5. Doneker, R. L., W. Frick, and P. Roberts, 1996. Course notes from "USEPA Mixing Zone Model Workshop," University of Portland, August 5-7, 1996.

6. Ferrick, M. G., and W. R. Waldrop. 1977. "Two Techniques for Flow Routing with Application to Wheeler Reservoir," TVA Division of Water Management, Water Systems Development Branch Report No. 3-519, Norris, Tennessee.

7. Jirka, G. H., R. L. Doneker, and W. W Hinton. 1996. "User's Manual for CORMIX: A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters" Office of Science and Technology, U.S. Environmental Protection Agency, Washington, DC.

8. Jones, Gilbert R., Jonathan D. Nash and Gerhard H. Jirka. 1996. "CORMIX3: An Expert System For Mixing Zone Analysis And Prediction Of Buoyant Surface Discharges," DeFrees Hydraulics Laboratory, School of Civil and Environmental Engineering, Cornell University, Ithaca, New York.

9. Lee, M., W. Harper, P. Ostrowski, M. Shiao, and N. Sutherland. 1993. "Discharge Temperature Limit Evaluation for Watts Bar Nuclear Plant," Tennessee Valley Authority, Engineering Laboratory Report No. WR28-1-85-137, Norris, Tennessee.

10. Reeves, Mark E (mereeves@tva.gov). (July 23, 1997). WBN Supplemental CCW Project. E-mail to Walter L. Harper (wlharper@tva.gov).

11. Tennessee Valley Authority. 1996. "Feasibility Study Supplemental Condenser Circulating Water to WBN," Mechanical Engineering Section, Watts Bar Nuclear Engineering.

12. Tennessee Valley Authority. 1988. "Raw Cooling Water System," Design Criteria No. WB-DC-40-63 (RIMS No. B26 880714 002), Nuclear Engineering, Watts Bar Nuclear Plant.

13. Tennessee Valley Authority. 1993. "Watts Bar Nuclear Plant System Description for Essential Raw Cooling Water System," System Description Document No. N3-67-4002 (RIMS No. T29 930302 856), Nuclear Engineering, Watts Bar Nuclear Plant.

14. Ungate, C. D., and K. A. Howerton. 1977. "Effects of Watts Bar Nuclear Plant and Watts Bar Steam Plant Discharges on Chickamauga Lake Water Temperatures," Tennessee Valley Authority, Engineering Laboratory Report No. WM28-1-85-100, Norris, Tennessee.

REE data

166554 March 11, 2009, The Unlined Pond, NPDES internal monitoring point (IMP 107), was batch released from March 11 at 10:53 and terminated on March 12 at 10:30. Per 0-PI-ENV-3.2, pre-release pH, iron, and copper were analyzed. Pre-release analysis for phosphorus was NA'd as no phosphorus containing cleaning compounds were known to have been used in plant systems since the last release. All release NPDES parameters were collected for analysis. Analytical results received from the contract lab, Environmental Science Corp., yielded a phosphorus of 5.5 mg/L and 5.6 mg/L. As the NPDES limit is 1.0 mg/L, this is a NPDES permit violation. No NOV was issued.

139754 On 1/30/08 WBN received a Compliance Evaluation Inspection (CEI) report from Tennessee Department of Conservation (TDEC), Division of Water Pollution Control, on March 3, 2008 for an NPDES permit inspection performed August 29-31, 2007. The report contains three findings related to an inoperable flow meter at Internal Monitoring Point, IMP 103, and from a potable water source discharge to storm water monitoring point SW-7. The Division requests a response from TVA regarding these inspection findings by March 31, 2008. These report findings meet the definition of an Reportable Environmental Event. No NOV was issued.

146896 On 6/16/08, OSN 112 NPDES samples collected on June 16th at 10:30, yielded a dissolved oxygen (DO) of 3.9 mg/L. The back-up sample analyzed June 17th yielded a DO of 3.9 mg/L. This is a NPDES violation as the daily permit limit is 5.0 mg/L. No NOV was issued.

149036 On 7/14/08, WBN - PA BOD sample collected July 14 at OSN 111, the sewage treatment plant, was not analyzed by Environmental Science Corporation within the 40 CFR 136 48-hour hold time requirement. As the analytical lab did not notify WBN of the hold time exceedance, WBN was unaware of the hold time exceedance until the following week when the results were received. Since WBN did not have the opportunity to collect an additional sample for the week of July 14 this results in a missed NPDES sample and a REE. No NOV was issued.

130054 The unit 1 cooling tower basin overflowed due to the Bromine addition on 9/9/07. Considerable algae has developed in the unit 1 basin as a result of not chemically treating the basin during the summer months while the power alert was in affect. This resulted in very high drops across the pre-screens and the trash rack.

94130 December 5, 2005, During the period of November 2005, WBN exceeded the monthly NPDES average discharge limitation for total nitrogen (ammonia) of 1.24 mg/l at Outfall 112. The monthly average concentration was 1.28 mg/ml. All samples obtained during the month of November for this outfall did meet the daily maximum limitation of 2.48 mg/ml. No NOV was issued.

104747 Feb, 16, 2003 STP UPSET, Uncontrollable, due to Flooding of effluent weir box. Appropriate verbal notifications made with followup written notification. TDEC agreed appeared to be an UPSET. TDEC later issued an NOV as part of a policy change. In a followup explanation TDEC indicated they would continue to issue NOVs for permit violations but agreed in this case their would not be any actions taken.

WBN PER 03-15936 Problem Statement:WBN must declare a Reportable Environmental Event (REE) for the high Total Suspended Solids (TSS) result in February due to an upset at the Sewage Treatment Plant (Reference PER 03-004043-000). Since the state issued a Notice of Violation, the excursion must be reported as a REE. (NOV)

104751 On April 13, 2003, Failed Toxicity test conducted week of 4/13/02. Side by side, concurrent testing with UV treatment passed. Petioned state to not count failure as pattern is consisten with previously documented instances of failure due to naturally occuring pathogens. State wanted more tests run before setting such a precedent. Results stood. State issued an NOV dated July 3, 2003. (NOV)

104754 On September 24, 2003, OSN 101, Diffuser Temperature, compensatory sample was missed when the electrical board powering the sensor was taken out of service during the U1C5 outage. This was a controllable REE that occurred on 9/24/2003. WBN PER 03-017359 was written on 10/6/03 when WBN discovered data was missing.

104755 On September 27, 2003, The sewer manhole located in the woods Northeast of the WBN Sewage Treatment Plant was discovered to be bubbling over with sewage on 9/27/2003. Appropriate notifications were made but there was uncertainty as to whether this would be considered an NOV. On 12/05/2003, TDEC issued a Notice of Violation for the paramater "Overflow Use Occurrences" at outfall 112. (NOV)

105022 On March 12, 2002, The Sewage Treatment Plant (STP) effluent , Outfall 111, release limit for BOD5 is 45 mg/l. The WBN sample collected on 3/12 and analyzed on 3/18 revealed 54 mg/l was being discharged. Contributing factors may include the heavy rains reducing contact time and that the site was involved in an outage where a lot more mopping and cleaning takes place.TVAN Management Review Committee determined this to be a level B PER. WBNPER-02-004202-000 was initiated.

01TVAN-3-WBN-1 The week of 04/16-21/2001 toxicity testing was performed at permitted outfalls of WBN. Outfall serial number 112 (Construction Runoff Holding Pond) demonstrated chronic toxicity for larval fathead minnows (Pimephales promelas) for the six day period from April 16 to April 21. The inhibition concentration causing 25% reduction (IC25) limit for fathead minnows is 100% effluent. The IC25 value for outfall 112 for the 04/16/21/2001 was 23.77%

00TVAN-6-WBN-3 The monthly average Total Suspended Solid (TSS) limit of 30 mg/l was exceeded for September for Outfall DSN 112.

0TVAN-1-WBN- 1 Confirmation was received that a sample of Outfall DSN 112 failed a toxicity test in October.

99TVAN-2-WBN-1 At the onsite sewage treatment facility, a lift pump malfunctioned. This resulted in bypassing the sewage treatment facility and release of untreated sewage on the ground.

99-TVAN-4-WBN-2 Lack of thermal instrumentation on the Supplementary Condenser Cooling Water system resulted in exceeding temperature limits at the outfall and inadequate data collection.

98TVAN-1-WBN-1 Temperature measurements at the diffuser were not manually done to compensate for an out-of-service monitor. Two occurrences on 10/11/97 and 10/13/97.

98TVAN-4-WBN-2 Semiannual toxicity testing of DSN 112, Runoff Pond, demonstrated an observable chronic effect for larval fathead minnows. Violation issued by the state.

98TVAN-11-WBN-3 Routine weekly sampling of Outfall 112 (Runoff Holding Pond) revealed 2.7 mg/l dissolved oxygen level. Permit minimum concentration is 5.0 mg/l. Condition caused by low flow from drought conditions. Flow ceased on 9-4-98, thereby ending noncompliance condition.

97TVAN-4-WBN-1 Sample from Outfall 112, Runoff holding pond. failed the fathead minnow portion of the quarterly toxicity test.

97TVAN-9-WBN-2 A sample at the Construction Runoff Pond was found to be out of specification for pH (~9.6 where limit is 9.5). Reading was out of specification for one day.

96TVAN9606-WBN-1 Water - NPDES DSN 102 overflowed during ice storm from 2200 on 2/4/96 0300 on 2/5/96. The required samples were not obtained in accordance with the NPDES permit requirements.

96TVAN9610-WBN-2 NPDES Discharge 107G exceeded iron permit limit . Limit= 1.0ppm, results= 1.1ppm

96TVAN9612-WBN-3 NPDES Outfall 111 exceeded permit limit due to lightening storm knocking out all chlorination equipment(including back-up equipment)

96TVAN9614-WBN-4 Water sample from Outfall 112 , runoff Holding Pond, failed the quarterly toxicity test.

TENNESSEE VALLEY AUTHORITY

RESOURCE GROUP
WATER MANAGEMENT

AQUATIC ENVIRONMENTAL CONDITIONS IN THE VICINITY OF WATTS BAR NUCLEAR PLANT DURING TWO YEARS OF OPERATION, 1996-1997

Norris, Tennessee
June 1998

Table of Contents

Page

Executive Summary ii

List of Tables v

List of Figures x

1.0 Introduction 1

1.1 Purpose and Objective 1
1.2 Plant Description 3

2.0 Juvenile and Adult Fish 6

2.1 Entrainment-Larval Fish 6
2.2 Electrofishing 16
2.3 Impingement 23
2.4 Fishery Creel Survey 25

3.0 Aquatic Macroinvertebrates 35

3.1 Hess Sampling 35
3.2 Native Mussel Fauna 42

4.0 Instream Water Quality Monitoring 61

4.1 Water Quality Analysis 61

5.0 Summary and Conclusions 65

6.0 References 70

Appendix A-1. List of scientific names and densities (number/m^2) of benthic macroinvertebrates collected at five locations in the vicinity of Watts Bar Nuclear Plant during operational monitoring in summer and fall 1996-1997. 161

Appendix A-2. Results of 14 native mussel surveys at 12 sites in the vicinity of Watts Bar Nuclear Plant, 1983-1997. 171

Appendix B-1. Selected water quality values measured during preoperational (1982-1991) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 518.0. 222

EXECUTIVE SUMMARY

As required by the National Pollutant Discharge Elimination System (NPDES) Permit Number TN0020168 for operation of Watts Bar Nuclear Plant (WBN), this report is a composite evaluation of nonradiological preoperational and operational aquatic monitoring conducted from 1973-1979, 1982-1985, and 1996-1997. The primary objective of the WBN Nonradiological Operational Monitoring Program is to evaluate and compare specific biological and chemical parameters during the first two years of operation of WBN to those reported in the WBN Nonradiological Preoperational Assessment. Biological and chemical components monitored to detect and evaluate significant effects, if any, of WBN during the first two years of operation included: juvenile and adult fish, entrainment of fish eggs and larvae, fish impingement, tailwater fishery creel survey, benthic macroinvertebrate communities, native mussel fauna, and various water quality parameters.

In the vicinity of WBN, occurrence and abundance of ichthyoplankton (fish eggs and larvae) is primarily the result of passage through the turbines at Watts Bar Dam. This is because most fish species are reservoir and not tailwater spawners. A combination of low densities and number of taxa of ichthyoplankton passing the WBN water intake and the low-volume of hydraulic entrainment required by the plant resulted in insignificant losses due to plant operation. Relative abundance and species composition of benthic macroinvertebrates and juvenile and adult fish were also primarily influenced by releases from Watts Bar Dam. Temporal analyses showed that seasonal and yearly changes in abundance and other variables for all component populations, except freshwater mussels, were common.

It is apparent based on comparisons of species composition, relative abundance, catch per unit effort (CPUE), and Reservoir Fish Assemblage Index (RFAI) scores between preoperational and operational monitoring, WBN has not adversely impacted the tailwater fish population below Watts Bar Dam during the first two years of operation. Comparison of fish community sampling during preoperational and operational monitoring showed minimal variations comparing 12 important species. Reservoir RFAI values also remained relatively stable.

Comparisons of angling effort between preoperational and operational periods were not possible as this information was not available during the preoperational period. During the two years of tailwater creel surveys (April 1996-April 1998), a total of 392,807 fishing hours and 88,151 angler trips was estimated. Catfish, sauger, white bass, crappie, sunfish, striped bass/cherokee bass, and black bass were the most sought after species by fisherman. An estimated of 341,106 fish were caught and 165,128 fish harvested from April 1996-April 1998. Peak angling effort (30,218 hours) and number of trips (9,717) occurred in April 1996. Angling trips ranged from 9,717 in April 1996 to 1,456 trips in November 1997. Annual catch rates (number per hour) in the vicinity of WBN during operational monitoring has increased to 1.54 (fish per hour) compared to the highest catch rate during the preoperational monitoring of 1.16 (fish per hour).

The first two years of operation of WBN has not impacted the benthic macroinvertebrate community. During operational monitoring, densities of benthic macroinvertebrates collected near WBN nearly doubled from those observed during preoperational monitoring. In addition to the increased number of taxa found during this period, zebra mussel average densities increased from 26.5/m^2 in 1996 to 41/m^2 in 1997 and were most abundant (72/m^2) at TRM 528.5 (upstream

of the WBN intake channel). Freshwater mussels in the vicinity of WBN are slow growing and quite old. Many of the 30 species found below Watts Bar Dam appear to have not reproduced in the past 50 years. Declining abundance trends were noted during preoperational assessment for several communities of macroinvertebrates, plankton and periphyton. These trends are mainly due to the wide range of flow and climatic conditions that occur.

Water quality in the vicinity of WBN, while generally satisfactory, was influenced by releases from Watts Bar Dam located two miles upstream. In 1996, TVA's Water Management installed an aeration system in the forebay of Watts Bar Reservoir to reduce stratification in the vicinity of Watts Bar Dam during summer and fall. This has resulted in higher dissolved oxygen levels in hydro releases. During the first two years of operation, WBN has not impacted the water quality in Chickamauga Reservoir.

WBN operation has had no effect on the aquatic communities nor water quality in upper Chickamauga Reservoir.

LIST OF TABLES

Juvenile and Adult Fish — Page

Table 2-1. Sample period, dates, number of samples, and mean temperatures for larval fish collections near Watts Bar Nuclear Plant during preoperational monitoring 1976 through 1979, 1982 through 1985 and operational monitoring 1996 and 1997. 73

Table 2-2. List of scientific and common names for fish egg and larval taxa collected near Watts Bar Nuclear Plant during 1976 through 1979, 1982 through 1985, and 1996 and 1997. 78

Table 2-3. Total numbers and percent composition of fish eggs and larvae collected during 1976-1985, 1996 and 1997 in the vicinity of Watts Bar Nuclear Plant. 80

Table 2-4. Day and night densities (number per 1,000 m^3)of larval fish collected during preoperational and operational monitoring in the vicinity of Watts Bar Nuclear Plant. 83

Table 2-5. Species list, total number collected, and occurrence spans of fish eggs and larvae collected during operational monitoring at Watts Bar Nuclear Plant, 1996. 84

Table 2-6. Species list, total number collected, and occurrence spans of fish eggs and larvae collected during operational monitoring at Watts Bar Nuclear Plant, 1997. 85

Table 2-7. Average and peak density (number per 1,000 m^3) of larval fish with mean water temperatures collected in the vicinity of Watts Bar Nuclear Plant during preoperational and operational monitoring. 86

Table 2-8. Distribution of larval fishes by size group (mm) collected at Watts Bar Nuclear Plant, during 1996 and 1997. 87

Table 2-9. Percent composition of dominant larval fish taxa collected in the cooling water intake channel at the Watts Bar Nuclear Plant Site, 1984 through 1985, and 1996 through 1997. 89

Table 2-10. Comparison of percent composition of the catch from preoperational (1977-1985 and 1990-1995) and operational (1996-1997) monitoring periods. 90

List of Tables (Continued) Page

Table 2-11. Comparison of average catch per electrofishing run (CPUE) and percent composition of the catch from vital signs preoperational (1990-1995) and operational results (1996-1997). 91

Table 2-12. Summary of one-way univariate ANOVA testing of effects of 1990-1995 preoperational compared to 1996-1997 operational monitoring results and interactions of these for variables on CPUE of each important species collected by electrofishing near Watts Bar Nuclear Plant. 92

Table 2-13. Actual and estimated fish impinged at Watts Bar Nuclear Plant during two sample periods, March 1996 through March 1997 and March 1997 through October 7, 1997. 93

Table 2-14. Estimated total impingement of fishes at Sequoyah Nuclear Plant (1981 through 1983. 94

Table 2-15. Location of access points, percent of clerk time allotted for interviews, and angler type encountered for the Watts Bar Tailwater creel survey. 95

Table 2-16. Number of days surveyed and number of interviews for the Watts Bar Tailwater creel survey, April 1996 through April 1998. 96

Table 2-17. Directed species effort for bank and boat fisherman during the Watts Bar Tailwater creel survey, April 1996 through April 1998. 97

Table 2-18. Number of interviews and percent angler use at six access points within the Watts Bar Tailwater survey, April 1996 through April 1998. 97

Table 2-19. Monthly estimated effort, percent effort, and estimated number of angling trips for Watts Bar Tailwater fishery, April 1996 through April 1998. 98

Table 2-20. Estimated effort, number, and length of trips for selected species groups by fishermen in the Watts Bar Tailwater fishery, April 1996 through April 1998. 99

Table 2-21. Mean catch and harvest rate with standard errors, and percent harvested for directed species group anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998. 99

Table 2-22. Estimated number of fish caught and harvested with standard errors for directed species group anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998. 100

List of Tables (Continued) Page

Table 2-23. Mean catch and harvest rate with standard errors, and percent harvested for any species anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998. 100

Table 2-24. Estimated number of fish caught and harvested with standard errors for any species anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998. 101

Table 2-25. Estimated number of fish caught and harvested with standard errors by all anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998. 101

Table 2-26. A comparison of harvest rates from preoperational (1982-1985) and operational (1996-1998) creel surveys conducted in the Watts Bar Tailwater. 102

Benthic Macroinvertebrates

Table 3-1. Benthic macroinvertebrate taxa collected during preoperational (1973 through 1985) and operational (1996 and 1997) monitoring at Watts Bar Nuclear Plant. 103

Table 3-2. Average densities (number/m^2) of dominant* macroinvertebrates collected with Hess samples near Watts Bar Nuclear Plant, during summer and fall 1983 through 1985 (preoperational) and 1996 through 1997 (operational). 109

Table 3-3. Number of taxa and diversity index ($\overline{d}$) values of benthic macroinvertebrates from Hess samples collected during preoperational monitoring (1983 through 1985), and operational monitoring (1996 and 1997) at Watts Bar Nuclear Plant. 110

Table 3-4. Results of one-way analysis of variance and Duncan's new multiple range test on total benthic macroinvertebrate standing crop (number/m^2) estimated from Hess samples during preoperational (1983 through 1985) and operational (1996 through 1997) monitoring, Watts Bar Nuclear Plant, Chickamauga Reservoir. 111

Table 3-5. Total densities of benthic macroinvertebrates (number/m^2) collected in Hess samples near Watts Bar Nuclear Plant, summer and fall, 1983 through 1985 (preoperational) and 1996 and 1997 (operational). 112

List of Tables (Continued) Page

Table 3-6. Results of the 1997 survey of native mussels in three beds monitored near the Watts Bar Nuclear Plant 113

Table 3-7. Total numbers of each native mussel species collected during preoperational (1983-1994) and operational (1996-1997) surveys near Watts Bar Nuclear Plant. 114

Table 3-8. Rank order relationships among the 12 mussel species encountered during all 14 surveys of three mussel beds near Watts Bar Nuclear Plant. Most rank order assignments were based on the total number of a species found during each survey; however, alphabetical order of scientific names was used to avoid ties when two or more species were represented by the same number of animals. 115

Table 3-9. Numbers of all mussel species and each of the five most abundant species encountered on each of the three mussel beds near Watts Bar Nuclear Plant during the 10 summer surveys used in the statistical analyses. 116

Table 3-10. Results of statistical analyses of native mussel abundance on three beds monitored near Watts Bar Nuclear Plant during 1983 through 1997. Only the summer sample data were used in these analyses to equalize the weight associated with each year. The significance level used in these analyses was $\alpha = 0.05$. 117

Table 3-11. Mean lengths (in millimeters) of each mussel species encountered on all during surveys conducted near Watts Bar nuclear Plant during 1983-1997. As a general rule, no more than 50 members of each species were measured from each bed during any given survey. 118

Table3-12. Statistical analyses of mean lengths of native mussel collected near Watts Bar Nuclear Plant during the period 1983 through 1997. Only the summer sample data were used in these analyses to equalize the weight associated with each year. The significance level used in these analyses was $\alpha = 0.05$. 120

Instream Water Quality

Table 4-1. Preoperational water quality monitoring summary statistics for parameters measured during 1982-1987 at WBN. 121

Table 4-2. Operational water quality monitoring summary statistics for parameters measured during 1996-1997 at WBN. 123

List of Tables (Continued) Page

Table 4-3. Statistical Comparison of WBN 1996 Operational Water Quality Data to Preoperational Data using Anova w/Duncan's Multiple Range Test. 125

Table 4-4. Statistical Comparison of WBN 1997 Operational Water Quality Data to Preoperational Data using Anova w/Duncan's Multiple Range Test. 126

Table 4-5. Statistical Comparison of WBN Combined 1996-1997 Operational Water Quality Data to Preoperational Data using Anova w/Duncan's Multiple Range Test. 126

Table 4-6. Preoperational (1982-1991) water quality monitoring summary values for metals at WBN. 127

Table 4-7. Operational (1996-1997) water quality monitoring summary values for metals at WBN. 129

LIST OF FIGURES

Introduction Page

Figure 1-1. Location of Watts Bar Nuclear Plant in Chickamauga Reservoir. 131

Juvenile And Adult Fish

Figure 2-1. Sample locations for entrainment samples in the vicinity of Watts Bar Nuclear Plant, 1996-1997. 132

Figure 2-2. Reservoir Fish Assemblage Index (RFAI) scores from preoperational (1991 through 1995) and operational (1996) periods on Chickamauga Reservoir in the vicinity of Watts Bar Nuclear Plant. 133

Figure 2-3. Percent of angler effort for selected directed species groups from the Watts Bar tailwater fishery, April 1996 through April 1998. 134

Figure 2-4. Percent of angler effort for selected directed species groups from the Watts Bar tailwater fishery, April 1996 through April 1998. 135

Figure 2-5. Estimated number of fish harvested in the Watts Bar Tailwater by directed and any species groups, April 1996 through April 1998. 136

Figure 2-6. Monthly catch rate for selected species from the Watts Bar Tailwater, April 1996 through April 1998. 137

Figure 2-7. Monthly harvest rate for selected species from the Watts Bar Tailwater, April 1996 through April 1998 138

Figure 2-8. Length frequency of angler-harvested black basses sampled during creel surveys in Watts Bar Tailwater, April 1996 through April 1998. 139

Figure 2-9. Age frequency of harvested black basses, from the Watts Bar Tailwater, April 1996 through April 1998. 140

Figure 2-10. Length frequency of angler-harvested blue catfish and channel catfish from the Watts Bar Tailwater, April 1996 through April 1998. 141

Figure 2-11. Length frequency of angler-harvested black and white crappie from the Watts Bar Tailwater, April 1996 through April 1998. 142

List of Figures (Continued) Page

Figure 2-12. Age distribution of angler-harvested black and white crappie from the Watts Bar Tailwater, April 1996 through April 1998. 143

Figure 2-13. Length frequency of angler-harvested sauger from Watts Bar Tailwater, April 1996 through April 1998. 144

Figure 2-14. Age distribution of angler-harvested sauger from Watts Bar Tailwater, April 1996 through April 1998. 145

Figure 2-15. Length frequency of angler-harvested white bass from Watts Bar Tailwater, April 1996 through April 1998. 146

Figure 2-16. Age distribution of angler-harvested white bass from Watts Bar Tailwater, April 1996 through April 1998. 147

Figure 2-17. Length frequency of angler-harvested striped bass from Watts Bar Tailwater, April 1996 through April 1998. 148

Figure 2-18. Age distribution of angler-harvested striped bass from Watts Bar Tailwater, April 1996 through April 1998. 149

Benthic Macroinvertebrates

Figure 3-1. Sampling locations for benthic macroinvertebrates near Watts Bar Nuclear Plant, 1996-1997. 150

Figure 3-2. Locations of sampling stations at three native mussel beds surveyed during the preoperational (1983-1994) and operational (1996 and 1997) monitoring program for Watts Bar Nuclear Plant. 151

Figure 3-3. Relationships among the mean numbers of all mussel species encountered on the bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values. 152

Figure 3-4. Relationships among the mean numbers of Elliptio crassidens encountered on three of the four sampling sites on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values. 153

List of Figures (Continued) Page

Figure 3-5. Relationships among the mean numbers of Pleurobema cordatum encountered on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values. 154

Figure 3-6. Relationships among the mean numbers of Quadrula pustulosa encountered on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values. 155

Figure 3-7. Relationships among the mean numbers of Quadrula pustulosa encountered on three of the four sampling sites on the mussel bed at Tennessee River Mile 526-527 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values. 156

Figure 3-8. Relationships among the numbers of Cyclonaias tuberculata encountered at the four sampling sites on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. While statistically significant trends are present in these data, the slopes of those trends are not parallel with each other. 157

Figure 3-9. Mean lengths of Elliptio crassidens and Cyclonaias tuberculata on the mussel bed at Tennessee River Miles (TRM) 520-521, and Elliptio crassidens on the bed at TRM 526-527 during 1983-1997. 158

Figure 3-10. Mean lengths of Pleurobema cordatum on two mussel beds, Tennessee River Miles (TRM) 526-527 and TRM 528-529, during 1983-1997. 159

Instream Water Quality

Figure 4-1. Water quality sampling locations during operational monitoring at Watts Bar Nuclear Plant, 1996 and 1997. 160

1.0 INTRODUCTION

1.1 Purpose and Objective

The Tennessee Valley Authority (TVA), in accordance with the NPDES Permit Number TN0020168, conducted a six-year (1973-1979) nonradiological preoperational aquatic monitoring program after receiving construction permits for WBN on January 23, 1973, from the Atomic Energy Commission. Due to policy changes and various construction delays, TVA conducted an additional preoperational aquatic monitoring program from March, 1982 through December, 1985 to update the data base. Information collected provided a composite analysis of biological and water quality conditions during both monitoring periods. TVA completed one reactor unit and began testing Unit 1 in March 1996 and first generated commercial power on May 27, 1996. This unit operated at 84% capacity and generated more than 8.5 billion kilowatt-hours of electricity during the first year of commercial operation (May 27, 1996 through September 5, 1997) and at or near forecast net capacity through the first quarter of 1998.

Part III, Section C.b. of the NPDES permit requires that an operational monitoring plan be implemented not later than the start of the biological year in which 100% power is predicted for Unit 1. The current operational monitoring plan was submitted to the Tennessee Department of Environmental Conservation (TDEC) on September 8, 1993 (Ref: Letter from Wilson C. McArthur to Thomas Roehm). This operational monitoring plan was revised from previous

versions based on numerous aquatic biological investigations conducted in the vicinity of WBN and throughout Chickamauga Reservoir since the original operational monitoring plan was prepared in 1977. These investigations focused on selected fish species and other specific problem areas (e.g., dissolved oxygen, aquatic vegetation) identified by the State of Tennessee. The cumulative results of these investigations changed the scope and focus of concerns regarding the potential effects of WBN operation on the ecology of Chickamauga Reservoir. In particular, results of species-specific investigations of sauger, white crappie, white bass, and channel catfish have provided information that reduced earlier concerns about the likelihood of WBN operational effects on these species.

The previously approved WBN Operational Nonradiological (Aquatic Biological) Monitoring Program contained types and frequencies of sampling that essentially duplicated those used in the preoperational monitoring program. The rationale for the preoperational monitoring program was to provide a broad base of information on all aspects of aquatic communities in the vicinity of WBN, regardless of whether or not the operation of the plant would reasonably be expected to significantly impact those communities. The rationale for the present operational monitoring program is to focus as much as possible on specific areas of concern to the State and TVA based on a realistic assessment of the likelihood of operational effects on a given community. It also provides sufficient data to indicate the presence of unexpected effects on other communities that might become the subject of more intensive studies in the future. The purpose of

operational aquatic monitoring is to evaluate plant effects on the aquatic environment for at least two years after commercial operation of Unit 1 as required by the NPDES permit. This monitoring program was designed to detect and evaluate significant changes in water quality and biological communities which could be plant-induced.

Data analyzing spatial and temporal differences were compared with preoperational monitoring data when possible to detect and evaluate significant changes in water quality and biological communities. Spatial differences were determined by comparing data from stations upstream and downstream of WBN. Temporal changes were determined by comparing operational (1996 through 1998) to preoperational monitoring data (1973-1979 and 1982-1985). Data from additional investigations conducted between 1985 and 1996 were also used to supplement preoperational data.

1.2 Plant Description

WBN is located on the west bank of upper Chickamauga Reservoir near Tennessee River Mile (TRM) 528 (Figure 1-1). This one-unit nuclear generating plant is designed for an electrical ouput of about 1270 megawatts (MWe). WBN is situated approximately two miles downstream of Watts Bar Dam (TRM 529.9) and one mile downstream of the four-unit Watts Bar Fossil Plant (WBF) that is also on the west bank of Chickamauga Reservoir (TRM 529). WBF was decommissioned on March 29, 1983, and has been off-line since 1981.

WBN is operated in closed cycle cooling mode, using one of the two cooling towers for heat dissipation. Blowdown from the cooling tower is discharged through multiport diffusers located in the main river channel at TRM 527.8. Makeup water and other water supply requirements are obtained from an intake channel and pumping station at TRM 528. These intake and discharge structures are shown in Figure 1-1.

The WBN intake channel cross-section opening is approximately 155 m^2 (1,650 ft^2) at Chickamauga Reservoir winter pool elevation of 206m (675 ft) mean sea level, and 293 m^2 (3,159 ft^2) at summer pool level of 208m (682.5 ft). Corresponding average velocities in the intake channel are 0.03 m/s (0.1 ft/s) and 0.015 m/s (0.05 ft/s). Four gates lead to the traveling screens with a combined opening of 33 m^2 (360 ft^2), so the maximum screen velocity is approximately 0.15 m/s (0.5 ft/s). Maximum intake pumping flowrate is 4.5 m^3/s (160 cfs) or 0.6 % of the long-term average flow past WBN of 767 m^3/s (27,100 cfs).

Blowdown from the cooling tower is discharged directly to the diffuser or into a holding pond which in turn releases water through the diffuser system. During periods of no releases from Watts Bar Dam, WBN blowdown is stored in the holding pond. Releases during normal operation are approximately 2.0 m^3/s.

The diffuser system consists of two pipes extending into the main channel. The downstream pipe segment extends 90m into the channel with a 50m long,

1.35m diameter diffuser section located in the deepest (5-6 m) portion of the 400m wide channel. The upstream pipe segment extends 140m with a 25m long, 1.0m diameter diffuser section beginning where the downstream diffuser section ends. The diffuser sections are half buried in the river bottom with two rows of 2.5cm (1 in) diameter ports oriented at a 45° angle in the downstream direction. The exit jet velocity is approximately 2 m/s. The expected discharge temperature varies, depending on cooling tower performance, from 17°C in January to 35°C in July. The maximum blowdown temperature is 35°C, so the expected monthly average temperature difference between the discharge and the river varies from 10°C during winter and spring to 5°C during summer and fall. The diffuser system will result in a near-field dilution of at least 15. Far-field mixing will depend on releases from Watts Bar Dam. The permitted diffuser mixing zone at WBN is 240 feet wide and extends 240 feet downstream over the entire river depth. At the long-term average releases, maximum diffuser discharge represents 0.6 % of river flow.

2.0 JUVENILE AND ADULT FISH

2.1 Entrainment-Larval Fish (and Eggs)

Introduction

Preoperational monitoring to determine spatio-temporal concentrations of ichthyoplankton in the vicinity of WBN was conducted from 1976-1979 and from 1982-1985. Preoperational data were compared with operational data collected during 1996 and 1997 to determine and assess any effects of plant operation. This sampling provided estimates of density and relative abundance by taxon to evaluate potential losses by determining the proportion of eggs and larvae passing the plant entrained in the condenser cooling water.

Materials and Methods

Data Collection

Ichthyoplankton samples during preoperational (1976-1979, 1984 and 1985) and operational (1996 and 1997) monitoring were collected biweekly (weekly during part of preoperational monitoring) on a diel schedule (day and night), during March-August (preoperational) and April-June (operational) at TRM 528.0 (Table 2-1), This sampling provided temporal abundance of larval fish at five stations along a transect perpendicular to river flow just upstream of the plant intake channel (Figure 2-1). Samples were taken with a beam net (0.5 m square, 1.8 m long, with 505 micron "nitex" mesh netting) towed upstream at a speed of 1.0 m/s for ten minutes. The volume of water filtered through the net was measured with a large-vaned General Oceanics flowmeter®. Approximately 150

m^3 of water were filtered per ten minute sample. Water temperature was recorded using a mercury thermometer calibrated to the tenth degree. Beginning in 1984 and during operational monitoring, additional towed samples were collected in the plant cooling water intake channel. Preoperational (1984-1985) intake channel samples consisted of four, four-minute samples taken from the plant intake pump building to the mouth of the intake channel. Each operational intake sample was a composite of four, one-minute samples taken from the trash boom to the mouth of the intake channel. Approximately 40-50 m^3 of water were filtered per intake sample.

Laboratory Analysis

Larval fish were removed from the samples, identified to the lowest possible taxon, counted and measured to the nearest millimeter total length following procedures outlined in NROPS-FO-BR-24.1 (TVA 1983). Taxonomic decisions were based on TVA's "Preliminary Guide to the Identification of Larval Fishes in the Tennessee River," (Hogue et al., 1976) and other pertinent literature.

The term "unidentifiable larvae" applies to specimens too damaged or mutilated to identify, while "unspecifiable" before a taxon implies a level of taxonomic resolution (i.e., "unspecifiable catastomids" designates larvae within the family Catostomidae that currently cannot be identified to a lower taxon). The category "unidentifiable eggs" applies to specimens that cannot be identified due to damage or lack of taxonomic knowledge. Taxonomic refinement is a function

of specimen size and developmental stage. Throughout this report, the designation "unspecifiable clupeids" refers to clupeids less than 20 mm in total length and could include Dorosoma cepedianum (gizzard shad), D. petenense (threadfin shad), and/or Alosa chrysochloris (skipjack herring), (Table 2-2). Any clupeid specimen identified to species level represents postlarva 20 mm or longer in total length.

Developmental stage of percichthyids also determines level of taxonomic resolution. Morone saxatilis (striped bass) hatch at a larger size than either M. chrysops (white bass) or M. mississippiensis (yellow bass). Although it is currently impossible to distinguish between larvae of the latter two species, M. saxatilis can be eliminated as a possibility based on developmental characteristics of specimens 6 mm or less in total length (hence, the taxonomic designation Morone, not saxatilis). Specimens identified as Morone spp. are greater than 6 mm total length.

Data Analysis

Temporal occurrence and relative abundance of eggs and larvae by taxon are presented and discussed for the entire preoperational and operational monitoring periods. Densities of fish eggs and larvae are expressed as numbers per 1000 m^3 for diel comparisons.

Estimated entrainment of fish eggs and larvae at WBN was calculated by the following method: densities of eggs and larvae transported past the plant were estimated for each sample period by averaging densities (all stations) of eggs and larvae from TRM 528 and multiplying by the corresponding 24-hour flow past the plant. Percentage of transported ichthyofauna entrained by the plant was estimated from the formula:

$$E = \frac{100\, D_i\, Q_i}{D_r\, Q_r}$$

where D_i = mean density (N/1000 m^3) of eggs or larvae in intake samples;

D_r = mean density (N/1000 m^3) of eggs or larvae in river (TRM 528 transect);

Q_i = plant intake water demand (m^3/d);

Q_r = river flow (m^3/d).

Results and Discussion

Fish Eggs

During the two preoperational study periods, 2,881 fish eggs were collected in WBN ichthyoplankton samples. This total consisted of 67% unidentified eggs and 33% freshwater drum eggs (TVA 1986). Overall, egg densities were low and identifiable eggs were freshwater drum eggs, with the exception of one *Hiodon* spp. egg (probably *Hiodon tergisus*) collected in 1985 sampling (Table 2-3). Low numbers of drum eggs occurred in samples from early May to early September with peak abundance occurring from May through early July (TVA 1986).

Low numbers of drum eggs were also recorded during operational monitoring (Tables 2-4 and 2-5). During both operational years, drum eggs were first collected after the water temperatures reached 20°C. Day and night densities were variable during the study with no apparent trend in diel distribution (Table 2-4). The planktonicity of freshwater drum eggs makes them highly vulnerable to capture by larval fish sampling gear; therefore, low abundance at the WBN site indicates little, if any, freshwater drum spawning in the Watts Bar tailwater upstream of the WBN intake channel. The occurrence of freshwater drum eggs at WBN probably results from dam passage. Large numbers of freshwater drum larvae were collected at the Lowe Branch site above Watts Bar Dam in 1978 (TVA 1980b), indicating considerable drum spawning occurs above the dam.

Fish Larvae

Taxonomic composition of larval fish samples during preoperational and operational monitoring consisted of 20 and 18 taxa, respectively (Table 2-3). During both years of operational monitoring (1996 and 1997) clupeid larvae represented 84 and 82 percent of the larval fish community, respectively, and were present eleven of thirteen sample periods (Tables 2-5 and 2-6). Percent composition of the remaining taxa exceeding 1% in 1996 and 1997 were freshwater drum (6.6%, 2.7%) temperate basses (4.5%, 12.3%) and sunfishes (1.9%, 1.3%), respectively. Gizzard shad (1.5%) and threadfin shad (1.0%) exceeded 1% during 1996 and crappie (1.3%) exceeded 1% during 1997. During 1996 and 1997 Morone (not saxatilis) and Percidae (not Stizostedion)

occurred during the first three sample periods (Table 2-5). Six yellow perch larvae were collected during 1996, but none were collected during 1997. No sauger larvae were collected during 1996, but two were collected during the first sample period of 1997. Morone sp. were present from the second through the seventh sample period and increased in composition from 0.83% (41 larvae) during 1996 to 8.3% (820 larvae) of the larval fish community during 1997 (Tables 2-5 and 2-6). Percent composition of crappie larvae also increased from 0.2% during 1996 to 1.3% during 1997 (Table 2-5 and Table 2-6).

During preoperational monitoring, average larval densities, measured from April-June, were highest (2,119/1000 m^3) in 1984 and lowest (146/1000 m^3) in 1979 (Table 2-7) with a mean preoperational density of 822/1000 m^3. The highest and lowest peak density occurred May 29, 1984 (10,485/1000 m^3) and May 22, 1979 (370/1000 m^3), respectively. During operational monitoring 1996 and 1997 average larval densities were 525/1,000 m^3 and 2,287/1000 m^3, respectively. Peak densities of 1,392/1,000 m^3 and 11,211/100 m^3 occurred on June 3, 1996 and June 23, 1997, respectively. Peak densities typically reflected periods of greatest larval shad abundance. During both preoperational and operational periods, seasonal larval densities were positively correlated with mean water temperatures ($r = 0.80$).

Larvae of migratory taxa (species known to have distinct spawning migrations) reported to spawn in tailwaters were not numerous in preoperational or

operational monitoring samples. Specimens of Stizostedion spp. collected during preoperational monitoring, 1976-1978 (Table 2-3), were the result of dam passage as they were too large (10-18 mm TL) to have hatched below Watts Bar Dam in the vicinity of WBN. Priegel (1969) reported that sauger hatch at 5-7 mm total length. Neither Stizostedion spp. nor S. canadense (sauger) larvae were collected in the last five years of preoperational monitoring, nor during the first year of operational monitoring. During the second year of operational monitoring two Stizostedion sp. were collected during the first sampling period (Table 2-6). Both individuals were 7 mm in length (Table 2-8) indicating these could have been walleye larvae that hatched above Watts Bar Dam or possibly incidental spawing by sauger in the tailwater. Priegel (1970) found that walleye hatch at 6.0-6.8 mm total length. Previous investigations (Hickman et al. 1990) have determined that sauger in Chickamauga Reservoir spawn at Hunter Shoals (TRM 521), and therefore larvae hatched downstream from WBN would not be subjected to entrainment by WBN.

Temperate basses (Morone spp.), another migratory taxon, accounted for more than 1% of total larvae during five of the last six years of preoperational monitoring and during both years of operational monitoring. White and yellow bass (not striped bass), comprise the majority of this taxon. Temperate basses as a whole made up 0.06% in 1976 to 6.63% of the ichthyoplankton community in 1982 (Table 2-3). During operational monitoring (1996 and 1997), percent composition of temperate bass ranged from 4.2% to 12.3%, respectively. There

was no clear diel pattern for Morone larval densities (Table 2-4). Table 2-8 illustrates a wide range of larval Morone sizes in ichthyoplankton samples during the two years of operational monitoring. This suggests a combination of both temperate bass spawning in the tailwater and dam passage of larvae produced in Watts Bar Reservoir.

Perca flavescens, (yellow perch), larvae were first collected in Chickamauga Reservoir in 1978, and were subsequently collected throughout preoperational monitoring. Adult yellow perch are common in Chickamauga and Watts Bar Reservoirs. Larvae collected in the vicinity of WBN likely result from dam passage. Yellow perch made up 0.12% of larval densities during the first year of operational monitoring (1996) which was consistent with the relative abundance observed during preoperational monitoring (Table 2-3). During the second year of operational monitoring (1997) larval yellow perch were not collected. It can be concluded that the tailwater habitat is not conducive to yellow perch spawning.

Due to their high reproductive potential, clupeids were consistently the most numerous larval fish taxon captured during both preoperational and operational periods (Table 2-3). It is unlikely that the Watts Bar Tailwater is an important spawning area for shad. Eggs of gizzard and threadfin shad are demersal and adhesive, and larvae of both species hatch at approximately 3.5 mm total length (Shelton 1972). Shelton also reported growth of both species to be 1 mm or

more the first day at 23°C. Typically, water transport time from Watts Bar Dam to the plant site would not exceed five to six hours (TVA 1986). Operational monitoring revealed that most clupeids collected were greater than 6mm (Table 2-8). This implies that larval and postlarval shad below the dam were there as a result of dam passage.

Two Centrarchids, sunfish and crappie, were collected all six years of preoperational monitoring, and during operational monitoring. Sunfish were relatively abundant in all monitoring years (Table 2-3). Preoperational data (TVA 1986) suggest that densities of sunfish larvae were found in greater numbers near the shoreline and in intake samples, indicating that these two areas serve as spawning and nursery areas for sunfish.

Crappie larvae were collected in greatest densities during May and June for all of preoperational and operational monitoring (Tables 2-5 and 2-6). Size distributions of crappie larvae collected at WBN (Table 2-8) show that approximately 63% of the larvae collected were 5 or 6 mm specimens in 1996 and 84% in 1997. Crappie larvae swim up from the nest when total length is between 4.1 and 4.6 mm (Siefert 1968 and Carlander 1977). Crappie spawning habitat has been well documented in Watts Bar Reservoir and a greater mean size of crappie larvae collected at WBN than at Lowe Branch in 1978 (TVA 1980a) suggests their occurrence at WBN is mainly via dam passage.

Freshwater drum comprised 5% of the total catch during operational monitoring and 0.3% to 18% during preoperational monitoring (Table 2-3). Mean densities of this species were the least variable of the abundant taxa and similar densities were observed during day and night samples (Table 2-4). As mentioned previously, freshwater drum were primarily spawned above Watts Bar Dam.

Estimated Entrainment of Eggs and Fish Larvae

Estimated average hydraulic entrainment by WBN (proportion of the Tennessee River flow entrained) during operation is very low (0.6%) compared to 13% by Sequoyah Nuclear Plant (SQN), (TVA 1996). Estimated percentage entrainment of fish eggs and larvae being transported past WBN during both years of operational monitoring was 0.1%, compared to 7.5% estimated entrainment at SQN during 1980-1984 (TVA 1984). Total transport of fish larvae and eggs past WBN during 1996 was estimated to be 4.5×10^5 and 2.7×10^5, respectively.

During the second year of operational monitoring, 1997, the total transport of fish larvae and eggs past WBN was estimated to be 7.0×10^4 and 6.8×10^5, respectively. During 1996, an estimated 449 fish eggs and 267 larvae were entrained at WBN. During 1997, the estimated total entrainment was 1,911 eggs and 120,000 larvae. Due to the low hydraulic entrainment at WBN, larvae residing in the intake channel are most susceptible to entrainment. Larval shad represented 91% in 1996 and 85% in 1997 of all larvae collected in the intake channel, followed in abundance by sunfish (7.7% and 8.2%), freshwater drum

(0.8% and 0.4%), and temperate basses (0.09% and 6.5%), respectively (Table 2-9). A total of 409 shad was estimated to be entrained during 1996 and 1,101 in 1997 compared to 35 and 107 sunfish larvae during 1996 and 1997, respectively. These low entrainment numbers indicate that WBN operation is not adversely impacting shad and sunfish populations. Relatively low densities of fish eggs and larvae observed in Watts Bar Tailwater, and minimal hydraulic entrainment by WBN, suggests no impact to the ichthyoplankton populations from plant operation.

2.2 Electrofishing

Introduction

Preoperational fish community sampling at WBN was initiated in March 1977, continued through November 1979, and resumed from March 1982 to December 1985. Additional preoperational fish community monitoring data were collected in the vicinity of WBN (TRM 526-529.9) from 1990 to 1995 in conjunction with the TVA Reservoir Vital Signs Monitoring program. Vital signs monitoring activities provide information from key physical, chemical, and biological indicators. The Reservoir Fish Assemblage Index (RFAI) provides one biological measure of the status of the environmental quality of a particular area of a reservoir (Hickman and McDonough 1996). The sampling schemes between these two data sets (older preoperational and vital signs monitoring) were somewhat different, limiting potential comparisons.

Usefulness and validity of electrofishing data, as with other gear types, is dependent on efficiency and consistency of sample collection. Factors which influence electrofishing data can generally be broken into three categories: fish characteristics, habitat characteristics, and operating conditions (Reynolds 1983). Fish characteristics are not anticipated to influence comparisons between WBN preoperational and operational electrofishing samples as the sampling schemes were directed at the same species. Influence of habitat characteristics was minimized by both sampling schemes directed at proportionally covering all shoreline habitats available above and below WBN. Operational variations, such as seasonal differences in Watts Bar Dam water releases, were reduced by comparing only fall samples between the data sets (spring, summer and winter samples were also available for the 1977-1985 preoperational period). Another operational difference was the start-up of WBN in 1996, and this was the focus of determining plant impacts.

Materials and Methods

Fish stunned by a boat electrofishing unit were captured, identified, enumerated, and recorded prior to release. During vital signs monitoring samples (1990-1997), young-of-the-year (YOY) individuals of all species were not included in counts and percent composition aspects due to their highly fluctuating densities (especially shad species), inaccurate sampling by electrofishing, and the uncertainty of their contribution to adult stocks. Earlier preoperational samples

(1977-1985) did include YOY individuals. Individual lengths were not measured during these samples, therefore, determination of YOY densities was not possible. As a result, gizzard and threadfin shad were eliminated from all density and percent composition results from all data sets.

Data collected from 1977-1979 were based on timed (three minute duration) electrofishing runs, while samples collected during 1982-1985 were distance based (100 m). Five electrofishing runs were collected monthly during both of these time periods. Vital signs samples were collected once during each fall (15 electrofishing runs) and were distance-based (300 meters of shoreline/run). Species occurrence and percent composition between the two preoperational sample sets and operational results, after elimination of shad, are comparable. Since operational data are limited to two annual samples (1996 and 1997), vital signs preoperational data (1990-1995) are reported in average annual results to allow more realistic comparisons.

Catch per unit effort (CPUE) results are not comparable between 1977-1985 preoperational and 1990-1996 vital signs results due to the differences in sampling protocol. Therefore, discussions of operational impacts of WBN on fish species CPUE will be based on comparisons between 1990-1995 (preoperational) and 1996-1997 (operational) vital signs monitoring results.

General comparisons were made between the 1977-1985 preoperational, 1990-1995 preoperational, and 1996-1997 operational data regarding species occurrence and relative composition of the resident fish population. Average CPUE results in electrofishing samples during vital signs preoperational and operational periods were compared using a univariate Analysis of Variance (ANOVA) to determine if there were significant ($P = 0.05$) differences. Only species termed "important" (those occurring in 50% or more of the samples and comprising at least 1% of the total catch) are discussed in detail. RFAI scores between vital signs preoperational and operational years were compared to determine if the overall fish community had been impacted by the initial two years of WBN operation.

Results and Discussion

Table 2-10 compares species occurrence and percent composition between preoperational electrofishing (1977-1979 and 1982-1985), preoperational vital signs monitoring data (1990-1995), and operational monitoring (1996-1997) electrofishing data. During the 1977-1985 preoperational monitoring period at WBN, monthly electrofishing yielded 43 species from 12 families (Table 2-10). Fall vital signs electrofishing preoperational monitoring resulted in the collection of 39 species from 10 families while 34 species (9 families) were captured during fall operational monitoring. The higher diversity found during 1977-1985 preoperational monitoring was likely due to samples occurring on a monthly basis instead of only one fall sample taken per year during vital signs monitoring

activities. Operational monitoring consisted of a total of two samples, fall 1996 and 1997, however, species occurrence was just slightly lower than 1990-1995 preoperational results, which included a total of six fall samples.

Percent composition of the various preoperational and operational electrofishing samples (excluding gizzard and threadfin shad) revealed minimal differences in the fish community make-up from 1977-1997 (Table 2-10). Only emerald shiners appear to have declined substantially in numerical importance over the course of the sample periods; making up 58.6% of the community during 1977-1985, 17.1% from 1990-1995, and only 1.5% during 1996-1997. This decline began prior to WBN startup, therefore plant operation is not considered responsible. Bluegill, redear sunfish, yellow bass , and largemouth bass have consistently dominated the overall catch. Bluegill and smallmouth bass increased in importance throughout the sampling period. Additional species of fish generally meeting the important species criteria (comprising more than 1% of the population) included; white bass, common carp, spotted sucker, golden redhorse, freshwater drum, brook silversides, logperch, smallmouth bass, spotted bass, and black crappie. Brook silversides were not collected during either year of operational monitoring, while golden redhorse, freshwater drum, and black crappie increased somewhat in importance to the community after WBN became operational.

Comparisons of CPUE (catch per electrofishing run) results between vital signs preoperational (1990-1995) and operational (1996-1997) monitoring are listed in Table 2-11. Mean CPUE for all species during preoperational and operational monitoring was 76 and 53 fish per shocking run, respectively. Threadfin shad were not included due to extreme variability of results caused by the schooling nature of these species. If a large school of shad is encountered during a particular electrofishing run, the catch rates are skewed out of proportion. Bluegill, redear sunfish, largemouth bass, yellow bass, spotted bass, and smallmouth bass dominated the catch during both periods. Only emerald shiners revealed any major change in abundance, and, as noted earlier, this decline began prior to WBN becoming operational. None of the differences between preoperational and operational sample results for 12 species meeting the criteria to be considered "important" were significant, P=0.05 level (Table 2-12).

RFAI values for the vicinity of WBN remained relatively stable with an average annual score of 44 during the 1991-1995 preoperational period and a of 45 in the operational period (1996-1997). Scores ranged from a maximum score of 56 in 1993 to a minimum of 33 in 1991 (Figure 2-2). The maximum RFAI score of 56 obtained in 1993 was followed by a gradual decline to 38 by 1996. This decline began two years before WBN became operational and rebounded to a score of 52 during the second year of operation. Reasons for the 1993-1996 decline are unknown, but it is apparent WBN operation was not responsible.

Conclusions

Fish community sampling results revealed only minor differences in species occurrence and percent composition between preoperational and operational samples. These differences were attributed to variations in sampling design with 1977-1985 data collected on a monthly basis throughout each year and 1990-1996 data collected only once during fall of each year. Operational data included only two samples.

Comparison of catch per electrofishing run (CPUE) during 1990-1995 preoperational and 1996-1997 operational monitoring also showed minimal variation (76 and 53 fish per shocking run, respectively). Only emerald shiners revealed any major change in abundance, and this decline began prior to WBN becoming operational. None of the differences between preoperational and operational CPUE for 12 species meeting the criteria to be considered "important" were significant.

Reservoir Fish Assemblage Index (RFAI) values for the vicinity of WBN remained relatively stable with an average annual score of 44 during the 1991-1995 preoperational period and an average score of 45 in 1996-1997.

It is apparent based on comparisons of species composition, relative abundance, CPUE, and RFAI scores between preoperational and operational monitoring,

WBN has not adversely impacted the tailwater fish population below Watts Bar Dam during the initial two years of operation.

2.3 Impingement

Introduction

Monitoring for impingement of fish on the WBN cooling water intake traveling screens began March 15, 1996, before Unit 1 became commercially operational. WBN operate in closed cycle cooling mode, with blowdown from the cooling tower being discharged through the multiport diffusers located in the main channel at TRM 527.8. Makeup water is pumped from the intake channel located at TRM 528.0 with a maximum flow rate of 4.5 m^3/s (160cfs), which represents 0.6% of the long-term average flow of 767 m^3/s (27,100 cfs) past WBN (TVA 1996). Results from the first and second year (partial) of fish impingement monitoring at WBN are compared with standing stocks of fish in Chickamauga Reservoir and previous impingement estimates from SQN. The Tennessee Department of Environment and Conservation (TDEC) Division of Water Pollution Control approved TVA's request in the first annual report (Baxter et.al 1997) to discontinue impingement sampling due to extremely low numbers of fish impinged. Sampling was suspended October 7, 1997.

Material and Methods

Total numbers and species of fish impinged on the screens were estimated from weekly screen washings during December-May and biweekly during June-November. Protocol for impingement sampling at the WBN intake pumping station consisted of four screens rotating and backwashing simultaneously to remove all fish and debris. Screens were left stationary for 24 hours to collect the sample and all four screens were rotated and backwashed again to remove impinged fish. These fish were collected from the screen backwash water as the water passed through a steel mesh basket at the end of the screen wash sluice pipe. Impinged fish were identified to species, measured, weighed and recorded. Thirty-six samples were collected between March 15, 1996, through February 28, 1997 and 21 samples were obtained from March 4, 1997 through September 30, 1997. Estimates of total annual impingement were calculated by multiplying average number of fish impinged per sample by the number of days in each month and year.

Results and Discussion

Fifty-five impingement samples, collected between March 15, 1996 through September 30, 1997, yielded only 20 fish representing nine species (Table 2-13). Numbers of impinged fish were consistently low due to the low volume of water withdrawn through the intake channel. Total annual estimated number of fish impinged during 1996 and 1997 was 162.2 and 40.8, respectively (Table 2-13).

This rate was extremely low compared to 70,022, 40,944 and 14,960 fish estimated impinged at SQN during 1981-1983, respectively (Table 2-14). None of the species were impinged at WBN in sufficient numbers to impact Chickamauga Reservoir populations. None of the species impinged are listed as threatened, endangered or of special concern by the State of Tennessee or the U. S. Fish and Wildlife Service.

2.4 Fishery Creel Survey

Introduction

The specific objectives of the creel survey were to determine recreational angler catch, harvest, and effort and provide insight into population characteristics of largemouth bass, smallmouth bass, spotted bass, channel catfish, blue catfish, black crappie, white crappie, sauger, striped bass, and white bass.

Due to the limited scope of the preoperational WBN vicinity creel survey (1982-1985), only annual catch rates could be compared with data obtained during the more intensive operational survey. Therefore, results of the operational monitoring creel survey are reported as a "baseline". Creel results (collected by Tennessee Wildlife Resources Agency) from subsequent years could be used to further determine impacts of WBN on the Watts Bar Tailwater fishery.

Materials and Methods

Recreational fishing data in the vicinity of WBN (TRM 523.2 to TRM 529.9) were collected during preoperational and operational monitoring using access point angler creel surveys. Preoperational creel survey results are limited to catch rate estimates, average weight of each species and percent composition. Fishing pressure was not estimated due to a limited sampling schedule. A modified bus stop angler survey was used during operational monitoring to assess harvest, catch, and effort data. Only catch rates between preoperational and operational creel results are used for comparison.

Study Area

The Tennessee River from Watts Bar Dam (TRM 529.9) downstream to Yellow Creek (TRM 526.8) served as the study area during preoperational monitoring, April 1982 to December 1985. During operational monitoring (April 1996-April 1998), the study area was extended an additional 3.6 miles, increasing the creel area to include accesses at Sewee Creek and Eaves Ferry boat ramp (TRM 523.2). Six access points are available to anglers in the study area (Table 2-15). Anglers can bank fish from all six locations and launch a boat from four of these locations.

Survey Technique

A modified bus stop creel technique was employed. Anglers utilizing six access points were surveyed. Proportion of time surveyed at each access point is

provided in Table 2-15. Creel surveys during preoperational monitoring used the same technique employing a creel clerk one day per week. During operational monitoring, a creel clerk surveyed three days per week (one weekend and two weekdays) within the study area. The clerk was stationed onsite either in the morning, afternoon, or evening (May-July). All schedule times were randomly assigned. The clerk was instructed to seek out anglers on the bank and to encounter any boat anglers as they either came ashore or as they fished near shore. The clerk interviewed anglers during the assigned period, and when completed, traveled to the next location.

Instantaneous counts were made once per day from April 1996 through June 1997 and three times per day from July 1997 through April 1998 at randomly assigned periods. The clerk counted all fisherman at Watts Bar Dam, including those boat and bank anglers visible with the aid of binoculars. Directly following that count, the clerk traveled to the Eaves Ferry Boat Ramp and counted all visible boat and bank anglers. Providing a complete count of all anglers within a 15 minute period. In addition, all vehicles with boat trailers were counted at each access ramp at the beginning of each sample period. To validate instantaneous counts, the clerk traversed the entire three mile reach via boat on one out of five of the survey days to count all anglers.

Creel Data Analysis

Creel data analysis followed standard techniques reported by TVA (1986) for preoperational monitoring and by Pollock et al. (1994) for operational monitoring. Monthly catch and harvest rates were determined for generalist anglers fishing for any species group, and for anglers directing their efforts toward a particular species group (i.e., black bass, crappie, catfish, etc.) during operational monitoring. To analyze catch and harvest rates for individual species (i.e., largemouth bass in the black bass group), only angler data from those indicating they were targeting largemouth bass were included.

Estimated effort (hours) was determined using instantaneous count data and using a standard expansion approach based on day of week, time of day probabilities, and an 8.5 hour sample period (Pollock et al. 1994). Estimated effort for a specific directed species group was determined by partitioning the annual effort estimate by the proportion of effort accounted for by each directed species group. Similarly, effort was determined by location, and boat or bank anglers. Estimated angling trips were determined by dividing the mean length of completed trips for a selected group (i.e., sauger anglers) into the estimated effort (hours) for that group. All estimated values are reported with a standard error of the mean as a measurement of variation.

Length and weight were obtained from individuals of selected species. Length frequency analysis was conducted, and an age-length key developed following the methods of Ricker (1975).

Results

During preoperational monitoring, April 1982-December 1985, 4,745 individual fisherman were interviewed. Interviews were taken from 3,555 angling parties during operational monitoring (April 1996-April 1998). Monthly interviews exceeded 100 except during December 1996, and September, November and December of 1997 (Table 2-16).

Boat versus bank angler information was not collected during preoperational monitoring. During the WBN operational creel, 69% of angling parties interviewed were fishing from the bank. A majority of both bank (60%) and boat (75%) anglers were fishing for a specific group of species. Bank anglers primarily sought catfish (13%), sauger (11%) and white bass (10%). Boat anglers primarily sought catfish (27%), sauger (13%), white bass (11%), and black bass (10%). (Table 2-17).

Of the six locations selected as potential access points to the fishery, three were used primarily by bank anglers and three by boat anglers (Table 2-18). The majority of bank anglers utilized the two access points at the dam (Table 2-18). Bank anglers used the Sewee Creek boat ramp primarily during the spring white

bass spawning period. All anglers used the public use areas below Watts Bar Dam greater than 95% of the time to gain access to the fishery.

Angling Effort

No comparison of angler use patterns prior to WBN becoming operational could be made as fishing pressure information was not collected during the preoperational phase. Anglers expended an estimated 392,807 hours during the WBN operational period (April 1996-April 1998). Mean length of an angling trip was 4.62 hours. Daily effort was 386.9 hours on weekdays and 865.5 hours on weekend days. An estimated 88,151 angling trips were conducted during the 25-month period.

Monthly angling effort varied from 30,218 hours in April 1996 to 7,395 hours in November 1997 (Table 2-19). Angling trips ranged from 9,717 in April 1996 to 1,456 trips in November1997 (Table 2-19). Mean length of angling trip ranged from 5.85 hours in April 1997 to 3.11 hours in April 1996.

Anglers seeking any species expended an estimated 129,313 hours or 29,116 trips (Table 2-20). Directed species groups expending greater than 40,000 hours included catfish (89,707 hours), white bass (42,473 hours) and sauger (40,670 hours).

Monthly angling effort by directed species group showed seasonal trends (Figures 2-3 and 2-4). Any species angler percent effort exceeded 20% of the total for each month except December 1997. Catfish angler effort peaked during the summer months. Sauger angler effort was greatest in November-January. Bank anglers expended an estimated 271,037 hours or 60,824 angling trips, as compared to 121,770 hours or 27,327 angling trips for boat anglers. Mean length of angling trips for bank anglers was 2.90 hours and 5.09 hours for boat anglers. An estimated 57,783 angling trips were taken at the two access points located at the dam.

Catch and Harvest

Overall annual catch rates (number of fish caught per hour) in the vicinity of WBN during preoperational monitoring from 1982-1985 were 0.73, 0.83, 1.00, and 1.16, respectively (TVA 1996). By comparison, annual catch rate during operational monitoring (1996-1997) was 0.61 (fish/hour).

Annual mean catch and harvest rates (Tables 2-21 and 2-23) and estimated numbers caught and harvested (Tables 2-22 and 2-24) were determined for both directed species group anglers and any species group anglers. In addition, the total number of fish caught and harvested for the fishery was estimated (Table 2-25). An estimated 41,331 sauger were caught from April 1996 through April 1998 of which 20% were harvested. Estimated number of blue catfish caught was 50,825 representing the largest portion of any catfish species. Bluegill

represented the greatest single species caught with 140,764 caught and 63,502 harvested.

The greater catch and harvest rates for directed species group anglers allowed for a greater annual catch and harvest by this group. Interestingly, yellow bass was the only species for which a greater portion of the catch and harvest was attributed to the any species group (Figure 2-5).

Monthly catch and harvest rates for directed species group anglers varied with season for sauger, blue catfish, and white bass during operational monitoring (Figure 2-6 and 2-7). Sauger catch and harvest rates peaked in April 1996 and was lowest during summer months. The peak in April 1996 for sauger was not achieved in spring of 1997, nor 1998. Blue catfish catch and harvest rates were fairly consistent except during winter months. White bass catch and harvest rates peaked in the spring of 1996 and 1997, but did reach similar levels in 1998. The poor angling success in spring of 1998 was attributed to low water in the early spring followed by record flooding in April.

Catch rate comparisons for each species collected between preoperational and operational monitoring are listed in Table 2-26. During operational monitoring, harvest rates exceeded those for the preoperational survey for all species compared.

Length and age frequency trends for largemouth bass, smallmouth bass, spotted bass, blue catfish, channel catfish, black crappie, white crappie, sauger, white bass, and striped bass were examined during the WBN operational, but not during preoperational survey.

Length frequency of the three black bass species harvested were similar. Anglers harvested mostly individuals from 275-300, 300-325, and 325-350 mm (Figure 2-8). Few large largemouth or smallmouth bass were harvested. Largemouth bass were primarily age-3 and-4 as were smallmouth bass (Figure 2-9). Spotted bass were dominated by age 2-4 individuals.

Length frequency of both blue catfish and channel catfish were similar. Anglers harvested more individuals from 350-450 mm (Figure 2-10). Larger blue catfish (> 500 mm) were caught more frequently than channel catfish.

Angler harvested black crappie and white crappie were primarily from 250-275 mm (Figure 2-11). This corresponds to the newly enacted statewide size limit on crappie 250 mm or 10 inches. Age frequency of harvested crappie indicated that most were either age 3 or 4 (Figure 2-12), but black crappie as old as age 8 were harvested.

The length frequency of harvested sauger was dominated by individuals from 375 -425 mm (Figure 2-13). Age frequency of harvested sauger was dominated by 3-5 year old individuals (Figure 2-14). Harvested white bass were mainly from 275-350 mm (Figure 2-15). The age frequency of white bass was dominated by 3 and 4 year olds (Figure 2-16). Striped bass harvested were generally greater than 650 mm, but some as small as 250 mm were harvested (Figure 2-17). Age frequency displayed a wide range of ages (2-11) with most harvested striped bass being between the ages of 4 and 8 (Figure 2-18).

Fishing effort, catch rates and total harvest data indicate a viable and popular tailwater fishery below Watts Bar Dam. It is apparent, during the first two years of operational monitoring, that WBN did not impact the tailwater fishery in the vicinity of the plant.

3.0 AQUATIC MACROINVERTEBRATES

3.1 Hess Sampling

Introduction

Benthic aquatic macroinvertebrates are animals that live part or all of their life cycles on or near the bottom of streams or reservoirs. These organisms serve as an important food resource for other forms of aquatic life, especially fish, and studies of their abundance and distribution are useful for detecting major environmental perturbations. Because many have an attached, or sessile, mode of life in the aquatic environment and are neither subject to rapid migrations nor severe translocation by water mass displacement (except under flood conditions), these organisms reflect exposure history and serve as natural monitors of environmental conditions. Additionally, many species are sensitive to pollution and some have a relatively long and complex life cycle of a year or more; hence, their presence or absence and abundance patterns help describe environmental conditions over a period of time.

Hynes (1970) reports that evaluation of power plant effects on benthic macroinvertebrate communities requires good preoperational monitoring assessment of "natural" abundance and distribution patterns. Macroinvertebrate species composition and population levels respond readily to not only power plant effects but also naturally occurring factors such as availability of food, nature of benthic sediments, flow, floods, proximity of suitable habitats,

temperature, and dissolved substances. The most obvious influential factors in the vicinity of WBN are flow and substrate composition. Traveling downstream from WBN, there is a lessening of current velocity which is accompanied by a transition from hard rock and sand to softer, more silty substrates (TVA 1986). These factors strongly influence spatial distribution of macroinvertebrate populations.

Materials and Methods

To measure abundance and species composition, Hess® samplers were used to collect benthic macroinvertebrates during summer (July-September) and fall (October-December) quarters from TRM 521.0, 526.3, 527.4, 528.0, and 528.5 in upper Chickamauga Reservoir (Figure 3-1). Samples were collected during both preoperational (1983-1985) and operational (1996-1997) periods.

Divers collected ten Hess samples at each station. The Hess sampler was pushed into the riverbed to a depth of 2.5 to 5.0 cm and the substrate within the confines (0.0856 m^2) of the sampler disturbed by hand or with a hand rake to a depth of approximately 15 cm. Dislodged organisms and detritus were carried by the current into a catch cup located on the down stream side of the sampler. All large rocks, mussels, clams, etc., encountered in a sample were placed in an attached mesh bag. The Hess sampler's mesh net and collection cup were tied closed after the sample was collected to keep material from being back flushed out of the catch cup and net. Collected material was pulled to the surface via a

tether line connected to the sampler, transferred to plastic containers, and preserved with 10% formalin.

Laboratory Analysis

Samples were sorted and identified using standard operating procedures (Pennington and Associates, Inc. 1992). Benthic samples were washed in a 270 micron mesh screen, organisms removed from the detritus and preserved in 85% ethanol. Organisms were then identified to the lowest practical taxonomic level.

Data Analysis

Results of summer and fall operational monitoring Hess samples (1996-1997) were compared with those collected during preoperational monitoring (1983-1985). Sorensen's Quotient of Similarity (McCain 1975) and Percentage Similarity (Pielou 1975) used to evaluate similarity among stations were inconsistent during preoperational and the first year of operational monitoring. Baxter et al. 1997 suggested that comparisons between preoperational and operational results must be made on an individual station to station basis. Therefore community diversity (D-Bar, diversity index) (Patten 1962), one-way ANOVA and Duncan's Multiple Range Test (Steel and Torrie 1960) were used to evaluate station differences (number of taxa present and abundance/m^2) in summer and fall quarters. Abundance data were transformed (log_{10}) prior to the analysis.

Results and Discussion

Table 3-1 compared occurrence of 59 macroinvertebrate taxa were collected during preoperational (1973-1985) monitoring in the vicinity of WBN. During operational monitoring (1996 and 1997), Hess samples collected a total of 104 taxa.

Densities of benthic macroinvertebrates also increased considerably at all five stations (Table 3-2) after WBN became operational. These increases are likely due to aforementioned improvements in dissolved oxygen levels in water released through Watts Bar Dam as a result of the aeration system in the forebay of Watts Bar Reservoir beginning in early summer, 1996.

Three of the 59 taxa collected during preoperational monitoring, Corbicula fluminea (formerly C. manilensis), Crynellus fraternus, and Oligochaeta, comprised approximately 85% of the total community (Table 3-2). During operational monitoring, four of 104 taxa collected, Corbicula fluminea, Dugesia tigrina, Gammarus minus and Oligochaeta, comprised 87.5% of the total community. Corbicula fluminea, Asiatic clam, was consistently the most abundant taxon during preoperational monitoring, but was less dominant during operational monitoring (Table 3-2). Dugesia tigrina was the most abundant taxon during operational monitoring, especially in fall samples (Table 3-

2)(Appendix A). C. fraternus (caddisfly) met the dominant taxon criterion (Table 3-2) during preoperational monitoring and comprised 5% of the total community and was found at each station during fall 1997 operational monitoring (Appendix A). Hydra americana also was dominant during the summer of operational monitoring but did not exceed 5% of the total community during the fall samples (Appendix A).

Average number of taxa collected in preoperational summer and fall Hess samples (1983, 1984 and 1985) was 11.5, 17.4, and 16.1, respectively (Table 3-3). Greatest number of taxa collected at a single station during preoperational monitoring was 24 in summer of 1985 at TRM 521.0. Community diversity was low (<2.5) at all stations during preoperational monitoring and frequently below 1.00, especially downstream of TRM 528.0 (Table 3-3). Low diversities generally reflected complete dominance by Corbicula fluminea at most stations. The greatest diversity value (2.20) was recorded at TRM 527.4 during fall 1985 when only 53% of the community was composed of Corbicula fluminea (TVA 1986).

During operational monitoring, an average of 28.3 (summer and fall combined) taxa were collected per station, which was significantly greater ($\alpha = 0.001$) than average of 15 collected during preoperational monitoring. The greatest number of taxa collected at a single station in fall 1997 was 35 at TRM 528.0. Community diversity during operational monitoring, as during preoperational

monitoring, was low (≤ 2.5) at all stations (Table 3-3). However, the number of taxa found at each station increased during operational monitoring. The number of taxa found at TRM's 527.4, 528.0 and 528.5 nearly doubled during operational monitoring, yet the diversity index stayed relatively the same (Table 3-3). These results indicate negative no impacts on the benthic community of upper Chickamauga Reservoir due to operation of WBN.

Analysis of variance and Duncan's Multiple Range Test of total benthic macroinvertebrate standing crop were used to compare stations (Table 3-4). Stations in summer 1983 were alike except for a highly significant difference ($P>F = 0.0002$) at TRM 527.4, where a greater than 50% reduction in the dominant organism, Corbicula fluminea, occurred. Stations differences were more pronounced in summer 1984, with densities again strongly influenced by abundance of Corbicula fluminea. In summer, 1985, abundance of macroinvertebrates again changed, with abundance much higher at TRM 526.3 than at other stations (Table 3-5). This station contained exceptionally large numbers (540 per m^2) of the silt tolerant midge, Chironomus sp., and other silt-tolerant organisms such as Branchiura sowerbyi, Tubificidae, Hexagenia, and Chironomidae, which were not present or abundant at other stations (TVA 1986). Sediment core samples collected during preoperational monitoring contained an average of 18.5 grams (dry weight) of silt/clay at this site.

During both summer and fall quarters of operational monitoring, stations that had similar benthic communities varied with preoperational results (Table 3-4). Benthic community standing crops at stations adjacent to WBN and upstream (528.0 and 528.5) were significantly higher than stations below the plant during fall of 1996 but not during fall of 1997. These annual differences are likely caused by fluctuating discharges from Watts Bar Dam and not related to the operation of WBN. Station similarities in total benthic macroinvertebrate densities were primarily due to abundance of Corbicula fluminea, Dugesia tigrina, Gammarus minus and Oligochaeta, (Table 3-2).

Silt-tolerant organisms such as Branchiura sowerbyi, Tubificidae, and Limnodrilus hoffmeisteri, were also somewhat abundant at TRM's 521.0, 526.3, and 527.4, (Appendix A). The substrate of the five benthic macroinvertebrate stations, during operational monitoring, consisted primarily of cobble/gravel mix with dead mollusk shell deposits, very little silt was present.

During fall preoperational monitoring, no significant differences were identified among stations in 1983 and 1985 (Table 3-4). In 1984, total abundance in fall was greater upstream of TRM 526.3, resulting from a large increase in the caddisfly, Cyrnellus fraternus , and amphipod, Crangonyx. During operational monitoring (1996 and 1997), densities (no/m^2) of benthic macroinvertebrates collected at five stations near WBN nearly doubled from those observed during preoperational monitoring, 1983-1985, (Table 3-2).

In addition to the increased number of taxa found during operational monitoring, Hess sampling collected Zebra Mussels (Dreissena polymorpha) at each station (Appendix A). Zebra mussels were most abundant (72 /m^2) in the fall of 1997 at TRM 528.5 upstream of the WBN intake channel (Appendix A). Zebra mussels were first found near WBN on June 1, 1995, at TRM 528.0 (adjacent to the WBN intake channel). Samples collected on that date indicated a density of 4.8/m^2 (TVA 1995). During operational monitoring (1996 and 1997), average densities of zebra mussels increased to 26.5/m^2 and 41/m^2, respectively.

Based on comparisons of species composition, occurrence, and densities of aquatic macroinvertebrates between preoperational and operational monitoring periods, WBN has not impacted the tailwater benthic macroinvertebrate community during the first two years of operation.

3.2 Native Mussel Fauna

Introduction

Preoperational monitoring of freshwater mussels in the vicinity of WBN was conducted 12 times during the years 1983 through 1994. On each occasion, the same sites on each of three mussel beds were examined by divers. Results of the preoperational surveys of these beds have been presented in various reports (TVA 1986; Ahlstedt 1989, 1991; Ahlstedt and McDonough 1996). The first year of WBN operational monitoring of the mussel fauna was conducted during 1996 at the same sites following the same techniques used during the

preoperational period. Results of that study were presented in the WBN first annual operational monitoring report (Baxter, et al., 1997).

In July1997, a second operational monitoring survey of the native mussel fauna was conducted in the Watts Bar Tailwater. This report also includes an evaluation of the long-term population trends on these three mussel beds throughout the 15-year period they have been monitored. The purposes of this evaluation are to identify how the mussel resources on these beds have changed and to determine if operation of WBN has had any obvious effect on the mussel resources in this part of the Tennessee River.

Study Area Description

In 1983, mussel monitoring sites were established in three known concentrations of mussels ("mussel beds") in the reach of the Tennessee River downstream from Watts Bar Dam near WBN: TRM 520-521L (left descending bank), TRM 526-527R (right descending bank), and TRM 528-529L (Figure 3-2). The most upstream of these beds (TRM 528-529L) is located on the opposite side of the river from WBN and upstream from its discharges. The middle bed (TRM 526-527R) is on the same side of the river as WBN and is just downstream from the confluence of Yellow Creek and all WBN discharges. The downstream bed (TRM 520-521L) is six river miles downstream from WBN and is located on the opposite side of the river. All three beds exist on submerged gravel and cobble bars in water approximately three to seven meters deep.

Four sampling sites were established along the length of each bed (Figure 3-2). Initially, each site was located as precisely as possible using river mile markers, navigation buoys, and bankside landmarks. During the 1996 survey, original notes and the original field crew leader assisted in adding global positioning system coordinates to these site locations.

Methods

Between 1983 and 1985, the examination of each site was conducted by two pairs of SCUBA divers collecting mussels for 11 minutes each (for an aggregate total of approximately 45 minutes of diver search time). Over the years, improvements in communications and diver equipment have allowed this search commitment to be met using two independent divers, each collecting mussels for 22 minutes of bottom time.

During the 1997 survey, two divers collected all of the live native mussels (thus excluding the Asiatic clam, Corbicula manilensis) they encountered during 22 minutes of bottom time at each of the 12 sampling sites. All of the mussels found at each site were brought to the surface where they were sorted by species, identified, and counted. Up to 50 live animals of each species from each bed were then measured in three dimensions (length, height, and thickness). All mussels were returned to the river in the vicinity of the site from which they were collected. The numbers of each species found at each site and the measurement

data from each bed were recorded on field sheets and, later, added to the existing WBN mussel database.

Summary results for the 1997 survey were prepared from the database using the same format included in previous reports. A variety of statistical analyses were used to examine the combined sets of survey results, and the 5 percent significance level ($\alpha = 0.05$) was used as a decision point in all analyses. Prior to any analysis, the abundance data were transformed to approximate a normal distribution using a $\log_{10}(x + 1)$ transformation.

For both the abundance and measurement data sets, regression analyses were used initially to test if the results on each mussel bed differed among the sampling sites or between years. If the slopes of all sites on a bed were not different from zero, then analysis of variance and Fishers Least Significant Difference Test were used to test for differences between sites. If the slopes were different from zero, and found to be parallel in a homogeneity of slopes test, covariance analysis and Fishers Least Significant Difference Test were used to identify differences between the sites. When appropriate, the nature of long-term trends were identified by plotting pertinent yearly mean values.

Results and Discussion

1997 Survey Results

Results during the 1997 survey of these three mussel beds (Table 3-6) indicate that 697 live mussels, representing 14 native species, were collected. Of this total, 199 mussels (28.5 percent) were found on the downstream bed (TRM 520-521), 154 (22.1 percent) were found on the middle bed (TRM 526-527), and 344 (49.4 percent) were found on the upstream bed (TRM 528-529). Six of the 14 species were found on all three beds, and five species each were found on only one of the beds.

With regard to individual species, the most abundant species on each bed was the elephantear, Elliptio crassidens (70.2 percent of the combined total). On the upstream and middle beds, the second most abundant species was the Ohio pigtoe, Pleurobema cordatum (14.5 percent of the combined total); however, the purple wartyback, Cyclonaias tuberculata, occupied second place on the downstream bed (15.6 percent on this bed, 6.7 percent overall) and Pleurobema cordatum was a close third (14.1 percent). No specimens of the pink mucket, Lampsilis abrupta, or any other federal endangered species were encountered on any of the three beds during this survey (however, TVA divers did encounter live pink muckets in the Watts Bar tailwater in 1997 during other survey activities). In the way of a short-term comparison, 846 live mussels representing 17 native species were encountered on these three mussel beds during the survey conducted in 1996 (Appendix A, Table 3-7). That total is approximately 20

percent higher than the number found during the 1997 survey. Numerical results from each of the three beds indicate that substantially more live mussels were found on the downstream and middle beds in 1996 than in 1997 (35 and 34 percent, respectively, more than in 1997). On the upstream bed, the 1996 survey yielded only slightly more (8 percent) live mussels than were found there in 1997.

With regard to individual species, even though three more species were found during the 1996 survey than in 1997, relative abundance of the common species changed very little between these two most recent surveys. As in 1997, the elephantear was the most abundant species encountered during the 1996 survey (70.2 percent of the combined total in both years), followed by the Ohio pigtoe (11.1 percent in 1996; 14.5 percent in 1997) and the purple wartyback (4.5 percent in 1996; 6.7 percent in 1997). In 1996, the pink heelsplitter, Potamilus alatus, was fourth in overall abundance (4.1 percent of the total) and the pimpleback, Quadrula pustulosa, was fifth (3.6 percent). Results from the 1997 survey show that the pink heelsplitter dropped to fifth place (1.7 percent of the total) while the pimpleback moved up to fourth place (3.4 percent of the total).

Long-term Evaluation

For reference purposes both in this report and during any future studies, results from all 14 surveys at the 12 sites on these three mussel beds are presented in Appendix A. The information presented in that appendix and the following

analyses are both divided into sections discussing separately the abundance and measurement data from these surveys.

Abundance Analysis

As an initial step in evaluating abundance data, Table 3-7 presents the total numbers of each mussel species found on all three beds during each of the 14 surveys. The greatest number of species collected in a year was 22 during 1983, 1988 and 1990. A total of 30 native mussel species was found during all of the surveys combined, ranging in abundance from over 10,000 specimens of the most common species (Elliptio crassidens, 63.6 percent of the overall total) to single specimens of two species (Dromus dromus and Lasmigona complanata). The species totals presented in this table showed that the five most abundant species made up 91.5 percent of the overall total, and the next five most abundant species raise that percentage to 97.3 percent of the total. All of the 20 other species encountered during these surveys represent just 2.7 percent of the total number of mussels found.

With regard to species occurrence patterns, Table 3-7 indicates that 12 species have been encountered during all of the 14 surveys, and six more have been found on at least half of the surveys. Each of the 12 species encountered in seven or fewer of the surveys is represented by fewer than ten animals. Three of the extremely uncommon species on these beds (Elliptio dilatata, Pleurobema oviforme, and Plethobasus cyphyus) were seen last in 1996 and 1994, four of

them (Anodonta imbecillis, Pleurobema rubrum, Anodonta suborbiculata, and Ptychobranchus fasciolaris) were encountered last in 1990 or 1988, three (Cyprogenia stegaria, Pleurobema plenum, and Lasmigona complanata) were last found on these beds in summer 1985 (Table 3-7), and the final two (Fusconaia subrotunda and Dromus dromas) were encountered only during the first survey in Summer 1983. Of these 12 rarely-encountered species, those found several times throughout this series of surveys may be simply extremely rare members of these mussel beds. Others of these species (perhaps those represented by one or two animals encountered only once or twice) appear to be the last survivors of populations nearly extirpated from this part of the river.

Table 3-8 presents rank order information for the 12 species that were found during all 14 surveys of these mussel beds. These rank order numbers were nearly always assigned based on how many members of a species were encountered during a given survey; however, when two or more species were represented by equal numbers of animals, alphabetical order of the scientific names was used to avoid assigning some sort of tie ranks.

The survey-by-survey rankings presented in Table 3-8 demonstrate considerable consistency in the relative abundance of these routinely-encountered species. During each of the 14 surveys, Elliptio crassidens was the most abundant species and Pleurobema cordatum was second in abundance. In all but one survey, third and fourth places were occupied by Cyclonaias tuberculata and Quadrula

pustulosa (mean ranks 3.4 and 3.7, respectively), even though five times out of the 14 surveys, their order was reversed. Similarly, rank order places five through seven typically were occupied by Potamilus alatus, Ellipsaria lineolata, and Amblema plicata (mean ranks of 5.7, 6.2, and 6.5, respectively). While these three species swapped rank order places during several surveys, other species occupied one of these three places only on six out of the possible 42 opportunities. The other five species found during every survey (mean ranks of 9.3 through 11.0) also routinely swapped rank order places among themselves; however, one of them occupied some other rank order spot only on five out of the 70 possible opportunities. The consistency of these rank order relationships suggests that the data sets from the 14 surveys are, at least, all valid representations of the mussel abundance patterns on these three beds.

Statistical analysis of the mussel abundance information from the 15-year study period was performed only on the data collected during the first (summer) survey conducted each year. Exclusion of the four second (fall) surveys conducted during a given year (in years 1983 through 1986) removed much of the early-year weighting in the data set and simplified the identification of long-term trends. Table 3-9 presents a summary of data used in the statistical analyses of mussel abundance. As indicated in the first section of this table, the divers encountered a total of 10,481 live native mussels on the three beds during these 10 surveys (66.0 percent of the 14-survey total). Overall, 33.0 percent of the mussels were found on the downstream bed, 21.0 percent were found on the middle bed, and

46.0 percent occurred on the upstream bed. The standard deviation information presented in Table 3-9 indicates that variations in the survey results on the middle and upstream beds were relatively similar (SDEV values are 31.9 and 38.6 percent of the means, respectively) but results on the downstream bed were nearly twice as variable (62.4 percent of that mean).

Statistical analysis of the all-species abundance data is presented in the first row of Table 3-10. The initial regression analysis indicated that a statistically significant trend was present in the data for the downstream bed (TRM 520-521, $p = 0.004$) but no trend was present in the data for the middle or upstream beds (TRM 526-527 and TRM 528-529). On the beds where no trend was present, analysis of variance indicated statistically significant differences among the sites on both beds, and Fishers Least Significant Distance tests indicated the relationships in abundance at those sites. In Table 3-10, these relationships are indicated by the order and underlining of the site locations. For example, the underline linking the site on the middle bed (TRM 526-527) with the lowest mean number of mussels present (TRM 526.3) with the next lowest mean (TRM 526.5) indicates these two values are not statistically different from each other. Similarly, the line linking TRM 526.5 and both of the other sites on that bed indicates that all three of those mean values are not statistically different from each other; however, the means for both TRM 526.8 and TRM 526.0 are statistically different from the mean for TRM 526.3.

For the downstream bed where the all-species analysis indicated a trend was present, covariance analysis indicated that the slopes of the abundance lines for each site mean were not different from each other ($p = 0.48$) and there was no significant difference between the sites ($p = 0.31$), but there was a significant relationship among the years ($p = 0.002$). The yearly mean values are listed in Table 3-9 and the general (downward) trend in these overall abundance values is illustrated on Figure 3-3.

Table 3-10 also presents the results of similar analyses for the five most abundant species encountered during these surveys. Similar analyses were not conducted for less-abundant species because of the large number of zeros present in the site-by-site survey data for those species. The analysis results presented in Table 3-10 indicate that the three most abundant species (Elliptio crassidens, Pleurobema cordatum, and Quadrula pustulosa) all showed statistically significant year trends on the downstream bed (TRM 520-521). For Pleurobema cordatum and Quadrula pustulosa, these trends included all four sites; however, the trend for Elliptio crassidens at TRM 520.0 was parallel, but different from the trend at the other three sites ($p = 0.02$). These trends, which are all downward, are illustrated on Figures 3-4, 3-5, and 3-6.

On the middle bed (TRM 526-527), only Quadrula pustulosa exhibited a significant year-related trend ($p = 0.05$), a downward trend illustrated on Figure

3-7. Like Elliptio crassidens on the downstream bed, the Quadrula pustulosa trend at TRM 526.0 was parallel but different from the other three sites on the middle bed ($p = 0.0007$).

On the upstream bed (TRM 528-529), none of these three species exhibited any year-related trends. For Elliptio crassidens and Pleurobema cordatum, however, the downstream site (TRM 528.2) was substantially different from the others ($p = 0.0001$ and 0.03, respectively)(Table 3-10).

Data for the fourth most abundant species (Cyclonaias tuberculata) indicated that trends were present on the downstream bed; however, the covariance analysis indicated that the lines for the four sites were not parallel ($p = 0.009$). Figure 3-7 illustrates the complex patterns produced by the abundance of this species at each of the four sites on this bed.

Abundance information for the fifth most abundant species (Potamilus alatus), did not indicate that any trend was present in the abundance data or any difference in its abundance among sites on any of the three beds.

Considered together, this analysis indicates that the abundance of the three most common species and, probably because of the dominance of these species, the all-species totals demonstrated statistically significant declines over the years on the downstream bed (TRM 520-521). In contrast to this, only the third most abundant species (Quadrula pustulosa) showed a similar decline on the middle

bed (TRM 526-527), and none of the five showed a statistically significant decline on the upstream bed (TRM 528-529). All other statistically significant analysis results on these beds were associated with variations in abundance between individual sampling sites. Where statistically significant declines did occur, plots of the mean values illustrate that those declines were gradual throughout the 15 year period, with no sharp breaks that might indicate a response to some specific adverse impact.

The statistically significant (declining) abundance trends among the three most abundant mussel species on the downstream bed and, for one of those species, on the middle bed, differ from the general impression presented by Ahlstedt and McDonough (1997). That report included data from the years 1983 through 1992 and was prepared before the 1994, 1996, and 1997 surveys were conducted. While some significant trends were present in the results of that earlier analysis, the general pattern was not particularly apparent and was overshadowed by the substantial variations among the survey results.

The statistically significant trends present on the downstream and middle beds probably account for some of the survey-to-survey variations included in this data set. The amount of year-to-year variations in abundance represented on Figures 3-3 through 3-8, however, seems unusually large for these beds of sedentary, long-lived animals living in a managed river reach. Some of the variations present in these survey results might be related to differences in diver

harvest speed and the relatively short time (22 minutes) involved in each timed dive. Other possible sources of the observed variations in abundance could be related to the fact that these 14 surveys were focused on examining the exact same sites on these mussel beds, but no concerted effort was always made to return the animals to the precise location where they had been found.

Measurement Analysis

As indicated in Methods, analysis of the measurement data followed the same format used for the abundance data. Like both earlier evaluations of the measurement data from these three beds (TVA 1986, Ahlstedt and McDonough 1997), these analyses were conducted only on the lengths of the mussel shells. Length, alone, was analyzed largely because that measurement appeared to be less affected by the extensive amount of shell erosion and other damage exhibited by the mussels living on these beds.

Results of the measurement component of each survey of these three mussel beds, including the 1997 survey, are presented in Appendix A. As a partial summary of these data, Table 3-11 presents the mean lengths of each mussel species measured during each year in which one or more surveys were conducted. It is important to note that each mean value in this summary table is based on a different number of measured mussels, and includes measurements from all three beds. The chief value of Table 3-11 is that it provides a concise indication of the range of length measurements for each species and the

relationship of those measurements to an overall mean for the survey period. The general impression presented in this table is that virtually all of the mean values are relatively large for each species, and relatively little variation exists for nearly all of the routinely-encountered species.

Table 3-12 presents the results of the statistical analyses of the length data for the five most abundant species, the same species included in the abundance analysis. As indicated in the table, regression analysis indicated statistically significant trends were present for three of these species. The most abundant species (Elliptio crassidens) showed statistically significant year trends on both the downstream (TRM 520-521, $p = 0.002$) and middle beds (TRM 526-527, $p = 0.0004$). These trends, both of which are illustrated on Figure 3-9, indicate very similar, gradual increases in length over the 15-year period. Mean length on the middle bed is rather consistently 8 to 10 millimeters larger than on the downstream bed.

The second most abundant species (Pleurobema cordatum) exhibited statistically significant trends on two of the three mussel beds (TRM 526-527, $p = 0.0002$; and TRM 528-529, $p = 0.002$); however, Fishers Least Significant Difference Tests indicated that sites on the upstream bed represented statistically different length groupings. Figure 3-10 includes the mean length plots for Pleurobema cordatum on both of these beds (with all sites included). Both of these plots include somewhat more year-to-year variation than was present in the Elliptio

crassidens data, but still illustrate slight increases in shell length over the study period.

The only other statistically significant trend for the fourth most abundant species (Cyclonaias tuberculata) was on the downstream bed (TRM 520-521, $p = 0.003$). The plot of the yearly mean lengths for this species (presented on Figure 3-8) indicates a very slight increase (approximately 2 millimeters) over the 15-year survey period.

Neither of the other two common species (Quadrula pustulosa and Potamilus alatus) demonstrated statistically significant year-related trends on any of the three beds. Quadrula pustulosa did not yield any type of statistically significant relationships on any of the beds, but Potamilus alatus produced significant differences between sites on both the downstream and middle beds.

As a whole, this analysis of length data for the five most abundant species indicates that, when statistically significant trends were present, each species exhibited a very slow, steady increase in shell length over the 15-year period. Overall, this data set also appears to include considerably less variation than is present in the abundance data collected during these surveys.

Summary and Conclusions

This study has examined the native mussel resources in the Tennessee River near WBN during the second year the plant was operating (1997) following the same techniques used in 1996 and during the preoperational monitoring period. In 1997, the three mussel beds involved in this survey program (TRM 520-521, TRM 526-527, and TRM 528-529) yielded 697 live mussels, representing 14 native species. In the way of a short-term comparison, approximately 20 percent more mussels were found on these beds during the 1996 survey (846 animals), and three more species were found on these beds in 1996 than in 1997. Substantially more live mussels were found on the downstream and middle beds in 1996 than in 1997 (35 and 34 percent, respectively, more than in 1997), but only slightly more (8 percent) live mussels than were found on the upstream bed in 1996 than in 1997.

One part of the long-term evaluation of this 14-survey, 15-year monitoring program was the analysis of the mussel abundance data. Over the years, 30 native mussel species have been encountered on these three mussel beds. Twelve of these species have been found on all of the surveys, and six more have been found on at least half of them. Five of the 12 rarely-encountered species have not been found on these beds since 1985 or 1983. Relative abundance ranks of the 12 most abundant species have changed very little over the 15-year monitoring period.

Statistical analysis of the mussel abundance data indicates that the three most common species and, probably because of the dominance of those species, the all-species totals demonstrated statistically significant declines in abundance over the years on the downstream bed (TRM 520-521). In contrast to this, only the third most abundant species (Quadrula pustulosa) showed a similar statistically significant decline on the middle bed (TRM 526-527), and none of the five showed a statistically significant decline on the upstream bed (TRM 528-529). Where the statistically significant declines did occur, the data indicate those declines were gradual throughout the 15 year period, with no sharp breaks that might indicate a response to some specific adverse impact.

An analysis of length data for the five most abundant species demonstrated some very slow, steady increases in shell lengths throughout the survey period. The length data also indicated that virtually all of the animals are relatively large for each species.

In general, these results and analyses indicate that individual mussels in the Tennessee River near WBN are continuing to grow slowly, but some species are disappearing from the communities and the some more abundant populations are demonstrating statistically significant declines. The freshwater mussels in the vicinity of WBN are quite old and most of the 30 species found may not have reproduced in the past 50 years. The data also indicate that these population

declines are gradual, and have been occurring throughout the 15-year monitoring period. There is no indication that operation of WBN during the last two years has had any effect on mussel resources in the river.

4.0 INSTREAM WATER QUALITY MONITORING

4.1 Water Quality Analysis

Introduction

Preoperational instream water quality monitoring data collected during the period 1982-1991 were compared to 1996 and 1997 operational monitoring data to determine if any significant changes have occurred to the nonradiological water quality of Watts Bar Tailwater since WBN became operational. Data obtained prior to 1982 were not included in the comparative analysis because improvements in the analytical detection limits since then could bias results.

Materials and Methods

Water samples for chemical analysis were collected monthly from April to September during 1996 and 1997 at four locations in the vicinity of WBN. The locations sampled correspond to the preoperational sampling locations at TRMs 529.9 (Watts Bar Forebay), 529.5 (upstream of WBN), 527.4, and 518.0 (downstream of WBN) (Figure 4-1).

Samples were collected during May, June, and July of 1996 and 1997 and analyzed for pH, turbidity, total solids, dissolved solids, ammonia, nitrogen, nitrate-nitrite nitrogen, organic nitrogen, total phosphorous, dissolved phosphorous, total organic carbon, chemical oxygen demand, and total alkalinity. Samples were also collected during April, May, June, and July of 1996 and 1997 for chlorophyll-a analysis. Samples for pH, turbidity, and total

solids were collected at a depth of 1 meter. All other samples were collected from multiple depths down to 5 meters at each location and the data averaged for analysis purposes. During April, August, and September 1996 and 1997, one mid-depth grab sample was collected from the four stations for metals analysis, including: calcium, magnesium, arsenic, boron, cadmium, chromium, copper, iron, lead, nickel, zinc, aluminum, selenium, mercury, and hardness.

Results and Discussion

In Tables 4-1 and 4-2, average values are presented for the preoperational and operational nonmetals data for each of the four sampling locations. All monthly values for preoperational and operational data were averaged for analysis. The individual concentrations measured for each parameter during preoperational and operational monitoring were also plotted for each sampling location over time (see Appendices B1 through B4). The plots of the preoperational nonmetals data exhibit high variability for all parameters at all locations. The operational (nonmetals) data tended to be less variable than the preoperational data. Dissolved phosphorous and chlorophyll-a were exceptions by being highly variable, which could be an artifact of the sample size. The reason for the difference in the preoperational and operational variability is not known, but the limited number of operational data points is probably a major factor. The significant observation regarding the data plots is that the range of operational data points fall well within the range of the preoperational data.

A statistical comparative analysis of the preoperational and operational nonmetals water quality data was performed using the Analysis of Variance (ANOVA) with Duncan's Multiple Range Test. The results of these analyses are shown in Tables 4-3, 4-4, and 4-5. In Table 4-3, the 1996 data are compared to the preoperational data; Table 4-4 compares the 1997 data, and Table 4-5 compares the combined 1996-1997 data to the preoperational data. The analysis indicates that, for most parameters, no significant differences (α=0.05) exist between preoperational and operational data. The only constituent with a consistent significant difference is chlorophyll-a, which shows an increase during the operational period at all sampling locations. Chlorophyll-a concentrations (a measure of plankton biomass) below Watts Bar Dam and in the vicinity of the WBN are a function of chlorophyll-a concentrations above Watts Bar Dam in the forebay of Watts Bar Reservoir. The increase in operational chlorophyll-a concentrations at TRM 529.9 (Watts Bar Forebay) could result from many factors, none of which are related to WBN.

The preoperational and operational concentrations of metals were plotted over time and are shown in Appendices B5 through B7. Concentrations of arsenic, boron, cadmium, chromium, copper, lead, nickel, zinc, selenium, and mercury were less than detectable in nearly all samples. The plots show that all measurable values of operational metals data were well within the variability of the preoperational data, and no changes or trends of any magnitude were

indicated. A statistical summary of the preoperational and operational metals data is presented in Tables 4-6 and 4-7.

Although operational data sample size limits the extent of data analysis, it is apparent that during the first two years of operation, WBN has not adversely impacted the nonradiological water quality of the Watts Bar tailwater.

5.0 SUMMARY AND CONCLUSIONS

WBN Unit 1 began commercial generation May 27, 1996, and operated at an 84% capacity factor during the first year of operation. Trends and similarities noted during preoperational monitoring, in addition to comparisons with operational data, were used to provide insight into potential plant-induced effects to aquatic communities and water quality.

Evaluation of entrainment of ichthyoplankton (fish eggs and larvae) by WBN revealed the presence of few taxa and relatively low densities. Eggs and larvae passing WBN were primarily spawned in Watts Bar Reservoir and exposed to passage through the turbines at Watts Bar Dam. Larval samples were dominated by clupeids (shad). Freshwater drum, sunfish, and the temperate basses were the only additional taxa to exceed one percent composition of total larvae collected throughout the study. Very few eggs or larvae of species known to spawn in tailwaters were collected, indicating most spawning in Chickamauga Reservoir occurred downstream of WBN. Sunfish (Lepomis) spawning in the littoral zone near WBN (including plant intake and shoreline stations) was indicated by significantly higher larval densities of this taxon. The proportion of the Tennessee River flow entrained by WBN (0.6%) is very low compared to SQN (13%). Percentage entrainment of fish larvae passing WBN was estimated to be 0.1% compared to 7.5% at SQN, 1981-1984. Total entrainment of larval fish and eggs at WBN during the period sampled was estimated to be 449 and 267 in 1996, and 1911 and 120,000 in 1997. Larval shad represented 91% of the sample in 1996 and 85% in 1997. These represent extremely

low numbers and would constitute no impact to the ichthyoplankton passing WBN or the fish community of Chickamauga Reservoir.

Fish community sampling results revealed only minor differences in species occurrence and percent composition between preoperational and operational samples. These differences were attributed to variations in sampling design with 1977-1985 data collected on a monthly basis throughout each year and 1990-1996 data collected only once during fall of each year. Operational data included only two samples.

Comparison of catch per electrofishing run (CPUE) during 1990-1995 preoperational and 1996-1997 operational monitoring also showed minimal variation (76 and 53 fish per shocking run, respectively). Only emerald shiners revealed any major change in abundance, and this decline began prior to WBN becoming operational. None of the differences between preoperational and operational CPUE for 12 species meeting the criteria to be considered "important" were significant, P=0.05 level.

Reservoir Fish Assemblage Index (RFAI) values for the vicinity of WBN remained relatively stable with an average annual score of 44 during the 1991-1995 preoperational period and an average score of 45 in 1996-1997. A gradual decline in RFAI values occurred from 1993-1996. Since this decline began prior to WBN becoming operational, and as a result of the 1997 RFAI rebounding to a score of 52, the plant is not considered responsible.

It is apparent based on comparisons of species composition, relative abundance, CPUE, and RFAI scores between preoperational and operational monitoring, WBN has not adversely impacted the tailwater fish population below Watts Bar Dam during the initial two years of operation.

Fish impingement on the WBN cooling water intake traveling screens was virtually nonexistent. A total of 203 fish were estimated to be impinged during the first two years of operation. Impingement at WBN has obviously not effected the fish community in Chickamauga Reservoir. This monitoring activity was suspended October 7, 1997 by the Tennessee Department of Environment and Conservation, Division of Water Pollution Control.

The operation of WBN has had no impact on the Watts Bar Tailwater fishery. Total tailwater fishing pressure in the Watts Bar tailwater has increased dramatically during the past 24 years. A total of 392,807 fishing hours and 88,151 angler trips was estimated during the first two years of WBN operation. Catfish, sauger, white bass, crappie, sunfish, striped bass/Cherokee bass, and black bass were the most sought after species by anglers. An estimate of 341,106 fish were caught and an estimated 165,128 fish were harvested from April 1996-April 1998. Peak angling effort (hours) and trips occurred both in April 1996 with 30,218 and 9,717, respectively. Angling trips ranged from 9,717 in April 1996 to 1,456 trips in November 1997. The increased fishing pressure and potential overharvest of popular species are likely to have greater impact on the fishery than operation of WBN.

Total number of benthic macroinvertebrate taxa collected in Watts Bar Tailwater has increased from 59 recorded during preoperational monitoring to 104 collected during operational monitoring. The average number of taxa per station during operational monitoring was 29.8 which almost doubled the average number (15) collected during preoperational monitoring. Based upon organism abundance and taxonomic occurrence, stations upstream and adjacent to the plant (TRM's 528.0 and 528.5) and below the plant (TRM's 526.3 and 527.4) were similar in the summer and fall samples. In addition to the increased number of taxa found during operational monitoring, zebra mussels were found at each station at an average density of $28.6/m^2$ in 1996 and $41/m^2$ in 1997. Zebra mussels were most abundant ($72/m^2$) in the fall of 1997 at TRM 528.5 (upstream to the WBN intake channel). Temporal analyses showed that seasonal and yearly changes in abundance and other variables for benthic macroinvertebrate populations, except freshwater mussels, were common.

The freshwater mussels in the vicinity of WBN are quite old and most of the 30 species found may not have reproduced in the past 50 years. A total of 15,878 live mussels were encountered during the 15-year monitoring program. On each mussel bed, the most abundant species was the elephantear, Elliptio crassidens (70.2 percent of the combined total). Each bed contributed to a total of four specimens of the pink mucket, Lampsilis abrupta, the only species encountered which is on the federal endangered species list. The numerical and relative abundance results comparing preoperational and operational monitoring were similar and changed very little over the 15-year monitoring period. These

results indicate the two years of operation of WBN has not impacted the aquatic macroinvertebrate resources below Watts Bar Dam.

Water quality in the vicinity of WBN, while generally satisfactory, is influenced by releases from Watts Bar Dam, located two miles upstream. In 1996, TVA's Water Management installed an aeration device in the forebay of Watts Bar Reservoir. This could reduce stratification of the forebay during the summer and fall and provide higher dissolved oxygen levels in the hydro releases. Concentrations of selected metals were less than detectable in nearly all samples. Measurable water quality data values during operational monitoring were well within the variability of the preoperational data. The first two years of operation of WBN has not impacted the nonradiological water quality in upper Chickamauga Reservoir.

Overall, it was concluded that WBN had no effect on either the aquatic communities nor the water quality in upper Chickamauga Reservoir from the first two years of operation.

6.0 REFERENCES

Ahlstedt, S. A. 1989. Update of the Watts Bar Nuclear Plant preoperational monitoring of the mussel fauna in Upper Chickamauga Reservoir. Tennessee Valley Authority, Water Resources, Aquatic Biology Department, TVA/WR/AB—89/9, 26 pages.

Ahlstedt, S. A. 1991. 1990 preoperational monitoring of the mussel fauna in upper Chickamauga Reservoir in the vicinity of the Watts Bar Nuclear Plant. Tennessee Valley Authority, Water Resources, Aquatic Biology Department, 19 pages.

Ahlstedt, S. A., and McDonough, T. A. 1997. Summary of preoperational monitoring of the mussel fauna in the upper Chickamauga Reservoir (Tennessee River) in the vicinity of TVA's Watts Bar Nuclear Plant, 1983-1993. Walkerana, 1995-1996, 8(19):107-126.

Baxter, D. S., Buchanan, J. P., Hickman, G. D., Jenkinson, J. J., Milligan, J. D., and O'Bara, C. J. 1997. Aquatic environmental conditions in the vicinity of Watts Bar Nuclear Plant during the first year of operation, 1996. Tennessee Valley Authority, Resource Group, Water Management, Norris, Tennessee, 167 pages.

Carlander, K. D. 1977. Handbook of Freshwater Fishery Biology, Vol. 2, Iowa State University Press, Ames, Iowa. 431 pp.

Hickman, G. D., K. W. Hevel, and E. M. Scott. 1990. Density, movement patterns, and spawning characteristics of sauger (Stizostedion canadense) in Chickamauga Reservoir - 1988. Tennessee Valley Authority, Water Resources, Chattanooga, TN. 53pp.

Hickman, G. D. and T. M. McDonough. 1996. Assessing the reservoir fish assemblage index: A potential measure of reservoir quality. Pages 85-97 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society, Bethesda, Maryland.

Hogue, Jacob J., Jr., Robert Wallus, and Larry Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. TVA Tech. Note B19. 67pp.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press. 554pp.

McCain, J. C. 1975. Fouling community changes induced by the thermal discharge of a Hawaiian power plant. Environmental Pollution 9:63-83.

McDonough, T. A., and J. P. Buchanan. 1991. Factors affecting abundance of white crappies in Chickamauga Reservoir, Tennessee, 1970-1989. North American Journal of Fisheries Management 11:513-524.

References (Continued)

Patten, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. Mar. Research. 20:57-75

Pennington and Associates, INC. 1992. Specifications for processing, identification and enumeration of phytoplankton, zooplankton, and periphyton samples.

Pielou, E. C. 1975. Ecological Diversity. John Wiley and Sons. New York. 165 pp.

Pollock, K.H. C.M. Jones and T.L. Brown. 1994. Angler survey methods and their applications in fisheries management American Fisheries Special Publication 25.

Priegel, G. R. 1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Wis. Dept. Nat. Res. Tech. Bull. No. 45. 105pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191.

Shelton, W. 1972. Comparative reproductive biology of the gizzard shad, Dorosoma cepedianum (Lesueur) and the threadfin shad, Dorosoma petenense (Gunther) in Lake Texoma, Oklahoma. Ph.D. dissertation. University of Oklahoma. 232 pp.

Siefert, Richard E. 1968. Reproductive behavior, incubation, and mortality of eggs, and postlarval food selection in the white crappie. Trans. Am. Fish. Soc., 97(3):252-259.

Steel, R.E.D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York. 482pp.

Tennessee Valley Authority. 1980a. Watts Bar Nuclear Plant preoperational fisheries monitoring report, 1977-1979. Division of Water resources. 147pp.

Tennessee Valley Authority. 1980b. Watts Bar Nuclear Plant preoperational aquatic monitoring report, 1973-1977. Division of Water Resources.

Tennessee Valley Authority. 1983. Field Operations Biological Resources Procedures Manual. Division of Natural Resource Operations.

Tennessee Valley Authority. 1986. Preoperational assessment of water quality and biological resources of Chickamauga Reservoir, Watts Bar Nuclear Plant, 1973 - 1985. Tennessee Valley Authority, Office of Natural Resources and Economic Development, Division of Air and Water Resources, TVA/ONRED/WRF-87/1, 2 volumes, 486 & 710 pages, respectively.

References (Continued)

Tennessee Valley Authority 1996. Chickamauga Reservoir 1995 fisheries monitoring cove rotenone results. 52pp.

Timmons, T. J. 1975. Range extension of the yellow perch, Perca flavescens (Mitchill), in Tennessee. J. Tenn. Acad. Sci., 50:101-102.

Table 2-1. **Sample periods, dates, number of samples, and mean temperatures for larval fish collections near Watts Bar Nuclear Plant during preoperational monitoring 1976 through 1979, 1982 through 1985 and operational monitoring 1996 and 1997.**

PREOPERATIONAL MONITORING			
Sample period	Date	Number of Samples	Mean Water Temperature (°C)
1976			
1	03/24/76	7	12.3
2	04/07/76	20	14.3
3	04/21/76	20	15.4
4	05/05/76	21	18.1
5	05/18/76	25	19.1
6	06/03/76	28	20.1
7	06/17/76	27	22.4
8	06/29/76	19	23.6
9	07/14/76	25	24.3
10	07/28/76	28	25.3
11	08/09/76	28	24.1
12	08/25/76	28	25.3
13	09/09/76	21	24.6
	Total	297	
1977			
1	03/16/77	10	10.9
2	03/23/77	10	12.2
3	03/29/77	10	13.6
4	04/12/77	10	15.1
5	04/19/77	10	16.5
6	04/26/77	10	17.2
7	05/04/77	10	17.7
8	05/10/77	10	18.4
9	05/16/77	10	19.0
10	05/24/77	10	19.7
11	06/02/77	10	21.3
12	06/08/77	10	21.9
13	06/15/77	10	23.0
14	06/21/77	10	23.0
15	07/07/77	10	26.1
16	07/19/77	16	26.5
17	08/01/77	10	26.8
18	08/16/77	10	24.8
	Total	186	

Table 2-1. (Continued)

PREOPERATIONAL MONITORING			
Sample period	Date	Number of Samples	Mean Water Temperature (°C)
1978			
1	03/28/78	10	10.1
2	04/11/78	10	14.4
3	04/25/77	10	16.8
4	05/09/78	10	16.6
5	05/23/78	10	17.9
6	06/06/78	10	20.9
7	06/20/78	10	23.1
8	07/05/78	10	25.6
9	07/18/78	10	25.4
10	08/01/78	10	25.5
11	08/15/78	10	N/A
12	08/29/78	10	26.2
13	09/12/78	10	26.4
	Total	130	
1979			
1	03/13/79	10	9.0
2	03/28/79	10	11.6
3	04/10/79	10	13.3
4	04/23/79	10	15.4
5	05/10/79	10	18.3
6	05/22/79	10	N/A
7	06/06/79	10	19.1
8	06/18/79	10	22.2
9	07/02/79	10	23.0
10	07/17/79	10	24.2
11	07/30/79	10	22.9
12	08/13/79	10	24.2
13	08/28/79	10	24.6
	Total	130	

Table 2-1. (Continued)

PREOPERATIONAL MONITORING			
Sample period	Date	Number of Samples	Mean Water Temperature (°C)
1982			
1	03/15/82	10	10.5
2	03/29/82	10	12.8
3	04/12/82	10	13.1
4	04/26/82	10	15.2
5	05/10/82	10	16.5
6	05/24/82	10	18.5
7	06/07/82	10	23.9
8	06/21/82	10	26.6
9	07/06/82	10	24.9
10	07/19/82	10	27.8
11	08/02/82	10	28.0
12	08/16/82	10	27.3
	Total	120	
1983			
1	03/07/83	20	10.6
3	04/04/83	10	11.5
4	04/18/83	10	11.7
5	05/03/83	10	16.0
6	05/17/83	10	20.0
7	05/31/83	10	21.8
8	06/14/83	10	23.0
9	06/27/83	10	N/A
10	07/11/83	10	28.0
11	07/25/83	10	25.5
12	08/08/83	10	25.9
13	08/23/83	10	28.0
	Total	130	

Table 2-1. (Continued)

PREOPERATIONAL MONITORING			
Sample period	Date	Number of Samples	Mean Water Temperature (°C)
1984			
1	03/06/84	10	7.8
2	03/20/84	10	9.1
3	04/03/84	18	11.1
4	04/16/84	10	N/A
5	04/30/84	10	14.3
6	05/29/84	18	18.8
7	06/11/84	18	20.8
8	06/25/84	18	23.6
9	07/09/84	18	23.1
10	07/23/84	18	26.7
11	08/06/84	18	24.4
12	08/20/84	18	25.7
	Total	184	
1985			
1	03/14/85	18	9.7
2	03/27/85	18	11.5
3	04/10/85	16	13.9
4	04/24/85	18	15.1
5	05/08/85	18	16.8
6	05/22/85	18	19.2
7	06/04/85	18	22.6
8	06/18/85	18	23.5
9	07/02/85	18	25.3
10	07/16/85	18	26.0
11	08/01/85	18	26.1
12	08/13/85	18	25.7
13	08/28/85	18	25.0
	Total	232	

Table 2-1. (Continued)

OPERATIONAL MONITORING			
Sample period	Date	Number of Samples	Mean Water Temperature (°C)
1996			
1	04/08/96	20	10.7
2	04/02/96	16	15.1
3	05/06/96	18	17.3
4	05/20/96	18	21.3
5	06/03/96	18	23.3
6	06/17/96	18	22.6
	Total	108	
Sample period	Date	Number of Samples	Mean Water Temperatures (°C)
1997			
1	03/31/97	18	15.0
2	04/14/97	18	17.0
3	04/28/97	18	17.1
4	05/15/97	18	19.5
5	05/27/97	18	20.4
6	06/09/97	18	20.5
7	06/23/97	18	22.4
	Total	126	

Table 2-2. List of scientific and common names for fish egg and larval taxa collected near Watts Bar Nuclear Plant during 1976 through 1979, 1982 through 1985, and 1996 and 1997.

Scientific Name	Common Name
Eggs	
Unidentifiable fish eggs	
Hiodon spp. eggs	Unidentifiable mooneye or goldeye eggs
Aplodinotus grunniens eggs	Freshwater drum eggs
Larvae	
Unidentified fish larvae*	
Clupeidae	
Unspecifiable clupeids	Unspecified shad and/or herring
Alosa chrysochloris	Skipjack herring
Dorosoma sp.	Unidentified shad
Dorosoma cepedianum	Gizzard shad
Dorosoma petenense	Threadfin shad
Hiodontidae	
Hiodon tergisus	Mooneye
Cyprinidae	
Unspecifiable cyprinids	Unspecified minnow or carp
Cyprinus carpio	Common carp
Macrhybopsis storeriana	Silver chub
Notropis sp.	Unidentified shiner
Notropis atherinoides	Emerald shiner
Notropis volucellus	Mimic shiner
Catostomidae	
Unspecifiable catostomids	Unspecified suckers
Ictiobinae	Unspecified Ictiobines**
Minytrema melanops	Spotted sucker
Ictaluridae	
Ictalurus furcatus	Blue catfish
Ictalurus punctatus	Channel catfish
Pylodictis olivaris	Flathead catfish
Percichthyidae	
Morone sp.	Unspecified temperate bass
Morone chrysops	White bass
Morone mississippiensis	Yellow bass
Morone (not saxatilis)	Unspecified temperate bass(not striped bass)

Table 2-2. (Continued)

Scientific Name	Common Name
Centrarchidae	
Lepomis or pomoxis	Unspecified crappie or sunfish
Lepomis sp.	Unspecified sunfish
Micropterus sp.	Unspecifies bass
Micropterus dolomieu	Smallmouth bass
Pomoxis sp.	Unspecified crappie
Pomoxis annularis	White crappie
Percidae	
Unspecifiable darter	Unspecified darter
Perca flavescens	Yellow perch
Stizostedion sp.	Walleye or sauger
Stizostedion canadense	Sauger
Sciaenidae	
Aplodinotus grunniens	Freshwater drum
Atherinidae	
Labidesthes sicculus	Brook silverside

* Damaged specimens.

** Members of the subfamily Ictiobinae (buffalo, carpsuckers).

Table 2-3. Total numbers and percent composition of fish eggs and larvae collected during 1976-1985, 1996 and 1997 in the vicinity of Watts Bar Nuclear Plant.

	PREOPERATIONAL									
	1976		1977		1978		1979		1982	
Taxon	Total Collected	% Comp.	Total Collected	% Comp.	Total Collected	% Comp.	Total Collected	% Comp.	Total Collected	% Comp.
EGGS										
Unidentifiable fish eggs	5	2.00	40	23.39	722	81.58	4	5.63	8	4.17
Hiodon spp. eggs	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Aplodinotus grunniens eggs	245	98.00	131	76.61	162	18.31	67	94.37	184	95.83
Total	250	100.00	171	100.00	885	100.00	71	100.00	192	100.00
LARVAE										
Unidentified fish	1	0.01	8	0.02	7	0.19	0	0.00	0	0.00
Clupeidae										
Unspecifiable clupeids	9913	91.17	31679	92.94	1569	42.44	1976	77.04	1259	38.86
Alosa chrysochloris	0	0.00	6	0.02	0	0.00	0	0.00	0	0.00
Dorosoma sp.	0	0.00	68	0.20	73	1.97	0	0.00	0	0.00
Dorosoma cepedianum	2	0.02	637	1.87	334	9.03	0	0.00	324	10.00
Dorosoma petenense	32	0.29	1	T	0	0.00	0	0.00	20	0.62
Hiodontidae										
Hiodon tergisus	0	0.00	4	0.01	0	0.00	1	0.04	0	0.00
Cyprinidae										
Cyprinidae	8*	0.07	14	0.04	28	0.76	5	0.19	5	0.15
Cyprinus carpio	27	0.25	16	0.05	0	0.00	8	0.31	1	0.03
*Macrhybopsis storeriana***	0	0.00	1	T	0	0.00	0	0.00	0	0.00
Notropis sp.	0	0.00	1	T	0	0.00	0	0.00	0	0.00
Notropis atherinoides	0	0.00	4	0.01	5	0.14	0	0.00	0	0.00
Catostomidae										
Unspecifiable catostomids	0	0.00	0	0.00	1	0.03	1	0.04	0	0.00
*Ictiobinae****	0	0.00	82	0.24	0	0.00	0	0.00	0	0.00
Minytrema melanops	2	0.02	1	T	0	0.00	0	0.00	0	0.00
Ictaluridae										
Ictalurus furcatus	1	0.01	0	0.00	1	0.03	1	0.04	1	0.03
Ictalurus punctatus	45	0.41	27	0.08	38	1.03	8	0.31	9	0.28
Pylodictis olivaris	1	0.01	2	0.01	0	0.00	0	0.00	0	0.00
Percichthyidae										
Morone sp.	1	0.01	62	0.18	73	1.97	13	0.51	16	0.49
Morone chrysops	0	0.00	0	0.00	1	0.03	0	0.00	0	0.00
Morone mississippiensis	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Morone (not *saxatilis*)	5	0.05	50	0.15	7	0.19	31	1.21	199	6.14
Centrarchidae										
Lepomis or *pomoxis*	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Lepomis sp.	209	1.92	428	1.26	873	23.61	57	2.22	857	26.45
Micropterus dolomieu	0	0.00	0	0.00	0	0.00	0	0.00	1	0.03

Table 2-3. (Continued)

Taxon	PREOPERATIONAL 1976 Total Collected	1976 % Comp.	1977 Total Collected	1977 % Comp.	1978 Total Collected	1978 % Comp.	1979 Total Collected	1979 % Comp.	1982 Total Collected	1982 % Comp.
Pomoxis sp.	24	0.22	281	0.82	334	9.03	9	0.35	328	10.12
Pomoxis annularis	0	0.00	1	T	0	0.00	0	0.00	0	0.00
Percidae										
Unidentifiable darter	0	0.00	4	0.01	5	0.14	1	0.04	4	0.12
Perflavescens	0	0.00	0	0.00	5	0.14	0	0.00	3	0.09
Stizostedion sp.	1	0.01	5	0.01						
Stizostedion canadense	0	0.00	0	0.00	1	0.03	0	0.00	0	0.00
Sciaenidae										
Aplodinotus grunniens	601	5.53	704	2.07	310	8.39	454	17.70	205	6.33
Atherinidae										
Labidesthes sicculus	0	0.00	0	0.00	32	0.87	0	0.00	8	0.25
Total	10873	100.00	34086	100.00	3697	100.00	2565	100.00	3240	100.00

Taxon	PREOPERATIONAL 1983 Total Collected	1983 % Comp.	1984 Total Collected	1984 % Comp.	1985 Total Collected	1985 % Comp.	OPERATIONAL 1996 Total Collected	1996 % Comp.	1997 Total Collected	1997 % Comp.
EGGS										
Unidentifiable fish eggs	1143	87.12	26	27.66	16	51.61	2908	99.28	1591	99.13
Hiodon spp. eggs	0	0.00	0	0.00	1	3.23	0	0.00	0	0.00
Aplodinotus grunniens eggs	169	12.88	68	72.34	14	45.16	21	0.72	14	0.87
Total	1312	100.00	94	100.00	31	100.00	2929	100.00	1605	100.00
LARVAE										
Unidentified fish	38	0.49	0	0.00	0	0.00	0	0.00	0	0.00
Clupeidae										
Unspecifiable clupeids	5658	73.01	22435	93.33	5890	68.63	4135	83.89	8086	82.08
Alosa chrysochloris	0	0.00	0	0.00	0	0.00	0	0.00	8	0.08
Dorosoma sp.	0	0.00	1	T	0	0.00	0	0.00	0	0.00
Dorosoma cepedianum	1	0.01	114	0.47	0	0.00	74	1.50	1	0.01
Dorosoma petenense	2	0.03	0	0.00	8	0.09	50	1.01	2	0.02
Hiodontidae										
Hiodon tergisus	0	0.00	7	0.03	0	0.00	0	0.00	0	0.00
Cyprinidae										
Unspecifiable cyprinids	110	1.42	1*	T	9*	0.10	2	0.04	6	0.06
Cyprinus carpio	15	0.19	7	0.03	0	0.00	2	0.04	2	0.02
*Macrhybopsis storeriana***	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Notropis sp.	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Notropis atherinoides	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 2-3. (Continued)

Taxon	PREOPERATIONAL 1983 Total Collected	1983 % Comp.	1984 Total Collected	1984 % Comp.	1985 Total Collected	1985 % Comp.	OPERATIONAL 1996 Total Collected	1996 % Comp.	1997 Total Collected	1997 % Comp.
Notropis volucellus	0	0.00	0	0.00	0	0.00	0	0.00	2	0.02
Catostomidae										
Unspecifiable catostomids	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Ictiobinae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Minytrema melanops	0	0.00	0	0.00	0	0.00	3	0.06	0	0.00
Ictaluridae										
Ictalurus furcatus	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Ictalurus punctatus	11	0.14	0	0.00	2	0.02	2	0.04	0	0.00
Pylodictis olivaris	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Percichthyidae										
Morone sp.	50	0.65	108	0.45	24	0.28	41	0.83	820	8.32
Morone chrysops	0	0.00	0	0.00	0	0.00	5	0.10	2	0.02
Morone mississippiensis	0	0.00	0	0.00	0	0.00	16	0.3	6	0.06
Morone (not saxatilis)	244	3.15	283	1.18	29	0.34	161	3.27	382	3.88
Centrarchidae										
Lepomis or pomoxis	20	0.26	0	0.00	0	0.00	0	0.00	0	0.00
Lepomis sp.	309	3.99	247	1.03	2427	28.28	95	1.93	129	1.31
Micropterus sp.	0	0.00	0	0.00	0	0.00	0	0.00	3	0.03
Micropterus dolomieu	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Pomoxis sp.	220	2.84	90	0.37	158	1.84	8	0.16	125	1.27
Pomoxis annularis	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Percidae										
Unidentifiable darter	4	0.05	0	0.00	0	0.00	0	0.00	8	0.08
Perca flavescens	12	0.15	9	0.04	9	0.10	6	0.12	0	0.00
Stizostedion sp.	0	0.00	0	0.00	0	0.00	0	0.00	2	0.02
Stizostedion canadense	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Sciaenidae										
Aplodinotus grunniens	1056	13.63	737	3.07	25	0.29	324	6.57	267	2.71
Atherinidae										
Labidesthes sicculus	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00
Total	7750	100.00	24039	100.00	8582	100.00	4929	100.00	9851	100.00

T = Less than 0.01 percent composition.
* Number collected changed or was previously missing.
** Scientific name changed.

Table 2-4. Day and night densities (number per 1,000 m^3) of larval fish collected during preoperational and operational monitoring in the vicinity of Watts Bar Nuclear Plant.

PREOPERATIONAL

	1976*		1977		1978		1979		1982		1983		1984		1985	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
EGGS																
Unidentifiable eggs	4.48	0.00	12.75	38.84	697.18	259.79	1.17	4.02	1.21	0.00	492.84	884.82	11.36	18.06	12.70	4.31
Aplodinotus grunniens eggs	61.34	35.75	109.67	55.28	37.04	68.65	8.18	12.05	1.21	79.42	73.57	132.82	1.14	73.37	0.00	3.23
LARVAE																
Aplodinotus grunniens	78.06	20.29	232.08	380.21	43.68	102.30	16.36	13.39	25.44	134.19	347.71	456.02	118.18	135.46	6.35	4.31
Centrarchidae	26.76	35.75	374.90	406.53	210.35	969.17	9.35	16.07	333.13	211.83	246.93	357.14	159.09	128.68	108.99	348.99
Clupeidae**	3071.28	2041.55	17978.83	23096.98	703.60	1391.84	578.47	867.59	574.20	1072.16	3010.48	3580.28	11354.55	13792.75	1423.28	2250.11
Dorosoma sp.	0.00	0.00	25.50	136.82	1.32	487.28	0.00	0.00	16.96	436.18	0.00	0.00	114.77	12.42	0.00	1.08
Morone(not saxatilis)***	0.00	0.00	24.23	38.15	3.97	5.38	22.20	14.73	119.93	136.93	94.74	184.47	111.36	208.83	20.11	10.77
Morone sp.	1.12	0.00	33.15	47.36	9.26	87.49	2.34	10.71	4.85	15.06	31.24	25.09	70.45	51.92	6.35	19.39

OPERATIONAL

	1996		1997	
	Day	Night	Day	Night
EGGS				
Unidentifiable eggs	2911.38	570.94	32.51	713.90
Aplodinotus grunniens eggs	13.37	8.60	9.10	9.43
LARVAE				
Aplodinotus grunniens	201.84	135.30	169.03	184.54
Centrarchidae	36.09	59.44	150.83	189.92
Clupeidae**	2101.32	2004.54	3847.12	7113.42
Dorosoma sp.	0.00	96.98	0.00	4.04
Morone (not saxatilis)***	49.46	96.98	133.92	343.48
Morone sp.	18.71	37.54	468.08	630.39

*Densities for 1976 based on samples taken from four (dawn, midday, dusk, midnight) diel periods.
**Includes unspecifiable clupeids, Alosa chrysochloris, Dorosoma spp., and Dorosoma petenense.
***Includes all Morone spp., Morone Chrysops, Morone Mississippiensis and Morone (not saxatilis).

Table 2-5. Species list, total number collected, and occurrence spans of fish eggs and larvae collected during operational monitoring at Watts Bar Nuclear Plant, 1996.

TAXON	TOTAL COLLECTED	PERCENT COMPOSITION	SAMPLING PERIODS					
FISH EGGS			1	2	3	4	5	6
Unidentifiable fish eggs	2908	99.28	x	x	x	x	x	
Aplodinotus grunniens eggs	21	0.72				x	x	x
Total	2929	100						
FISH LARVAE								
Clupeidae	4135	83.89			x	x	x	x
Dorosoma cepedianum	74	1.50					x	x
Dorosoma petenense	50	1.01					x	x
Pimephales sp.	2	0.04						x
Cyprinus carpio	2	0.04				x	x	
Minytrema melanops	3	0.06			x			
Ictalurus punctatus	2	0.04						x
Morone sp.	41	0.83				x	x	x
Morone chrysops	5	0.10					x	
Morone mississippiensis	16	0.32					x	
Morone (not saxatilis)	161	3.27	x	x	x			
Lepomis sp.	95	1.93					x	x
Pomoxis sp.	8	0.16			x	x	x	
Percidae (not stizostedion)	5	0.10	x	x	x			
Perca flavescens	6	0.12		x	x			
Aplodinotus grunniens	324	6.57				x	x	x
TOTAL	4929	100						

T = less than 0.01 percent composition

Table 2-6. Species list, total number collected, and occurrence spans of fish eggs and larvae collected during operational monitoring at Watts Bar Nuclear Plant, 1997.

TAXON	TOTAL COLLECTED	PERCENT COMPOSITION	SAMPLING PERIODS						
FISH EGGS			1	2	3	4	5	6	7
Unidentifiable fish eggs	1591	99.13	x	x	x	x			x
Aplodinotus grunniens eggs	14	0.87					x		x
Total	1605	100							
FISH LARVAE									
Clupeidae	8086	82.08	x	x	x	x	x	x	x
Alosa chrysochloris	8	0.08					x	x	
Dorosoma cepedianum	1	0.01							x
Dorosoma petenense	2	0.02						x	x
Cyprinidae	6	0.06						x	x
Cyprinus carpio	2	0.02						x	
Notropis volucellus	2	0.02		x	x				
Morone sp.	820	8.32		x	x	x	x	x	x
Morone chrysops	2	0.02				x	x		
Morone mississippiensis	6	0.06					x	x	x
Morone (not saxatilis)	382	3.88	x	x	x	x		x	
Lepomis sp.	129	1.31					x	x	x
Micropterus sp.	3	0.03					x		x
Pomoxis sp.	125	1.27			x	x	x	x	x
Percidae (not stizostedion)	8	0.08	x	x	x				
Stizostedion sp.	2	0.02	x						
Aplodinotus grunniens	267	2.71				x	x	x	x
TOTAL	9851	100							

T = less than 0.01 percent composition

Table 2-7. Average and peak density (number per 1,000 m^3) of larval fish with mean water temperatures collected in the vicinity of Watts Bar Nuclear Plant during preoperational and operational monitoring.

	PREOPERATIONAL								OPERATIONAL	
	1976	1977	1978	1979	1982	1983	1984	1985	1996	1997
Average Density	444	1,960	358	146	365	835	2,119	347	525	2,287
Mean Water Temperature (°C)	19.1	19.3	18.3	17.7	19.0	17.3	23.9	18.5	18.4	22.4
Peak Density	1,334	4,559	624	370	731	3,011	10,485	1,007	1,392	11,211
Date of Peak Density	5/19	4/26	6/6	5/22	6/7	6/14	5/29	6/4	6/3	6/23

Table 2-8. Distribution of larval fishes by size group (mm) collected at Watts Bar Nuclear Plant, during 1996 and 1997.

1996	Size Group (mm)															
TAXON	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16-19**	**20-30**	**>30**
Clupeidae		10	172	346	364	498	562	525	461	367	253	119	111	347		
Dorosoma cepedianum															73	1
Dorosoma petenense															50	
Pimephales sp.			1	1												
Cyprinus carpio					2											
Minytrema melanops									3							
Ictalurus punctatus														1	1	
Morone sp.			4	2	5	10	5	6	5	4						
Morone chrysops									2			1		2		
Morone mississippienis									1	5	9	1				
Morone (not saxatilis)	119	42														
Lepomis sp.		1	6	64	13	6	3	1		1						
Pomoxis sp.			4	1		1		1	1							
Unidentified Darter				1	2	2										
Perca flavescens				2	1	1	1	1								
Aplodinotus grunniens	1	4	164	81	19	22	25	5	2					1		

NOTE: These numbers represent expanded subsample measurements.

Table 2-8 (Continued)

1997	Size Group (mm)																
TAXON	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-19	20-30	>30
Clupeidae			6	247	1014	1104	1575	1663	1205	597	300	123	79	52	45		
Alosa chrysochloris																8	
Dorosoma cepedianum																1	
Dorosoma petenense																2	
Cyprinidae					2	3					1						
Cyprinus carpio							1										
Notropis volucellus																	2
Morone sp.				2	349	245	115	42	20	34	8	2		1			
Morone chrysops											1	1					
Morone mississippienis												5				1	
Morone (not saxatilis)		133	57	169													
Lepomis sp.			1	55	55	15	1	1									
Micropterus sp.					2	1											
Pomoxis sp.	2			65	40	8	5	3	2								
Unidentified Darter							1	2		3	1	1					
Stizostedion sp.						2											
Aplodinotus grunniens			2	176	81	4	4	2									

NOTE: These numbers represent expanded subsample measurements.

Table 2-9. Percent composition of dominant larval fish taxa collected in the cooling water intake channel at the Watts Bar Nuclear Plant Site, 1984 through 1985, and 1996 through 1997.

	Preoperational		Operational	
TAXON	Year	Percent Composition	Year	Percent Composition
A. grunniens	1984	0.1	1996	0.8
	1985	0.2	1997	0.4
Centrachidae	1984	0.9	1996	7.7
	1985	12.5	1997	8.2
Clupeidae	1984	97.8	1996	90.5
	1985	86.4	1997	84.7
Dorosoma sp.	1984	0.09	1996	0.8
	1985	--------	1997	0.2
Morone (not saxatilis)	1984	0.6	1996	0.09
	1985	0.5	1997	0.9
Morone sp.	1984	0.5	1996	0.09
	1985	0.5	1997	5.6

Table 2-10. Comparison of percent composition of the catch from preoperational (1977-1985 and 1990-1995) and operational (1996-1997) monitoring periods.

Common Name	1977-1985 Preoperational	1990-1995 Preoperational	1996-1997 Operational
Chestnut lamprey			0.1%
Spotted gar	0.1%	–	–
Longnose gar	0.5%	0.0%	0.1%
Mooneye	0.2%	–	0.1%
American eel	0.0%	–	–
Skipjack herring	1.5%	0.7%	–
Gizzard shad	*	*	*
Threadfin shad	*	*	*
Spotfin shiner	0.1%	1.8%	0.4%
Steelcolor shiner	–	2.5%	–
Common carp	1.2%	1.0%	3.8%
Striped shiner	–	0.0%	–
Silver chub	0.0%	–	–
Golden shiner	0.2%	0.4%	0.1%
Emerald shiner	58.6%	17.1%	1.5%
Bluntnose minnow	–	0.1%	0.1%
Bullhead minnow	0.0%	0.1%	–
River carpsucker	0.0%	–	–
Northern hogsucker	0.1%	0.1%	0.1%
Smallmouth buffalo	0.0%	0.1%	–
Spotted sucker	1.2%	1.3%	2.0%
River redhorse	0.0%	–	0.1%
Black redhorse	–	0.2%	0.3%
Golden redhorse	0.5%	0.5%	1.2%
Blue catfish	0.0%	0.1%	–
Channel catfish	0.0%	1.6%	0.6%
Flathead catfish	0.0%	0.6%	0.9%
Brook silversides	5.4%	1.1%	–
White bass	1.3%	1.7%	1.8%
Yellow bass	4.1%	4.3%	8.5%
Striped bass	0.1%	0.2%	0.2%
Rock bass	0.0%	–	–
Redbreast sunfish	0.9%	1.3%	0.4%
Green sunfish	0.0%	0.4%	0.3%
Warmouth	0.1%	0.7%	0.2%
Bluegill	10.0%	32.4%	45.1%
Longear sunfish	0.2%	0.1%	0.3%
Redear sunfish	7.2%	13.4%	12.5%
Hybrid sunfish	–	0.0%	0.2%
Smallmouth bass	0.3%	1.8%	3.5%
Spotted bass	1.0%	3.1%	3.2%
Largemouth bass	3.4%	7.8%	6.9%
White crappie	0.8%	0.2%	0.4%
Black crappie	0.0%	0.8%	1.8%
Yellow perch	0.4%	0.4%	0.6%
Logperch	0.1%	1.5%	1.3%
Sauger	0.1%	0.1%	0.4%
Walleye	0.0%	–	–
Freshwater drum	0.2%	0.6%	1.0%

* Numbers not included.

Table 2-11. Comparison by species of average catch per electrofishing run (CPUE) and percent composition of the catch from vital signs preoperational (1990-1995) and operational (1996-1997) results.

	1990-1995 Preoperational		1996-1997 Operational	
Common Name	Average CPUE	Percentage of CPUE	CPUE	Percentage of CPUE
Chestnut lamprey	--	--	0.03	0.06%
Longnose gar	0.03	0.04%	0.07	0.13%
Mooneye	--	--	0.07	0.13%
Skipjack herring	0.51	0.67%	--	--
Gizzard shad	*		*	
Threadfin shad	*		*	
Spotfin shiner	1.41	1.85%	0.23	0.44%
Steelcolor shiner	1.91	2.51%	--	--
Common carp	0.76	1.00%	2.00	3.82%
Striped shiner	0.03	0.04%	--	--
Golden shiner	0.28	0.37%	0.07	0.13%
Emerald shiner	13.03	17.13%	0.80	1.53%
Bluntnose minnow	0.04	0.05%	0.07	0.13%
Bullhead minnow	0.04	0.05%	--	--
Northern hogsucker	0.07	0.09%	0.07	0.13%
Smallmouth buffalo	0.07	0.09%	--	--
Spotted sucker	0.97	1.27%	1.03	1.97%
River redhorse	--	--	0.03	0.06%
Black redhorse	0.18	0.24%	0.17	0.32%
Golden redhorse	0.41	0.54%	0.63	1.20%
Blue catfish	0.05	0.07%	--	--
Channel catfish	1.19	1.56%	0.30	0.57%
Flathead catfish	0.49	0.64%	0.47	0.90%
Brook silverside	0.82	1.08%	--	--
White bass	1.26	1.66%	0.93	1.78%
Yellow bass	3.26	4.28%	4.47	8.54%
Striped bass	0.18	0.24%	0.10	0.19%
Redbreast sunfish	0.97	1.27%	0.23	0.44%
Green sunfish	0.30	0.39%	0.13	0.25%
Warmouth	0.50	0.66%	0.10	0.19%
Bluegill	24.68	32.44%	23.60	45.10%
Longear sunfish	0.08	0.11%	0.13	0.25%
Redear sunfish	10.20	13.41%	6.57	12.55%
Hybrid sunfish	0.03	0.04%	0.10	0.19%
Smallmouth bass	1.36	1.79%	1.83	3.50%
Spotted bass	2.35	3.09%	1.67	3.19%
Largemouth bass	5.92	7.78%	3.60	6.88%
White crappie	0.12	0.16%	0.23	0.44%
Black crappie	0.61	0.80%	0.93	1.78%
Yellow perch	0.28	0.37%	0.30	0.57%
Logperch	1.16	1.52%	0.67	1.28%
Sauger	0.11	0.14%	0.20	0.38%
Freshwater drum	0.42	0.55%	0.53	1.01%
Total	76	100%	52	100%
Average RFAI score	44		45	

* Densities not included.

Table 2-12. Summary of one-way univariate ANOVA testing of effects of 1990-1995 preoperational compared to 1996-1997 operational monitoring results and interactions of these for variables on CPUE of each important species collected by electrofishing near Watts Bar Nuclear Plant.

Species	P-Value	Preoperational CPUE 1990-1995	Operational CPUE 1996-1997
Largemouth Bass	0.0711	5.9	3.6
Redear Sunfish	0.1183	10.2	6.6
Emerald Shiner	0.2441	13.0	0.8
Brook Silversides	0.3676	0.8	0
Bluegill	0.5120	24.7	23.6
Spotted Sucker	0.6556	1.3	1
Spotted Bass	0.7367	2.4	1.7
White Bass	0.7498	1.3	0.9
Common Carp	0.8137	0.8	2
Logperch	0.8761	1.2	0.7
Smallmouth Bass	0.9359	1.4	1.8
Yellow Bass	0.9379	3.3	4.5

Table 2-13. Actual and estimated numbers of fish impinged at Watts Bar Nuclear Plant during two sample periods, March 1996 through March 1997 and March 1997 through October 7, 1997.

Common Name	Total Number of Fish Impinged		Estimated Number of Fish Impinged		Percentage Composition	
	Sample Period		Sample Period		Sample Period	
	1	2	1	2	1	2
Gizzard shad	4	0	40.6	0	25.0	0
Threadfin shad	2	0	20.3	0	12.5	0
Freshwater drum	3	3	30.4	30.6	18.7	75.0
Channel catfish	1	0	10.1	0	6.3	0
Flathead catfish	1	0	10.1	0	6.3	0
Bluegill	2	0	20.3	0	12.5	0
Redear sunfish	1	0	10.1	0	6.2	0
White crappie	2	0	20.3	0	12.5	0
Log Perch	0	1	0	10.2	0	25.0
Total	**16**	**4**	**162.2**	**40.8**	**100.3**	**100.0**

Table 2-14. Estimated total impingement of fishes at Sequoyah Nuclear Plant (1981 through 1983).

COMMMON NAME	1981	1982	1983
Unidentified Fish	0	7	0
Lamprey	0	0	37
Chestnut lamprey	29	0	0
Unidentified shad	0	0	183
Skipjack herring	73	149	270
Gizzard shad	453	9,967	2,365
Threadfin shad	56,582	15,829	4,687
Mooneye	37	60	15
Minnow, carp	0	7	0
Carp	0	0	7
Silver chub	102	30	0
River chub	7	0	0
Golden shiner	153	15	15
Emerald shinner	22	7	22
Mimic shiner	0	0	15
Bluntnose minnow	22	238	37
Bullhead minnow	110	350	241
Spotted sucker	7	0	0
Golden redhorse	0	0	7
Blue catfish	102	127	146
Black bullhead	0	7	0
Yellow bullhead	7	7	7
Channel catfish	387	179	387
Flathead catfish	58	97	22
Mosquitofish	7	0	0
White bass	51	782	95
Yellow bass	212	1,862	350
Unidentified sunfish	0	37	0
Warmouth	153	45	37
Redbreast sunfish	51	97	7
Green sunfish	2,759	74	22
Bluegill	4,672	3,553	2,613
Longear sunfish	110	0	7
Redear sunfish	256	216	73
Spotted bass	117	670	22
Largemouth bass	44	67	29
White crappie	190	97	139
Yellow perch	445	387	190
Logperch	22	268	15
Sauger	22	7	7
Freshwater drum	2,759	5,706	2,891
Total	70,022	40,944	14,960

Table 2-15. Location of access points, percent of clerk time allotted for interviews, and angler type encountered for the Watts Bar Tailwater creel survey.

Access Point Location	Percent of Time Allotted	Type of Anglers Intercepted
Bank @ Lock	30	Bank
Bank @ Power Plant	40	Bank
TVA Ramp	20	Boat/Bank
Unimproved Ramp	5	Bank
TWRA Sewee Creek Ramp	10	Boat/Bank
Eaves Ferry Ramp	5	Boat

Table 2-16. Number of days surveyed and number of interviews for the Watts Bar Tailwater creel survey, April 1996 through April 1998.

Month	Number of Days Surveyed	Number of Interviews
	1996	
April	14	152
May	15	208
June	13	168
July	14	144
August	12	120
September	12	115
October	12	128
November	13	128
December	8	80
	1997	
January	16	182
February	16	211
March	16	228
April	12	143
May	15	172
June	14	188
July	10	111
August	14	145
September	12	98
October	15	118
November	12	64
December	9	57
	1998	
January	13	148
February	11	146
March	14	157
April	13	144

Table 2-17. Directed species effort for bank and boat fishermen during the Watts Bar Tailwater creel survey, April 1996 through April 1998.

Directed Species Group	Percent Participation		
	Bank	Boat	Overall
Any Species	40	25	35
Black Bass	1	10	4
Catfish	13	27	18
Crappie	7	4	6
Sauger	11	13	11
Striped Bass/Cherokee Bass	9	6	8
Sunfish	9	4	7
White Bass	10	11	11

Table 2-18. Number of interviews and percent angler use at six access points within the Watts Bar Tailwater survey, April 1996 through April 1998.

Access Point	Number of Interviews	Percent Participation
Bank Anglers		
Bank@Lock	1315	52
Bank@Power Plant	1051	43
TVA Ramp	49	2
TWRA Sewee Creek Ramp	39	2
Eaves Ferry Ramp	13	1
Boat Anglers		
TVA Ramp	1047	96
Unimproved Ramp	2	< 1
TWRA Sewee Creek Ramp	10	1
Eaves Ferry Ramp	29	3

Table 2-19. Monthly estimated effort, percent effort, and estimated number of angling trips for the Watts Bar Tailwater survey, April 1996 through April 1998.

Month	Estimated Effort (hrs)	Standard Error	Percent Effort	Estimated Trips	Standard Error
1996					
April	30,218	1,362	8	9,717	438
May	20,526	826	5	4,970	200
June	24,157	694	6	6,178	178
July	21,758	687	6	5,193	164
August	15,190	700	4	3,714	171
September	10,002	357	3	2,037	73
October	16,951	409	4	3,229	78
November	11,884	569	3	2,285	109
December	15,641	795	4	3,724	189
1997					
January	12,204	660	3	2,885	156
February	16,365	610	4	2,976	111
March	20,781	921	5	3,906	173
April	19,988	749	5	3,417	128
May	17,014	626	4	3,389	125
June	24,481	674	6	5,165	142
July	15,456	285	4	3,816	70
August	9,333	230	2	2,333	57
September	11,052	341	3	2,303	71
October	10,814	338	3	1,975	62
November	7,395	127	2	1,456	25
December	8,718	273	2	1,851	58
1998					
January	9,636	120	2	2,190	27
February	9,894	466	3	2,401	113
March	14,542	699	4	3,438	165
April	18,780	621	5	3,603	113

Table 2-20. Estimated effort, number, and length of trips for selected species groups by fishermen in the Watts Bar Tailwater fishery, April 1996 through April 1998.

Directed Species Group	Percent Effort	Estimated Effort (hrs)	Estimated Trips	Mean Length of Trip (hrs)	Standard Error	Number of Trips Creeled
Any Species	33	129,313	29,116	4.5	0.1	1251
Black Bass	5	20,024	4,451	5.1	0.2	140
Catfish	23	89,707	20,409	4.8	0.1	618
Crappie	4	15,789	3,679	3.7	0.3	224
Sauger	10	40,670	9,163	4.6	0.2	406
Striped Bass/Cherokee Bass	8	31,363	6,550	4.5	0.3	279
Sunfish	6	23,467	5,085	4.4	0.3	262
White Bass	11	42,473	9,695	4.8	0.2	375

Table 2-21. Mean catch and harvest rate with standard errors, and percent harvested for directed species group anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998.

Species	Mean Catch Rate (No/hr)	Standard Error	Mean Harvest Rate (No/hr)	Standard Error	Percent Harvested
Largemouth Bass	0.56	0.06	0.08	0.03	15
Smallmouth Bass	0.26	0.05	0.02	0.01	9
Spotted Bass	0.18	0.04	0.03	0.01	14
Blue Catfish	0.55	0.06	0.36	0.07	67
Channel Catfish	0.43	0.10	0.34	0.09	79
Black Crappie	0.51	0.13	0.31	0.07	61
White Crappie	1.17	0.26	0.68	0.15	58
Sauger	0.88	0.14	0.15	0.03	18
Striped Bass	0.18	0.02	0.08	0.02	42
Bluegill	4.98	0.63	2.34	0.29	47
White Bass	1.60	0.21	0.80	0.14	50
Yellow Bass	0.56	0.16	0.25	0.11	45

Table 2-22. Estimated number of fish caught and harvested with standard errors for directed species group anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998.

Species	Estimated Number Caught	Standard Error	Estimated Number Harvested	Standard Error
Largemouth Bass	9,072	6,628	1,236	1,959
Smallmouth Bass	1,684	550	198	306
Spotted Bass	1,726	1,653	290	436
Blue Catfish	46,650	46,558	26,622	23,953
Channel Catfish	26,831	19,522	18,349	13,219
Black Crappie	5,522	6,141	3,917	4,863
White Crappie	11,141	8,962	6,758	5,898
Sauger	33,390	51,382	7,426	11,511
Striped Bass	3,104	2,136	1,543	1,482
Bluegill	123,391	128,857	56,832	59,715
White Bass	67,976	79,450	38,046	51,109
Yellow Bass	10,619	10,798	3,911	5,538

Table 2-23. Mean catch and harvest rate with standard errors, and percent harvested for any species anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998.

Species	Mean Catch Rate (No./hr)	Standard Error	Mean Harvest Rate (No./hr)	Standard Error	Percent Harvested
Largemouth Bass	0.02	< 0.01	< 0.01	< 0.01	21
Smallmouth Bass	0.02	< 0.01	< 0.01	< 0.01	15
Blue Catfish	0.04	0.01	0.02	< 0.01	47
Channel Catfish	0.02	< 0.01	0.01	< 0.01	36
Black Crappie	0.03	< 0.01	0.02	< 0.01	61
White Crappie	0.04	0.01	0.02	< 0.01	46
Sauger	0.05	0.01	0.01	< 0.01	16
Bluegill	0.16	0.04	0.06	0.02	39
White Bass	0.12	0.02	0.04	0.01	34
Yellow Bass	0.11	0.02	0.03	0.01	25

Table 2-24. Estimated number of fish caught and harvested with standard errors for any species anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998.

Species	Estimated Number Caught	Standard Error	Estimated Number Harvested	Standard Error
Largemouth Bass	2,564	1,155	554	466
Smallmouth Bass	3,017	3,038	460	464
Blue Catfish	4,175	2,554	1,942	1,721
Channel Catfish	2,666	1,161	979	659
Black Crappie	4,189	2,795	2,467	2,000
White Crappie	4,772	3,287	2,365	2,333
Sauger	7,942	6.250	1,075	1,353
Bluegill	17,373	13,474	6,670	6,214
White Bass	15,814	12,771	5,893	7,755
Yellow Bass	15,540	19,741	4,604	9,372

Table 2-25. Estimated number of fish caught and harvested with standard errors by all anglers in the Watts Bar Tailwater fishery, April 1996 through April 1998.

Species	Estimated Number Caught	Standard Error	Estimated Number Harvested	Standard Error
Largemouth Bass	11,635	6,728	1,790	2,014
Smallmouth Bass	4,701	3,087	657	556
Spotted Bass	1,726	1,653	290	435
Blue Catfish	50,825	46,628	28,564	24,015
Channel Catfish	29,496	19,557	19,328	13,236
Black Crappie	9,710	6,748	6,383	5,258
White Crappie	15,914	9,546	9,122	5,343
Sauger	41,331	51,762	8,501	11,591
Striped Bass	3,104	2,136	1,542	1,482
Bluegill	140,764	42,918	63,502	60,038
White Bass	83,791	79,450	43,938	51,695
Yellow Bass	26,158	22,501	8,515	10,869

Table 2-26. A comparison of harvest rates from preoperational and operational creel surveys conducted in the Watts Bar Tailwater.

Species	Operational 1982-1985		Preoperational 1996-1998
	Harvest Rate	Standard Error	Harvest Rate
Largemouth Bass	0.08	0.03	0.03
Smallmouth Bass	0.02	0.01	0.01
Spotted Bass	0.03	0.01	< 0.01
Blue Catfish	0.36	0.05	0.04
Channel Catfish	0.34	0.09	0.08
Black Crappie	0.36	0.05	< 0.01
White Crappie	0.68	0.15	0.11
Sauger	0.15	0.03	0.11
Striped Bass	0.08	0.02	-
Bluegill	2.34	0.29	0.34
White Bass	0.80	0.14	0.10
Yellow Bass	0.25	0.11	0.06

Table 3-1. Benthic macroinvertebrate taxa collected during preoperational (1973 through 1985) and operational (1996 and 1997) monitoring at Watts Bar Nuclear Plant.

	Preoperational	Operational
Nematoda		X
Coelenterata		X
Hydrozoa		
Hydroida		
Clavidae		
Cordylophora lacustris		X
Hydridae		
Hydra americana		X
Turbellaria		
Tricladida		
Planariidae	X	
Dugesia tigrina	X	X
Oligochaeta	X	
Haplotaxida		
Lumbricidae		X
Naididae	X	X
Dero sp.		X
Nais sp.		X
Nais communis		X
Nais simplex		X
Pristina sp.		X
Pristina leidyi		
Slavina appendiculata		X
Tubificidae	X	X
Branchiura sowerbyi	X	X
Limnodrilus sp.	X	
Limnodrilus hoffmeisteri		X
Lumbriculida		
Lumbriculidae		X
Lumbriculus sp.		X
Hirudinea	X	X
Rhynchobdellida		
Glossiphoniidae	X	
Helobdella sp.		X
Helobdella triserialis		X
Pharyngobdellida		
Erpobdellidae	X	
Erpobdella sp.		X
Erpobdella punctata		X

Table 3-1 (Continued)

	Preoperational	Operational
Crustacea		
Isopoda		
Asellidae		
Caecidotea sp.	X	X
Lirceus sp.	X	
Amphipoda		
Crangonyctidae		
Crangonyx sp.	X	
Gammaridae		
Gammarus sp.	X	
Gammarus minus		X
Decapoda		
Cambaridae		
Orconectes sp.	X	X
Cladocera		
Daphnidae		
Daphnia lumholtzi		X
Sididae		
Sida crystallina		X
Podocopa		X
Candoniidae		
Candona sp.		X
Insecta		
Plecoptera		
Perlidae		X
Odonata		
Coenagrionidae	X	
Argia sp.		X
Enallagma sp.	X	
Ischnura sp.	X	
Corduliidae		
Neurocordlia molesta		X
Gomphidae		
Dromogomphus sp.	X	
Gomphus sp.	X	
Ephemeroptera		
Baetidae		X
Baetis amplus		X
Caenidae		

Table 3-1 (Continued)

	Preoperational	Operational
Caenis sp.	X	
Ephemeridae		
Hexagenia sp.	X	
Heptageniidae		X
Stenacron sp.	X	X
Stenacron interpunctatum		X
Stenonema sp.		X
Leptophlebiidae		
Paraleptophlebia sp.		X
Tricorythidae		
Tricorythodes sp.	X	
Heteroptera		
Corixidae		X
Trichoptera		
Hydropsychidae		
Cheumatopsyche sp.	X	X
Hydropsyche sp.	X	
Hydroptilidae		
Hydroptila sp.		X
Leptoceridae		
Ceraclea sp.	X	X
Oecetis sp.		X
Polycentropodidae		
Cyrnellus fraternus	X	X
Megaloptera		
Corydalidae		
Nigronia sp.		X
Sialidae		
Sialis sp.	X	X
Diptera		
Chaoboridae		
Chaoborus sp.	X	
Chironomidae	X	X
Ablabesmyia sp.	X	X
Ablabesmyia annulata		X
Ablabesmyia mallochi		X
Ablabesmyia parajanta		X
Chironomus sp.	X	X
Cladotanytarsus sp.		X

Table 3-1 (Continued)

	Preoperational	Operational
Clinotanypus pinguis		X
Coelotanypus sp.	X	
Coelotanypus tricolor		X
Conchapelopia sp.	X	
Cricotopus bicinctus		X
Cryptochironomus sp.	X	
Cryptochironomus fulvus		X
Dicrotendipes sp.	X	X
Glyptotendipes sp.	X	X
Harnischia sp.		X
Microtendipes sp.		X
Nanocladius sp.		X
Parachironomus sp.	X	X
Paratanytarsus sp.		
Paratendipes sp.		
Phaenopsectra obediens		X
Polypedilum sp.		X
Polypedilum convictum		X
Polypedilum halterale		X
Polypedilum illinoense		
Procladius sp.	X	
Pseudochironomus sp.		X
Rheotanytarsus sp.		X
Stenochironomus sp.		X
Stictochironomus sp.		X
Synorthocladius semivirens		X
Tanytarsus sp.		X
Thienemanniella xena		X
Thienemannimyia sp.		X
Tvetenia discoloripes sp. gp.		X
Coleoptera		
Elmidae		
Dubiraphia sp.		X
Macronychus sp.	X	
Stenelmis sp.		X
Arachnoidea		
Hydrachnellae		
Hydrachnidae	X	
Gastropoda		

Table 3-1. (Continued)

Mesogastropoda		
Hydrobiidae		X
Amnicola sp.	X	X
Somatogyrus sp.		X
Pleuroceridae		
Leptoxis praerosa		X
Pleurocera sp.	X	X
Pleurocera canaliculata		X
Viviparidae		
Campeloma sp.	X	
Campeloma decisum		X
Basommatophora		
Ancylidae		
Ferrissia rivularis		X
Physidae		
Physa sp.	X	
Physella sp.		X
Planorbidae		X
Gyraulus sp.	X	
Gyraulus parvus		X
Menetus sp.		X
Micromenetus dilatatus		X
Bivalvia		
Unionoida		
Unionidae		
Actinonaias ligamentina		X
Amblema plicata	X	
Anodonta imbecillis	X	X
Cyclonaias tuberculata	X	
Ellipsaria lineolata	X	
Elliptio crassidens	X	X
Fusconaia ebena	X	
Lampsilis abrupta		X
Obliquaria reflexa	X	X
Pleurobema cordatum	X	
Pleurobema pyramidatum	X	
Potamilus alatus		X
Quadrula pustulosa pustulosa	X	X

Table 3-1. (Continued)

Veneroida		
Corbiculidae		
Corbicula fluminea	X	X
Dreissenidae		
Dreissena polymorpha		X
Sphaeriidae		X
Musculium transversum		X
Sphaerium sp.	X	
TOTAL	**59**	**104**

Table 3-2. Average densities (number/m^2) of dominant* macroinvertebrates collected with Hess samples near Watts Bar Nuclear Plant, during summer and fall 1983 through 1985 (preoperational) and 1996 and 1997 (operational).

Season	Organism	Tennessee River Mile				
		521.0	526.3	527.4	528.0	528.5
1983-1985 (Preoperational)						
Summer	Chironomus	5.2	180.0	5.6	0.0	1.2
	Corbicula fluminea	681.6	901.2	616.0	552.4	796.8
	Cyrnellus fraternus	12.4	14.4	31.6	53.2	55.2
	Oligochaeta	45.6	114.0	65.2	47.6	61.2
	Total	853.6	1283.2	791.6	770.4	1008.4
Fall	Corbicula fluminea	640.4	704.4	676.0	509.6	511.6
	Crangonyx	13.6	3.2	13.6	79.6	38.0
	Cyrnellus fraternus	59.6	106.0	219.2	426.0	415.6
	Oligochaeta❖	43.6	88.8	61.2	9.2	31.2
	Total	883.2	965.6	1064.0	1212.0	1148.4
1996-1997 (Operational)						
Summer*	Corbicula fluminea	594	725	867	1604	886
	Dugesia tigrina	622	675	1468	1226	855
	Gammarus minus	829	441	1002	1014	1122
	Oligochaeta	285	164	159	60	38
	Hydra americana	153	66	13	48	709
	Total	2636	2157	3596	3978	3612
*90% of Total Benthic Community						
Fall*	Corbicula fluminea	350	318	739	1042	597
	Dugesia tigrina	1294	1085	1118	1189	1678
	Gammarus minus	386	58	126	126	347
	Oligochaeta❖	352	75	54	133	282
	Cyrnellus fraternus	14	39	414	647	409
	Total	2396	1716	2471	3190	3313
*85% of Total Benthic Community						

❖Includes Branchiura sowerbyi and Tubificidae

Table 3-3. Number of taxa and diversity index ($\overline{d}$) values of benthic macroinvertebrates from Hess samples collected during preoperational monitoring (1983 through 1985), and operational monitoring (1996 and 1997) at Watts Bar Nuclear Plant.

		Tennessee River Mile									
		521.0		526.3		527.4		528.0		528.5	
Year	Quarter	No. taxa	$\overline{d}$	No. taxa	$\overline{d}$	No. taxa	$\overline{d}$	No. taxa	$\overline{d}$	No. taxa	$\overline{d}$
Preoperational											
1983	Summer	12	0.77	8	0.60	14	1.76	12	1.30	14	1.21*
	Fall	10	0.93	13	0.99	12	0.97	9	1.47	11	1.55
1984	Summer	19	1.03	20	0.66	15	0.84	18	1.27	17	0.75
	Fall	16	1.95	14	1.59	17	1.65	20	2.10	18	2.02
1985	Summer	24	2.11	19	2.12	13	1.88	18	2.18	12	2.11
	Fall	18	2.02	16	1.87	14	2.20	13	2.05	14	2.16
Operational											
1996	Summer	31	2.13	27	2.03	31	2.20	24	2.10	26	1.89
	Fall	29	2.15	25	1.97	27	2.12	29	2.34	32	2.46
1997	Summer	28	2.23	32	2.13	28	2.25	35	2.35	29	2.50
	Fall	31	2.27	24	2.02	25	2.19	26	2.26	27	2.29

*Data collected from TRM 528.8 in summer 1983.

Table 3-4. Results of one-way analysis of variance and Duncan's new multiple range test on total benthic macroinvertebrate standing crop (number/m^2) estimated from Hess samples during preoperational (1983 through 1985) and operational (1996 through 1997) monitoring, Watts Bar Nuclear Plant, Chickamauga Reservoir.

				Tennessee River Mile				
Year	Quarter	F-Ratio	P>F	Low $\bar{x}$				High $\bar{x}$
Preoperational								
1983	Summer	7.1	0.0002	527.4	521.0	526.3	528.0	528.8
	Fall	1.3	0.2818	N.S.D.*				
1984	Summer	5.5	0.0011	528.0	521.0	528.5	526.3	527.4
	Fall	11.2	0.0001	521.0	526.3	527.4	528.5	528.0
1985	Summer	27.2	0.0001	527.4	528.5	528.0	521.0	526.3
	Fall	0.8	0.5663	N.S.D.*				
Operational								
1996	Summer	4.7	0.0030	528.5	526.3	521.0	528.0	527.4
	Fall	7.6	0.0001	526.3	527.4	521.0	528.0	528.5
1997	Summer	4.13	0.0062	528.5	528.0	527.4	521.0	526.3
	Fall	5.9	0.0007	528.5	521.0	528.0	527.4	526.3

*No significant difference.

Table 3-5. Total densities of benthic macroinvertebrates (number/m^2) collected in Hess samples near Watts Bar Nuclear Plant, summer and fall, 1983 through 1985 (preoperational) and 1996 and 1997 (operational).

		Tennessee River Mile				
Season	**Year**	**521.0**	**526.3**	**527.4**	**528.0**	**528.5**
Preoperational						
Summer	1983	793	790	514	863	1,082*
	1984	766	1,172	1,194	654	1,162
	1985	1,002	1,888	667	794	781
Fall	1983	881	826	834	866	752
	1984	901	1,130	1,392	1,754	1,654
	1985	868	941	966	1,015	1,039
Operational						
Summer	1996	2,963	2,156	3,705	3,001	1,775
Fall	1996	2,603	2,222	2,552	3,920	4,558
Summer	1997	3014	2926	4207	5596	6226
Fall	1997	3335	2835	2981	3321	3649

*Collected at TRM 528.8

Table 3-6. Results of the 1997survey of native mussels in three monitored beds near the Watts Bar Nuclear Plant.

Native Mussel Species	Tennessee River Mile 520					Tennessee River Mile 526					Tennessee River Mile 528					Grand Total	%
	520.0	520.3	520.6	520.8	Total	526.0	526.3	526.5	526.8	Total	528.2	528.5	528.8	528.9	Total		
Elliptio crassidens	24	13	51	35	123	45	33	17	14	109	20	66	126	45	257	489	70.16
Pleurobema cordatum	4	4	9	11	28	2	16	0	0	18	3	33	7	12	55	101	14.49
Cyclonaias tuberculata	1	16	9	5	31	1	2	0	0	3	2	7	4	0	13	47	6.74
Quadrula pustulosa	0	5	2	2	9	1	0	2	3	6	1	7	1	0	9	24	3.44
Potamilus alatus	0	0	1	1	2	0	1	4	1	6	4	0	0	0	4	12	1.72
Ellipsaria lineolata	1	0	2	2	5	0	0	0	1	1	1	0	1	0	2	8	1.15
Amblema plicata	0	0	0	0	0	0	0	3	1	4	0	0	1	0	1	5	0.72
Obliquaria reflexa	0	0	0	1	1	0	0	0	2	2	0	0	0	0	0	3	0.43
Leptodea fragilis	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	2	0.29
Quadrula metanevra	0	0	0	0	0	0	1	0	0	1	1	0	0	0	1	2	0.29
Anodonta grandis	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0.14
Lampsilis ovata	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0.14
Ligumia recta	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.14
Tritogonia verrucosa	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0.14
Grand Total	30	38	74	57	199	49	53	26	26	154	32	114	141	57	344	697	100.00
Number of Species Collected	4	4	6	7	7	4	5	4	9	12	7	5	7	2	10	14	

Table 3-7. Total numbers of each native mussel species collected during preoperational (1983-1994) and operational (1996-1997) surveys near Watts Bar Nuclear Plant.

	Preoperational												Operational			
	1983	1983 Fall	1984	1984 Fall	1985	1985 Fall	1986	1986 Fall	1988	1990	1992	1994	1996	1997	Totals	Times Found
Elliptio crassidens	754	836	779	984	738	929	734	765	970	524	424	583	594	489	10103	14
Pleurobema cordatum	264	275	220	156	113	177	110	169	224	139	82	95	94	101	2219	14
Cyclonaias tuberculata	88	70	73	62	60	66	55	76	93	90	68	64	38	47	950	14
Quadrula pustulosa	99	75	85	53	53	85	31	41	80	79	48	65	30	24	848	14
Potamilus alatus	14	29	18	29	34	43	41	27	55	45	16	10	35	12	408	14
Ellipsaria lineolata	24	29	24	25	8	27	19	18	23	28	14	11	15	8	273	14
Amblema plicata	18	33	19	11	17	25	23	24	49	10	13	13	11	5	271	14
Anodonta grandis	18	10	5	4	3	7	9	7	29	20	5	7	7	1	132	14
Quadrula metanevra	14	24	11	13	6	10	7	7	8	8	8	4	2	2	124	14
Tritogonia verrucosa	6	12	5	5	4	15	8	13	18	9	9	7	4	1	116	14
Obliquaria reflexa	14	6	8	3	7	5	9	3	7	11	6	11	6	3	99	14
Ligumia recta	6	3	4	10	3	8	8	10	7	2	3	1	2	1	68	14
Lampsilis abrupta	3	7	6	2	1	7	6	2	12	4	6	2	4	-	62	13
Leptodea fragilis	1	3	4	2	3	2	6	3	12	8	-	3	1	2	50	13
Actinonaias ligamentina	3	2	2	-	4	7	-	8	3	5	1	-	-	-	35	9
Megalonaias nervosa	2	1	-	1	1	4	5	1	9	3	4	2	1	-	34	12
Lampsilis ovata	3	1	1	4	5	4	1	2	3	1	-	-	-	1	26	11
Elliptio dilatata	4	2	1	1	-	2	2	1	3	1	-	-	1	-	18	10
Pleurobema oviforme	-	-	2	-	-	1	-	2	2	1	-	1	-	-	9	6
Anodonta imbecillis	-	-	-	2	-	-	-	1	1	1	-	-	-	-	5	4
Cyprogenia stegaria	2	1	-	1	1	-	-	-	-	-	-	-	-	-	5	4
Pleurobema plenum	1	1	2	-	1	-	-	-	-	-	-	-	-	-	5	4
Plethobasus cyphyus	-	2	-	-	-	-	-	-	-	-	1	1	-	-	4	3
Pleurobema rubrum	-	-	-	-	-	3	-	-	1	-	-	-	-	-	4	2
Anodonta suborbiculata	-	-	-	-	-	-	-	-	1	1	-	-	-	-	2	2
Fusconaia subrotunda	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1
Lasmigona costata	-	-	-	-	-	-	1	-	-	-	-	-	1	-	2	2
Ptychobranchus fasciolaris	-	-	1	-	-	-	-	-	-	1	-	-	-	-	2	2
Dromus dromas	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Lasmigona complanata	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	1
Total Mussels	1341	1422	1270	1368	1063	1427	1075	1180	1610	991	708	880	846	697	15878	
Number of Species Collected	22	21	20	19	20	20	18	20	22	22	16	17	17	14	30	

Table 3-8. Rank order relationships among the 12 mussel species encountered during all 14 surveys of three mussel beds near Watts Bar Nuclear Plant. Most rank order assignments were based on the total number of a species found during each survey; however, alphabetical order of scientific names was used to avoid ties when two or more species were represented by the same number of animals.

	1983	1983 Fall	1984	1984 Fall	1985	1985 Fall	1986	1986 Fall	1988	1990	1992	1994	1996	1997	Mean Rank	Overall Totals
Elliptio crassidens	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.0	10103
Pleurobema cordatum	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2.0	2219
Cyclonaias tuberculata	4	4	4	3	3	4	3	3	3	3	3	4	3	3	3.4	848
Quadrula pustulosa	3	3	3	4	4	3	4	4	4	4	4	3	5	4	3.7	950
Potamilus alatus	9	7	7	5	5	5	5	5	5	5	5	8	4	5	5.7	124
Ellipsaria lineolata	5	6	5	6	7	6	7	7	8	6	6	6	6	6	6.2	408
Amblema plicata	6	5	6	8	6	7	6	6	6	9	7	5	7	7	6.5	273
Anodonta grandis	7	10	10	11	11	11	8	10	7	7	11	9	8	10	9.3	271
Obliquaria reflexa	8	11	9	12	8	12	9	12	12	8	10	7	9	8	9.6	132
Quadrula metanevra	10	8	8	7	9	9	12	11	10	11	9	11	12	9	9.7	116
Tritogonia verrucosa	12	9	11	10	10	8	11	8	9	10	8	10	10	12	9.9	68
Ligumia recta	11	12	12	9	12	10	10	9	11	12	12	12	11	11	11.0	99

Table 3-9. Numbers of all native mussel species and each of the five most abundant species encountered on each of the three mussel beds near Watts Bar Nuclear Plant during the 10 summer surveys used in the statistical analyses.

All Species	1983	1984	1985	1986	1988	1990	1992	1994	1996	1997	Mean	SDEV
TRM 520-521	625	467	296	331	418	364	220	299	268	199	348.7	127.5
TRM 526-527	375	161	193	244	271	216	135	212	207	154	216.8	69.2
TRM 528-529	341	642	574	500	921	411	353	369	371	344	482.6	186.4
Totals	**1341**	**1270**	**1063**	**1075**	**1610**	**991**	**708**	**880**	**846**	**697**	**1048.1**	**291.2**
Percent @ TRM 520-521	46.6	36.8	27.8	30.8	26.0	36.7	31.1	34.0	31.7	28.6	33.3	6.0
Percent @ TRM 526-527	28.0	12.7	18.2	22.7	16.8	21.8	19.1	24.1	24.5	22.1	20.7	4.4
Percent @ TRM 528-529	25.4	50.6	54.0	46.5	57.2	41.5	49.9	41.9	43.9	49.4	46.0	8.8
Elliptio crassidens	**1983**	**1984**	**1985**	**1986**	**1988**	**1990**	**1992**	**1994**	**1996**	**1997**	**Mean**	**SDEV**
TRM 520-521	414	232	203	224	236	195	110	197	212	123	214.6	82.2
TRM 526-527	132	81	95	142	87	85	42	110	114	109	99.7	28.5
TRM 528-529	208	466	440	368	647	244	272	276	268	257	344.6	136.7
Totals	**754**	**779**	**738**	**734**	**970**	**524**	**424**	**583**	**594**	**489**	**658.9**	**164.8**
Percent @ TRM 520-521	54.9	29.8	27.5	30.5	24.3	37.2	25.9	33.8	35.7	25.2	32.6	9.0
Percent @ TRM 526-527	17.5	10.4	12.9	19.3	9.0	16.2	9.9	18.9	19.2	22.3	15.1	4.7
Percent @ TRM 528-529	27.6	59.8	59.6	50.1	66.7	46.6	64.2	47.3	45.1	52.6	52.3	11.5
Pleurobema cordatum	**1983**	**1984**	**1985**	**1986**	**1988**	**1990**	**1992**	**1994**	**1996**	**1997**	**Mean**	**SDEV**
TRM 520-521	90	107	36	55	68	34	26	35	27	28	50.6	28.8
TRM 526-527	109	12	23	8	44	24	27	19	20	18	30.4	29.3
TRM 528-529	65	101	54	47	112	81	29	41	47	55	63.2	26.8
Totals	**264**	**220**	**113**	**110**	**224**	**139**	**82**	**95**	**94**	**101**	**144.2**	**66.1**
Percent @ TRM 520-521	34.1	48.6	31.9	50.0	30.4	24.5	31.7	36.8	28.7	27.7	35.1	8.5
Percent @ TRM 526-527	41.3	5.5	20.4	7.3	19.6	17.3	32.9	20.0	21.3	17.8	21.1	10.6
Percent @ TRM 528-529	24.6	45.9	47.8	42.7	50.0	58.3	35.4	43.2	50.0	54.5	43.8	9.7

Table 3-9. (Continued)

Quadrula pustulosa	1983	1984	1985	1986	1988	1990	1992	1994	1996	1997	Mean	SDEV
TRM 520-521	32	27	7	3	5	17	14	6	1	9	12.1	10.4
TRM 526-527	45	20	18	12	21	26	16	30	9	6	20.3	11.4
TRM 528-529	22	38	28	16	54	36	18	29	20	9	27.0	13.1
Totals	**99**	**85**	**53**	**31**	**80**	**79**	**48**	**65**	**30**	**24**	**59.4**	**26.2**
Percent @ TRM 520-521	32.3	31.8	13.2	9.7	6.3	21.5	29.2	9.2	3.3	37.5	20.4	12.5
Percent @ TRM 526-527	45.5	23.5	34.0	38.7	26.3	32.9	33.3	46.2	30.0	25.0	34.2	7.9
Percent @ TRM 528-529	22.2	44.7	52.8	51.6	67.5	45.6	37.5	44.6	66.7	37.5	45.5	13.6
Cyclonaias tuberculata	**1983**	**1984**	**1985**	**1986**	**1988**	**1990**	**1992**	**1994**	**1996**	**1997**	**Mean**	**SDEV**
TRM 520-521	45	62	34	23	56	71	44	46	18	31	43.0	16.9
TRM 526-527	18	2	7	8	8	5	12	8	7	3	7.8	4.6
TRM 528-529	25	9	19	24	29	14	12	10	13	13	16.8	7.0
Totals	**88**	**73**	**60**	**55**	**93**	**90**	**68**	**64**	**38**	**47**	**67.6**	**18.6**
Percent @ TRM 520-521	51.1	84.9	56.7	41.8	60.2	78.9	64.7	71.9	47.4	66.0	63.6	13.7
Percent @ TRM 526-527	20.5	2.7	11.7	14.5	8.6	5.6	17.6	12.5	18.4	6.4	11.5	6.0
Percent @ TRM 528-529	28.4	12.3	31.7	43.6	31.2	15.6	17.6	15.6	34.2	27.7	24.9	10.1
Potamilus alatus	**1983**	**1984**	**1985**	**1986**	**1988**	**1990**	**1992**	**1994**	**1996**	**1997**	**Mean**	**SDEV**
TRM 520-521	6	7	3	4	10	13	6	2	3	2	5.6	3.6
TRM 526-527	7	9	25	23	30	28	5	5	28	6	16.6	11.0
TRM 528-529	1	2	6	14	15	4	5	3	4	4	5.8	4.8
Totals	**14**	**18**	**34**	**41**	**55**	**45**	**16**	**10**	**35**	**12**	**28.0**	**16.0**
Percent @ TRM 520-521	42.9	38.9	8.8	9.8	18.2	28.9	37.5	20.0	8.6	16.7	20.0	13.1
Percent @ TRM 526-527	50.0	50.0	73.5	56.1	54.5	62.2	31.3	50.0	80.0	50.0	59.3	13.7
Percent @ TRM 528-529	7.1	11.1	17.6	34.1	27.3	8.9	31.3	30.0	11.4	33.3	20.7	11.0

Table 3-10. Results of statistical analyses of native mussel abundance on three beds monitored near Watts Bar Nuclear Plant during 1983 through 1997. Only the summer sample data were used in these analyses to equalize the weight associated with each year. The significance level used in these analyses was $\alpha = 0.05$.

	Trend	Trend not Significant (ANOVA)		Significant Trend Present (Covariance)			
Test Subject	Present	Site	*Multiple Range Results*	Parallel	Site	Year	*Multiple Range Results*
All Species							
TRM 520-521	0.004			0.477	0.312	0.002	
TRM 526-527	0.381	0.034	526.3 526.5 526.8 526.0				
TRM 528-529	0.427	0.002	528.8 528.9 528.5 528.2				
Elliptio crassidens							
TRM 520-521	0.02			0.17	0.02	0.01	520.0 520.8 520.6 520.3
TRM 526-527	0.79	0.30					
TRM 528-529	0.50	0.0001	528.9 528.8 528.5 528.2				
Pleurobema cordatum							
TRM 520-521	0.004			0.13	0.72	0.001	?
TRM 526-527	0.42	0.0002	526.3 526.5 526.0 526.8				
TRM 528-529	0.31	0.03	528.9 528.5 528.8 528.2				
Quadrula pustulosa							
TRM 520-521	0.05			0.13	0.16	0.05	
TRM 526-527	0.04			0.18	0.0007	0.02	526.6 526.8 526.3 526.0
TRM 528-529	0.10	0.50					
Cyclonaias tuberculata							
TRM 520-521	0.02			0.009			Trends at sites not parallel
TRM 526-527	0.77	0.0009	526.5 526.3 526.0 526.8				
TRM 528-529	0.47	0.04	528.5 528.8 528.2 528.9				
Potamilus alatus							
TRM 520-521	0.75	0.27					
TRM 526-527	0.32	0.07					
TRM 528-529	0.58	0.78					

Table 3-11. **Mean lengths (in millimeters) of each native mussel species encountered during surveys conducted near Watts Bar Nuclear Plant during 1983-1997. As a general rule, no more than 50 members of each species were measured from each bed during any given survey.**

Species	1983	1984	1985	1986	1988	1990	1992	1994	1996	1997	Number Measured	Overall Mean
Actinonaias ligamentina	104.00	109.55	104.72	99.23	97.87	110.38	94.80				35	103.57
Amblema plicata	96.86	98.18	103.37	103.36	102.47	102.16	105.46	106.79	104.90	96.00	272	101.52
Anodonta grandis	121.88	124.58	123.14	122.18	126.85	135.42	130.06	135.29	141.10	147.00	132	127.57
Anodonta imbecillis		53.60		39.20	54.00	52.00					5	50.48
Anodonta suborbiculata					107.80	126.20					2	117.00
Cyclonaias tuberculata	79.14	76.09	78.39	76.16	79.12	79.65	80.10	78.52	83.00	81.50	897	79.30
Cyprogenia stegaria	54.83	52.90	57.70								5	55.02
Dromus dromas	60.10										1	60.10
Ellipsaria lineolata	85.29	82.92	87.83	84.30	87.22	85.42	90.49	87.68	92.20	81.80	265	85.90
Elliptio crassidens	107.96	109.58	110.22	110.53	110.06	115.21	112.26	113.88	112.90	113.10	2182	111.08
Elliptio dilatata	103.32	96.35	98.80	109.23	101.10	94.60			95.40		17	101.64
Fusconaia subrotunda	66.09										1	66.09
Lampsilis abrupta	94.39	96.66	101.94	100.44	100.78	105.95	108.85	105.05	110.20		62	101.18
Lampsilis ovata	124.93	127.98	127.36	141.40	130.37	121.70	157.27			115.30	26	128.39
Lasmigona complanata			180.20								1	180.20
Lasmigona costata				122.10					118.40		2	120.25
Leptodea fragilis	84.13	111.33	100.28	96.87	99.81	110.46		117.67	126.20	92.20	50	102.46
Ligumia recta	155.34	157.96	165.39	147.23	160.27	172.60		161.40	157.50	160.00	67	156.70
Megalonaias nervosa	13.83	180.00	173.70	152.35	160.61	166.60	173.35	174.45	180.00		34	166.23
Obliquaria reflexa	53.80	53.63	55.72	55.11	54.84	55.06	57.17	57.30	56.10	54.10	99	55.12
Plethobasus cyphyus	91.80						91.40	88.60			4	90.90
Pleurobema cordatum	95.39	95.08	96.42	92.87	96.57	97.37	98.53	97.71	99.40	98.20	1628	96.06
Pleurobema oviforme		69.80	72.90	68.90	72.20	72.80		71.90			9	71.04
Pleurobema plenum	58.10	60.10	84.60								4	65.73
Pleurobema rubrum			87.97		88.30						4	88.05
Potamilus alatus	135.39	142.73	139.79	139.66	142.76	142.78	142.99	149.92	145.90	146.40	407	141.46
Ptychobranchus fasciolaris		94.40				116.80					2	105.60
Quadrula metanevra	76.52	78.68	78.07	74.75	83.34	84.28	78.61	74.18	81.90	88.00	122	78.24
Quadrula pustulosa	55.91	56.75	57.98	54.97	58.73	57.56	56.37	58.02	60.80	59.00	827	57.18
Tritogonia verrucosa	110.06	110.44	124.66	110.36	112.68	107.59	106.24	115.60	109.70	109.60	116	112.77

Table 3-12. Statistical analyses of mean lengths of native mussels collected near Watts Bar Nuclear Plant during the period 1983 through 1997. Only the summer sample data were used in these analyses to equalize the weight associated with each year. The significance level used in these analyses was $\alpha = 0.05$.

	Trend	Trend not Significant (ANOVA)		Significant Trend Present (Covariance)			
Test Subject	Present	Site	Multiple Range Results	Parallel	Site	Year	Multiple Range Results
Elliptio crassidens							
TRM 520-521	0.02			0.45	0.65	0.002	
TRM 526-527	0.002			0.18	0.12	0.0004	
TRM 528-529	0.10	0.52					
Pleurobema cordatum							
TRM 520-521	0.02			0.05	0.001	0.06	520.0 520.3 520.8 520.6
TRM 526-527	0.002			0.36	0.10	0.0002	
TRM 528-529	0.02			0.42	0.03	0.002	528.5 528.8 528.2 528.9
Quadrula pustulosa							
TRM 520-521	0.14	0.98					
TRM 526-527	0.65	0.09					
TRM 528-529	0.13	0.42					
Cyclonaias tuberculata							
TRM 520-521	0.01			0.22	0.11	0.003	
TRM 526-527	0.82	0.46					
TRM 528-529	0.21	0.15					
Potamilus alatus							
TRM 520-521	0.23	0.01	520.3 520.0 520.6 520.8				
TRM 526-527	0.34	0.02	526.5 526.3 526.8 526.0				
TRM 528-529	0.18	0.18					

Table 4-1. Preoperational water quality monitoring summary statistics for parameters measured during 1982-1987 at WBN.

Tennessee River Mile 518.0					
Parameter	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
pH (standard units)	459	7.55	0.36	6.8	8.7
Turbidity (NTU)	115	5.40	2.98	1.1	16.0
Total Solids (mg/L)	0	-	-	-	-
Suspended Solids (mg/L)	79	4.6	2.3	1	9
Volatile Suspended Solids (mg/L)	52	2.4	1.0	1	5
Dissolved Solids (mg/L)	19	96.8	23.6	40	130
Ammonia Nitrogen (mg/L)	140	0.047	0.032	0.01	0.28
Nitrate+Nitrate Nitrogen (mg/L)	140	0.291	0.081	0.17	0.48
Organic Nitrogen (mg/L)	140	0.209	0.099	0.04	0.63
Total Phosphorus (mg/L)	116	0.0341	0.0162	0.010	0.110
Dissolved Phosphorus (mg/L)	125	0.0139	0.0058	0.010	0.030
Total Organic Carbon (mg/L)	139	2.50	0.86	1.1	5.8
COD (mg/L)	19	7.9	3.4	2	15
Total Alkalinity (mg/L)	133	63.0	8.4	46	78
Chlorophyll a (ug/L)	85	4.7	3.9	1	19.1
Tennessee River Mile 527.4					
Parameter	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
pH (standard units)	553	7.48	0.39	6.5	9.0
Turbidity (NTU)	105	5.01	2.40	0.8	12.0
Total Solids (mg/L)	0	-	-	-	-
Suspended Solids (mg/L)	69	3.4	1.3	1	6
Volatile Suspended Solids (mg/L)	0	-	-	-	-
Dissolved Solids (mg/L)	69	98.1	18.3	50	150
Ammonia Nitrogen (mg/L)	114	0.042	0.027	0.01	0.21
Nitrate+Nitrate Nitrogen (mg/L)	114	0.333	0.338	0.02	3.50
Organic Nitrogen (mg/L)	114	0.196	0.102	0.04	0.62
Total Phosphorus (mg/L)	79	0.0284	0.0126	0.010	0.060
Dissolved Phosphorus (mg/L)	109	0.0114	0.0037	0.010	0.030
Total Organic Carbon (mg/L)	114	3.00	2.58	1.2	26.0
COD (mg/L)	69	6.9	3.0	1	22
Total Alkalinity (mg/L)	103	62.5	8.6	46	76
Chlorophyll a (ug/L)	76	5.8	3.3	2.3	17.8

Table 4-1. (Continued)

Tennessee River Mile 529.5					
Parameter	N	Mean	Std Dev	Minimum	Maximum
pH (standard units)	163	7.50	0.45	6.4	9.1
Turbidity (NTU)	78	5.40	2.82	1.2	14.0
Total Solids (mg/L)	0	-	-	-	-
Suspended Solids (mg/L)	43	3.6	1.4	1	6
Volatile Suspended Solids (mg/L)	0	-	-	-	-
Dissolved Solids (mg/L)	43	99.1	20.9	70	180
Ammonia Nitrogen (mg/L)	104	0.038	0.023	0.01	0.13
Nitrate+Nitrate Nitrogen (mg/L)	104	0.301	0.118	0.02	0.85
Organic Nitrogen (mg/L)	104	0.191	0.091	0.01	0.48
Total Phosphorus (mg/L)	80	0.0285	0.0120	0.010	0.050
Dissolved Phosphorus (mg/L)	95	0.0118	0.0041	0.010	0.030
Total Organic Carbon (mg/L)	103	2.71	1.02	1.3	10.0
COD (mg/L)	45	7.3	2.8	2	14
Total Alkalinity (mg/L)	91	63.1	8.8	46	76
Chlorophyll a (ug/L)	76	5.7	3.7	2.2	19.3
Tennessee River Mile 529.9					
Parameter	N	Mean	Std Dev	Minimum	Maximum
pH (standard units)	195	7.61	0.40	5.8	8.8
Turbidity (NTU)	42	5.38	2.79	1.5	13.0
Total Solids (mg/L)	0	-	-	-	-
Suspended Solids (mg/L)	31	4.9	1.9	1	9
Volatile Suspended Solids (mg/L)	22	2.5	0.8	1	4
Dissolved Solids (mg/L)	1	100.0	.	100	100
Ammonia Nitrogen (mg/L)	42	0.034	0.021	0.01	0.11
Nitrate+Nitrate Nitrogen (mg/L)	51	0.262	0.098	0.07	0.61
Organic Nitrogen (mg/L)	42	0.203	0.078	0.03	0.42
Total Phosphorus (mg/L)	51	0.0320	0.0165	0.010	0.100
Dissolved Phosphorus (mg/L)	33	0.0142	0.0144	0.010	0.090
Total Organic Carbon (mg/L)	42	2.28	0.67	1.2	4.1
COD (mg/L)	1	9.0	.	9	9
Total Alkalinity (mg/L)	38	64.7	9.8	41	82
Chlorophyll a (ug/L)	17	5.4	2.6	2	12

Table 4-2. **Operational water quality monitoring summary statistics for parameters measured during 1996-1997 at WBN.**

Tennessee River Mile 518.0					
Parameter	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
pH (standard units)	12	7.47	0.14	7.2	7.7
Turbidity (NTU)	11	3.36	1.21	2.0	6.0
Total Solids (mg/L)	11	107.3	15.6	80	130
Suspended Solids (mg/L)	0	-	-	-	-
Volatile Suspended Solids (mg/L)	0	-	-	-	-
Dissolved Solids (mg/L)	11	90.0	14.8	70	110
Ammonia Nitrogen (mg/L)	38	0.039	0.015	0.01	0.06
Nitrate+Nitrate Nitrogen (mg/L)	38	0.284	0.076	0.18	0.43
Organic Nitrogen (mg/L)	38	0.165	0.063	0.07	0.27
Total Phosphorus (mg/L)	38	0.0311	0.0118	0.008	0.070
Dissolved Phosphorus (mg/L)	38	0.0155	0.0060	0.002	0.030
Total Organic Carbon (mg/L)	38	1.68	0.17	1.4	2.0
COD (mg/L)	11	5.5	1.5	5	10
Total Alkalinity (mg/L)	12	65.1	6.8	54	74
Chlorophyll a (ug/L)	80	5.8	2.9	2	18
Tennessee River Mile 527.4					
Parameter	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
pH (standard units)	12	7.63	0.22	7.3	8.0
Turbidity (NTU)	11	3.55	0.69	3.0	5.0
Total Solids (mg/L)	12	104.2	16.2	80	130
Suspended Solids (mg/L)	0	-	-	-	-
Volatile Suspended Solids (mg/L)	0	-	-	-	-
Dissolved Solids (mg/L)	12	90.8	13.8	80	120
Ammonia Nitrogen (mg/L)	41	0.030	0.014	0.01	0.05
Nitrate+Nitrate Nitrogen (mg/L)	41	0.272	0.075	0.19	0.42
Organic Nitrogen (mg/L)	41	0.176	0.055	0.02	0.26
Total Phosphorus (mg/L)	41	0.0273	0.0059	0.020	0.040
Dissolved Phosphorus (mg/L)	41	0.0127	0.0045	0.008	0.020
Total Organic Carbon (mg/L)	41	1.71	0.18	1.5	2.2
COD (mg/L)	12	5.8	1.7	5	10
Total Alkalinity (mg/L)	12	63.9	8.0	52	74
Chlorophyll a (ug/L)	80	7.7	3.2	4	18

Table 4-2. (Continued)

Tennessee River Mile 529.5					
Parameter	N	Mean	Std Dev	Minimum	Maximum
pH (standard units)	10	7.61	0.22	7.1	7.9
Turbidity (NTU)	10	3.50	0.97	2.0	5.0
Total Solids (mg/L)	11	102.7	14.2	90	130
Suspended Solids (mg/L)	0	-	-	-	-
Volatile Suspended Solids (mg/L)	0	-	-	-	-
Dissolved Solids (mg/L)	11	92.7	11.0	80	120
Ammonia Nitrogen (mg/L)	33	0.029	0.014	0.01	0.06
Nitrate+Nitrate Nitrogen (mg/L)	33	0.267	0.077	0.16	0.41
Organic Nitrogen (mg/L)	33	0.189	0.067	0.07	0.29
Total Phosphorus (mg/L)	33	0.0252	0.0083	0.020	0.060
Dissolved Phosphorus (mg/L)	33	0.0091	0.0029	0.002	0.010
Total Organic Carbon (mg/L)	33	1.74	0.20	1.5	2.1
COD (mg/L)	11	5.8	1.3	5	8
Total Alkalinity (mg/L)	10	63.0	6.8	55	73
Chlorophyll a (ug/L)	69	8.0	3.0	3	15
Tennessee River Mile 529.9					
Parameter	N	Mean	Std Dev	Minimum	Maximum
pH (standard units)	11	8.55	0.56	7.3	9.2
Turbidity (NTU)	11	1.73	0.79	1.0	3.0
Total Solids (mg/L)	11	101.8	14.0	80	130
Suspended Solids (mg/L)	0	-	-	-	-
Volatile Suspended Solids (mg/L)	0	-	-	-	-
Dissolved Solids (mg/L)	11	90.9	14.5	70	110
Ammonia Nitrogen (mg/L)	42	0.014	0.007	0.01	0.03
Nitrate+Nitrate Nitrogen (mg/L)	42	0.189	0.107	0.03	0.42
Organic Nitrogen (mg/L)	42	0.242	0.201	0.08	1.40
Total Phosphorus (mg/L)	42	0.0212	0.0055	0.010	0.030
Dissolved Phosphorus (mg/L)	42	0.0100	0.0022	0.005	0.020
Total Organic Carbon (mg/L)	42	1.92	0.38	1.5	3.1
COD (mg/L)	11	9.0	6.2	5	26
Total Alkalinity (mg/L)	11	65.8	5.5	56	74
Chlorophyll a (ug/L)	81	11.3	5.1	1	28

Table 4-3. Statistical Comparison of WBN 1996 Operational Water Quality Data to Preoperational Data using Anova w/Duncan's Multiple Range Test.

1996 Compared to Preop Period	TRM 518.0	TRM 527.4	TRM 529.5	TRM 529.9	All
pH	-	-	-	Up	Up
Turbidity	-	-	-	Down	Down
Dissolved Solids	-	-	-	-	-
Ammonia Nitrogen	-	-	-	Down	-
Nitrate+Nitrate Nitrogen	-	-	-	Down	-
Organic Nitrogen	Down	-	-	-	-
Total Phosphorous	-	-	-	Down	Down
Dissolved Phosphorus	-	-	Down	-	-
Total Organic Carbon	Down	-	Down	-	Down
Chemical Oxygen Demand	-	-	-	-	-
Total Alkalinity	-	-	-	-	-
Chlorophyll a	Up	Up	Up	Up	Up

Table 4-4. Statistical Comparison of WBN 1997 Operational Water Quality Data to Preoperational Data using Anova w/Duncan's Multiple Range Test.

1997 Compared to Preop Period	TRM 518.0	TRM 527.4	TRM 529.5	TRM 529.9	All
pH	-	-	-	Up	Up
Turbidity	Down	-	-	Down	Down
Dissolved Solids	-	-	-	-	Down
Ammonia Nitrogen	Down	Down	Down	Down	Down
Nitrate+Nitrate Nitrogen	-	-	Down	Down	Down
Organic Nitrogen	-	-	-	-	-
Total Phosphorous	-	-	-	Down	Down
Dissolved Phosphorus	-	Up	Down	-	-
Total Organic Carbon	Down	Down	Down	Down	Down
Chemical Oxygen Demand	Down	-	-	-	-
Total Alkalinity	-	-	-	-	-
Chlorophyll a	-	Up	Up	Up	Up

Table 4-5. Statistical Comparison of WBN Combined 1996-1997 Operational Water Quality Data to Preoperational Data using Anova w/Duncan's Multiple Range Test.

1997 Compared to Preop Period	TRM 518.0	TRM 527.4	TRM 529.5	TRM 529.9	All
pH	-	-	-	Up	Up
Turbidity	Down	Down	Down	Down	Down
Dissolved Solids	-	-	-	-	Down
Ammonia Nitrogen	-	Down	Down	Down	Down
Nitrate+Nitrate Nitrogen	-	-	-	Down	Down
Organic Nitrogen	Down	-	-	-	-
Total Phosphorous	-	-	-	Down	Down
Dissolved Phosphorus	-	-	Down	Down	Down
Total Organic Carbon	Down	Down	Down	Down	Down
Chemical Oxygen Demand	Down	-	-	-	-
Total Alkalinity	-	-	-	-	-
Chlorophyll a	Up	Up	Up	Up	Up

Shaded boxes indicate differences from those identified in 1996 comparisons in top table. "-" indicates no significant (p=>.05) difference between preoperational and post-operational periods. "Up" indicates a statistically significant increase in the indicated parameter. "Down" indicates a statistical decrease in the indicated parameter.

Table 4-6. Preoperational (1982-1991) water quality monitoring summary values for metals at WBN.

Tennessee River Mile 518.0					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	25	21.8	3.2	11.0	25.7
Total Magnesium (mg/L)	25	5.6	1.2	2.3	7.3
Total Arsenic (ug/L)	25	1.2	0.5	1.0	3.0
Total Boron (ug/L)	25	50.0	0.0	50.0	50.0
Total Cadmium (ug/L)	25	0.1	0.1	0.1	0.8
Total Chromium (ug/L)	25	1.4	0.7	1.0	4.0
Total Copper (ug/L)	25	11.0	9.0	5.0	50.0
Total Iron (ug/L)	25	189.2	139.2	50.0	590.0
Total Lead (ug/L)	25	2.8	3.9	1.0	20.0
Total Manganese (ug/L)	25	57.1	33.4	10.0	134.0
Total Nickel (ug/L)	25	2.2	2.0	1.0	9.0
Total Zinc (ug/L)	25	10.5	7.6	1.0	36.0
Total Aluminum (ug/L)	25	189.2	118.9	50.0	410.0
Total Selenium (ug/L)	25	1.1	0.6	1.0	4.0
Total Mercury (ug/L)	25	0.2	0.1	0.2	0.5
Ca/Mg Hardness (mg/L)	25	77.6	12.7	37.0	92.0
Tennessee River Mile 527.4					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	78	22.5	3.6	16.0	38.0
Total Magnesium (mg/L)	78	5.4	0.9	3.7	8.4
Total Arsenic (ug/L)	79	1.3	0.6	1.0	3.0
Total Boron (ug/L)	79	45.3	16.7	6.0	130.0
Total Cadmium (ug/L)	79	0.3	0.5	0.1	2.0
Total Chromium (ug/L)	79	1.4	0.9	1.0	4.0
Total Copper (ug/L)	79	12.6	13.6	5.0	90.0
Total Iron (ug/L)	79	177.0	120.3	10.0	610.0
Total Lead (ug/L)	75	3.9	5.7	1.0	40.0
Total Manganese (ug/L)	75	64.9	34.5	12.0	180.0
Total Nickel (ug/L)	79	2.0	1.8	1.0	10.0
Total Zinc (ug/L)	79	18.8	43.4	5.0	330.0
Total Aluminum (ug/L)	79	148.4	95.0	50.0	480.0
Total Selenium (ug/L)	79	1.1	0.4	1.0	3.0

Table 4-6 (Continued)

Tennessee River Mile 529.5					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Mercury (ug/L)	79	0.2	0.0	0.2	0.3
Ca/Mg Hardness (mg/L)	79	78.2	12.0	56.0	130.0
Total Calcium (mg/L)	53	22.9	4.9	17.0	40.0
Total Magnesium (mg/L)	53	5.7	1.3	3.9	8.7
Total Arsenic (ug/L)	53	1.3	1.1	1.0	8.0
Total Boron (ug/L)	53	71.1	125.7	50.0	940.0
Total Cadmium (ug/L)	53	0.1	0.1	0.1	0.6
Total Chromium (ug/L)	53	1.7	1.7	1.0	12.0
Total Copper (ug/L)	53	11.2	10.2	5.0	59.0
Total Iron (ug/L)	53	201.5	163.3	10.0	700.0
Total Lead (ug/L)	53	2.0	2.2	1.0	14.0
Total Manganese (ug/L)	53	63.1	35.4	5.0	174.0
Total Nickel (ug/L)	53	1.7	1.5	1.0	9.0
Total Zinc (ug/L)	53	15.7	29.5	2.0	220.0
Total Aluminum (ug/L)	53	166.2	102.7	50.0	390.0
Total Selenium (ug/L)	53	1.3	0.9	1.0	6.0
Total Mercury (ug/L)	53	0.2	0.0	0.2	0.3
Ca/Mg Hardness (mg/L)	53	80.6	17.3	58.0	130.0
Tennessee River Mile 529.9					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	1	22.0	.	22.0	22.0
Total Magnesium (mg/L)	1	5.5	.	5.5	5.5
Total Arsenic (ug/L)	1	1.0	.	1.0	1.0
Total Boron (ug/L)	1	8.0	.	8.0	8.0
Total Cadmium (ug/L)	1	0.1	.	0.1	0.1
Total Chromium (ug/L)	1	2.0	.	2.0	2.0
Total Copper (ug/L)	1	40.0	.	40.0	40.0
Total Iron (ug/L)	1	130.0	.	130.0	130.0
Total Lead (ug/L)	0	.	.	.	.
Total Manganese (ug/L)	0	.	.	.	.
Total Nickel (ug/L)	1	1.0	.	1.0	1.0
Total Zinc (ug/L)	1	10.0	.	10.0	10.0
Total Aluminum (ug/L)	1	100.0	.	100.0	100.0
Total Selenium (ug/L)	1	1.0	.	1.0	1.0
Total Mercury (ug/L)	1	0.2	.	0.2	0.2
Ca/Mg Hardness (mg/L)	1	78.0	.	78.0	78.0

Table 4-7. Operational (1996-1997) water quality monitoring summary values for metals at WBN.

Tennessee River Mile 518.0					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	13	19.5	4.0	12.0	23.0
Total Magnesium (mg/L)	13	5.6	0.6	4.4	6.2
Total Arsenic (ug/L)	13	1.0	0.0	1.0	1.0
Total Boron (ug/L)	13	500.0	0.0	500.0	500.0
Total Cadmium (ug/L)	13	0.1	0.0	0.1	0.2
Total Chromium (ug/L)	13	1.0	0.0	1.0	1.0
Total Copper (ug/L)	13	10.0	0.0	10.0	10.0
Total Iron (ug/L)	13	490.8	583.0	150.0	1800.0
Total Lead (ug/L)	13	1.0	0.0	1.0	1.0
Total Manganese (ug/L)	13	63.7	24.9	30.0	110.0
Total Nickel (ug/L)	13	1.0	0.0	1.0	1.0
Total Zinc (ug/L)	13	10.0	0.0	10.0	10.0
Total Aluminum (ug/L)	13	170.0	76.9	50.0	280.0
Total Selenium (ug/L)	13	1.0	0.0	1.0	1.0
Total Mercury (ug/L)	13	0.2	0.0	0.2	0.2
Ca/Mg Hardness (mg/L)	13	71.6	10.7	55.5	82.5
Tennessee River Mile 527.4					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	14	21.1	2.3	16.0	23.0
Total Magnesium (mg/L)	14	5.5	0.6	4.4	6.1
Total Arsenic (ug/L)	14	1.1	0.3	1.0	2.0
Total Boron (ug/L)	14	500.0	0.0	500.0	500.0
Total Cadmium (ug/L)	14	0.1	0.0	0.1	0.1
Total Chromium (ug/L)	14	1.0	0.0	1.0	1.0
Total Copper (ug/L)	14	10.0	0.0	10.0	10.0
Total Iron (ug/L)	14	237.1	43.6	180.0	320.0
Total Lead (ug/L)	14	1.0	0.0	1.0	1.0
Total Manganese (ug/L)	14	60.1	20.4	20.0	85.0
Total Nickel (ug/L)	14	1.1	0.3	1.0	2.0
Total Zinc (ug/L)	14	10.7	2.7	10.0	20.0
Total Aluminum (ug/L)	14	175.0	44.3	120.0	280.0
Total Selenium (ug/L)	14	1.0	0.0	1.0	1.0
Total Mercury (ug/L)	14	0.2	0.0	0.2	0.2
Ca/Mg Hardness (mg/L)	14	75.4	8.1	58.1	82.5

Table 4-7 (Continued)

Tennessee River Mile 529.5					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	12	21.5	2.8	16.0	25.0
Total Magnesium (mg/L)	12	5.5	0.6	4.4	6.4
Total Arsenic (ug/L)	12	1.0	0.0	1.0	1.0
Total Boron (ug/L)	12	500.0	0.0	500.0	500.0
Total Cadmium (ug/L)	12	0.1	0.0	0.1	0.1
Total Chromium (ug/L)	12	1.0	0.0	1.0	1.0
Total Copper (ug/L)	12	10.0	0.0	10.0	10.0
Total Iron (ug/L)	12	215.8	49.4	140.0	300.0
Total Lead (ug/L)	12	1.0	0.0	1.0	1.0
Total Manganese (ug/L)	12	60.9	21.1	25.0	91.0
Total Nickel (ug/L)	12	1.0	0.0	1.0	1.0
Total Zinc (ug/L)	12	10.0	0.0	10.0	10.0
Total Aluminum (ug/L)	12	170.8	36.3	110.0	220.0
Total Selenium (ug/L)	12	1.0	0.0	1.0	1.0
Total Mercury (ug/L)	12	0.2	0.0	0.2	0.3
Ca/Mg Hardness (mg/L)	12	76.4	9.5	58.1	88.8
Tennessee River Mile 529.9					
Parameter	N	Mean	Std Dev	Minimum	Maximum
Total Calcium (mg/L)	15	21.1	2.8	16.0	24.0
Total Magnesium (mg/L)	15	5.4	0.6	4.4	6.0
Total Arsenic (ug/L)	15	1.0	0.0	1.0	1.0
Total Boron (ug/L)	15	500.0	0.0	500.0	500.0
Total Cadmium (ug/L)	15	0.1	0.0	0.1	0.1
Total Chromium (ug/L)	15	1.0	0.0	1.0	1.0
Total Copper (ug/L)	15	10.0	0.0	10.0	10.0
Total Iron (ug/L)	15	184.0	57.4	100.0	300.0
Total Lead (ug/L)	15	1.0	0.0	1.0	1.0
Total Manganese (ug/L)	15	41.5	9.9	24.0	52.0
Total Nickel (ug/L)	15	1.0	0.0	1.0	1.0
Total Zinc (ug/L)	15	10.0	0.0	10.0	10.0
Total Aluminum (ug/L)	15	127.3	64.2	50.0	270.0
Total Selenium (ug/L)	15	1.0	0.0	1.0	1.0
Total Mercury (ug/L)	15	0.2	0.0	0.2	0.2
Ca/Mg Hardness (mg/L)	15	75.1	9.2	58.1	83.8

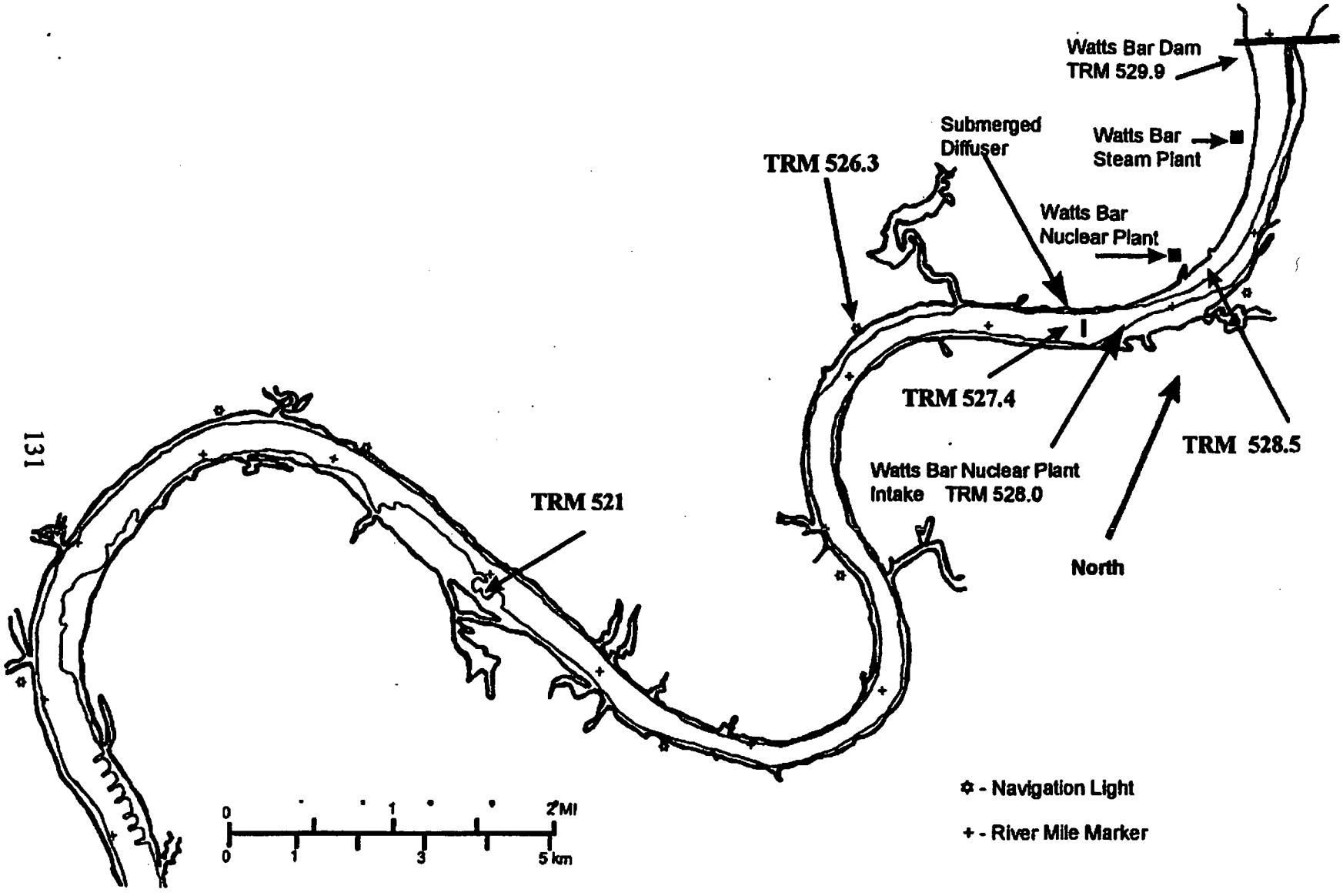


Figure 1-1. Location of Watts Bar Nuclear Plant on Chickamauga Reservoir.

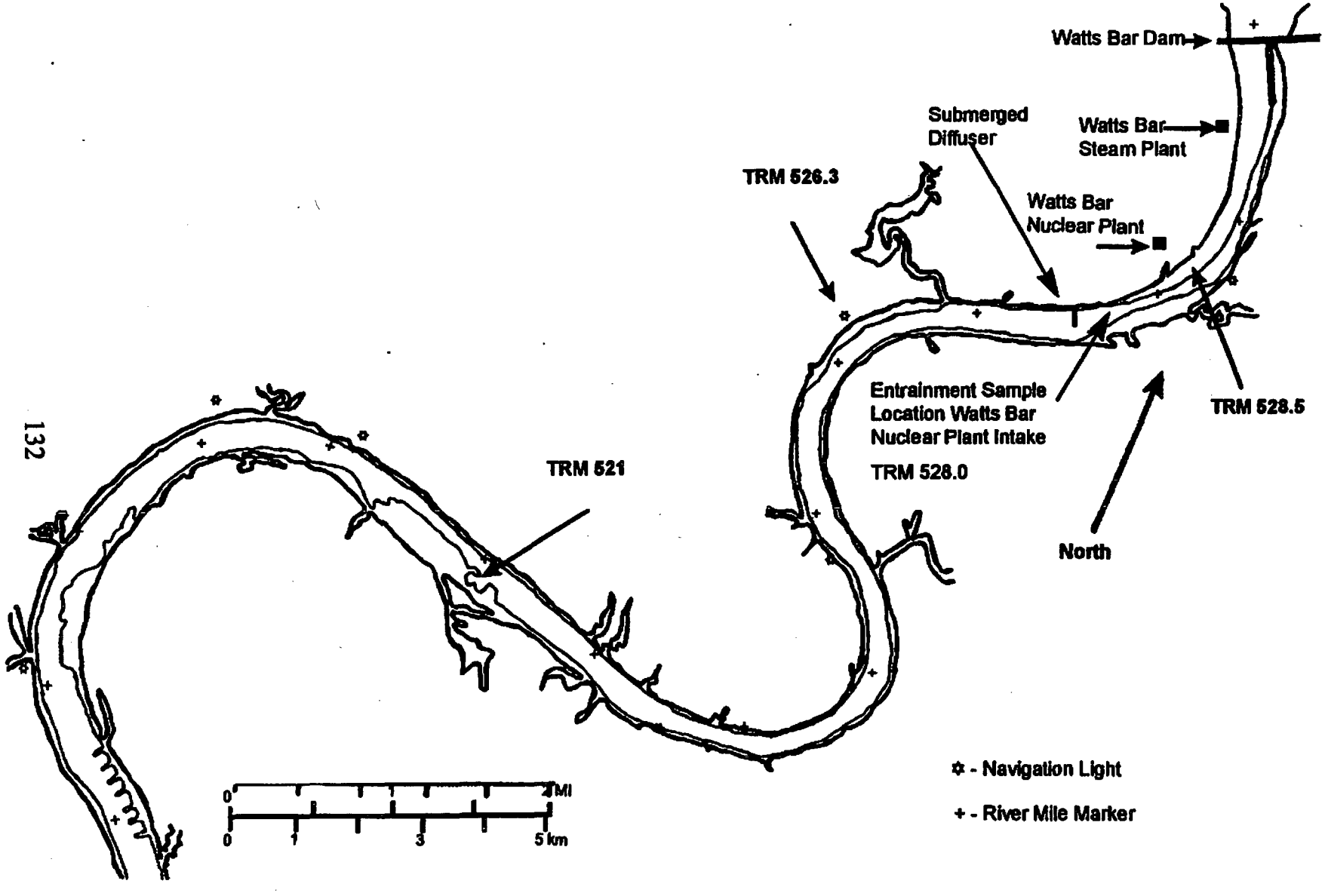


Figure 2-1. Sample Locations for Entrainment Samples in the vicinity of Watts Bar Nuclear Plant, 1996-1997.

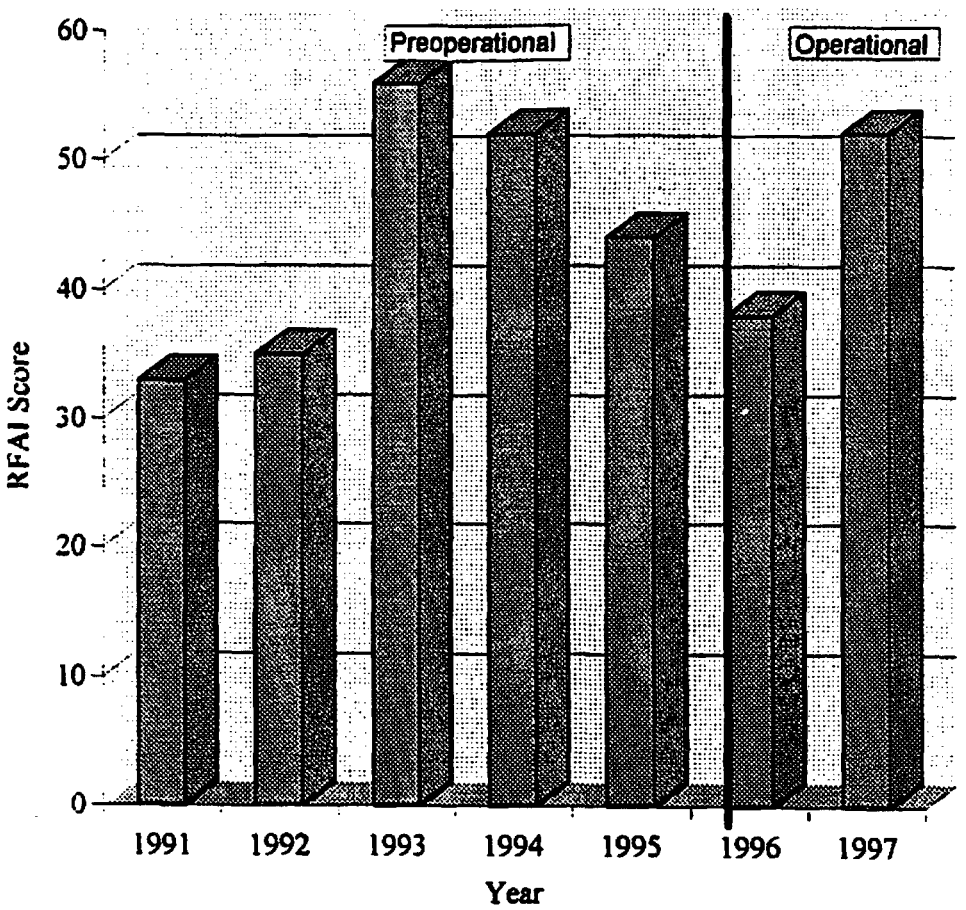


Figure 2-2. Reservoir Fish Assemblage Index (RFAI) scores from preoperational (1991-1995) and operational (1996-1997) periods on Chickamauga Reservoir in the vicinity of Watts Bar Nuclear Plant.

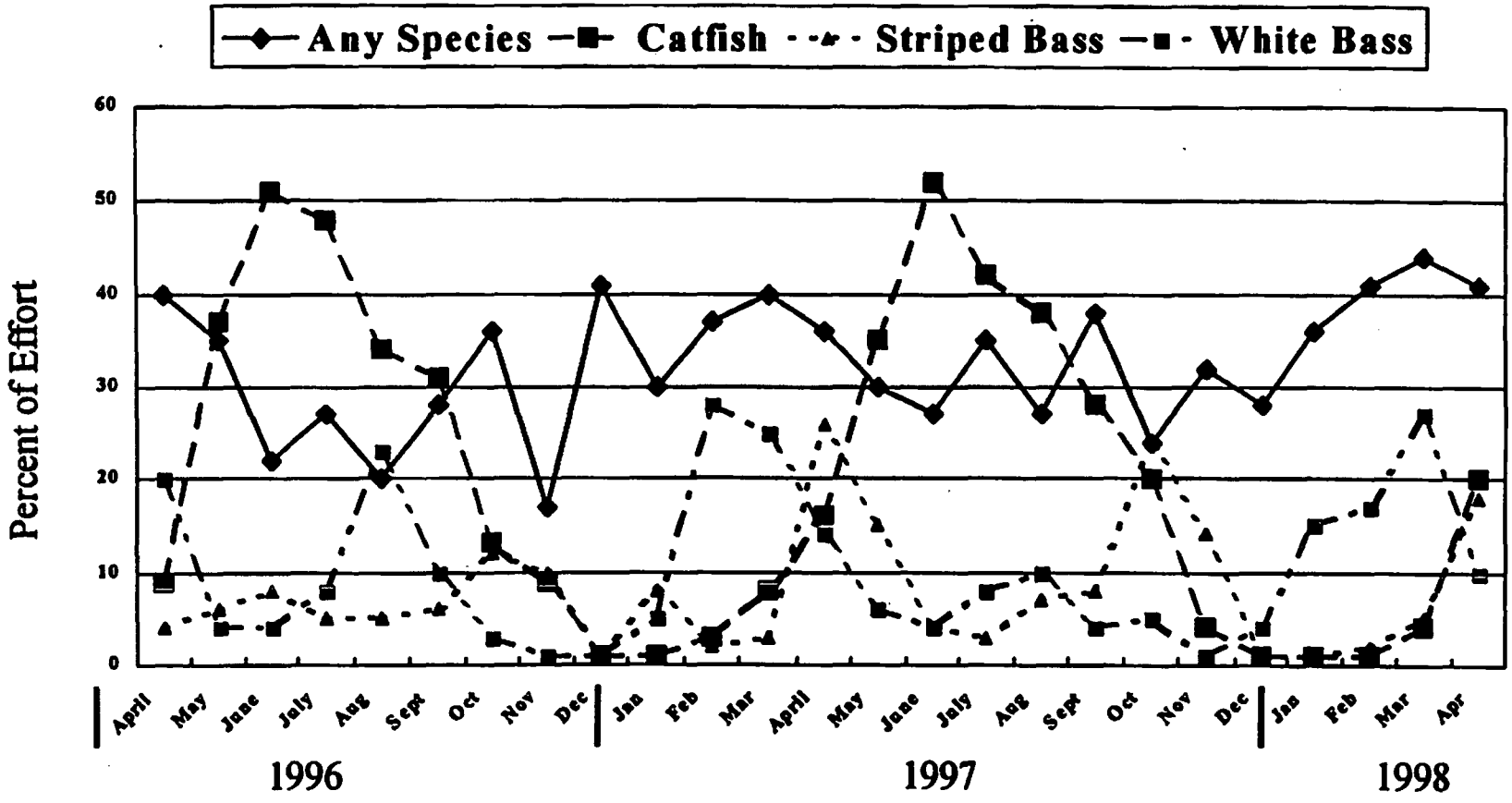


Figure 2-3. Percent of angler effort for selected directed species groups from the Watts Bar tailwater fishery, April 1996 through April 1998.

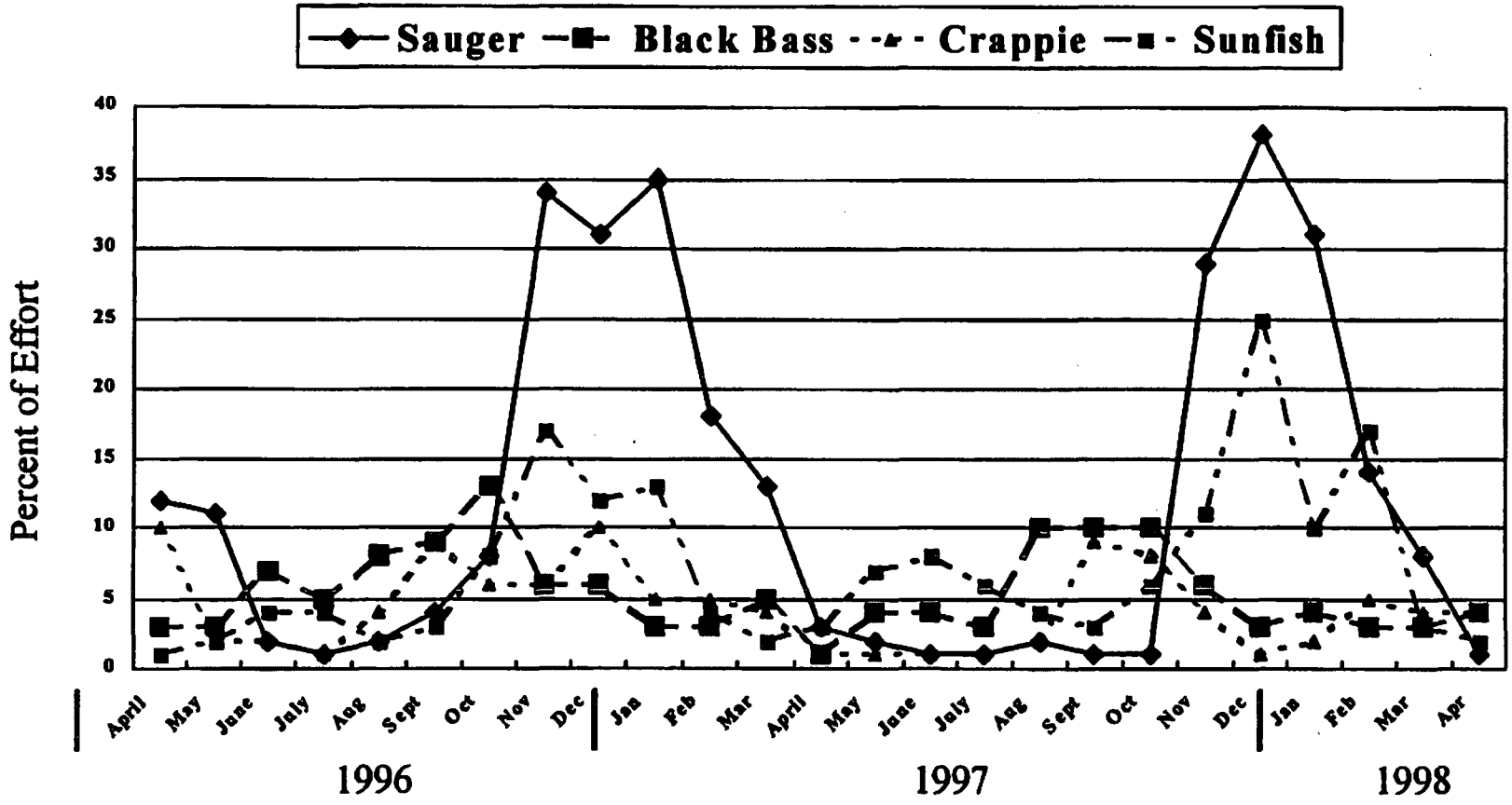


Figure 2-4. Percent of angler effort for selected directed species groups from the Watts Bar tailwater fishery, April 1996 through April 1998.

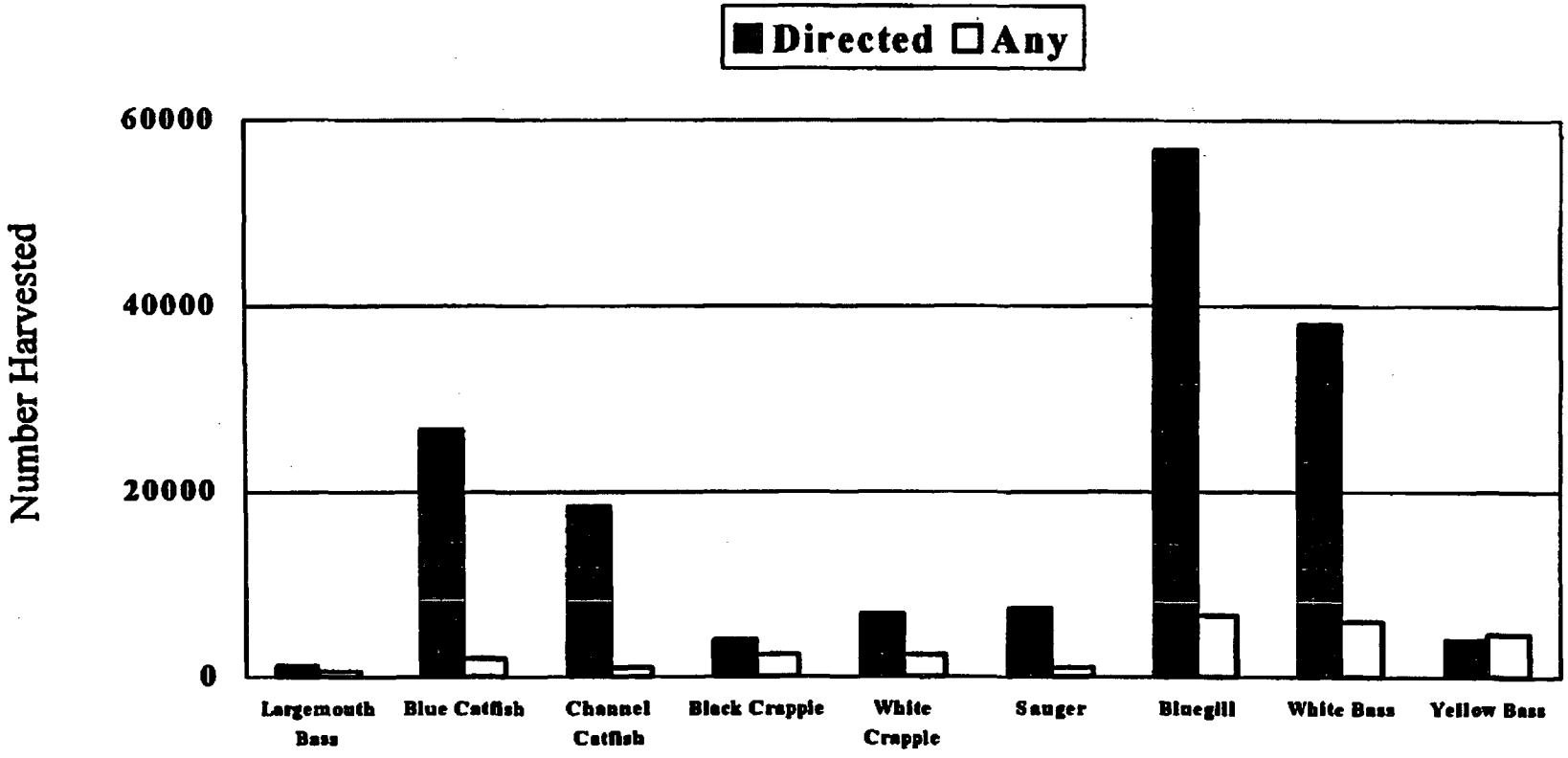


Figure 2-5. Estimated number of fish harvested in the Watts Bar Tailwater by directed and any species groups, April 1996 through April 1998.

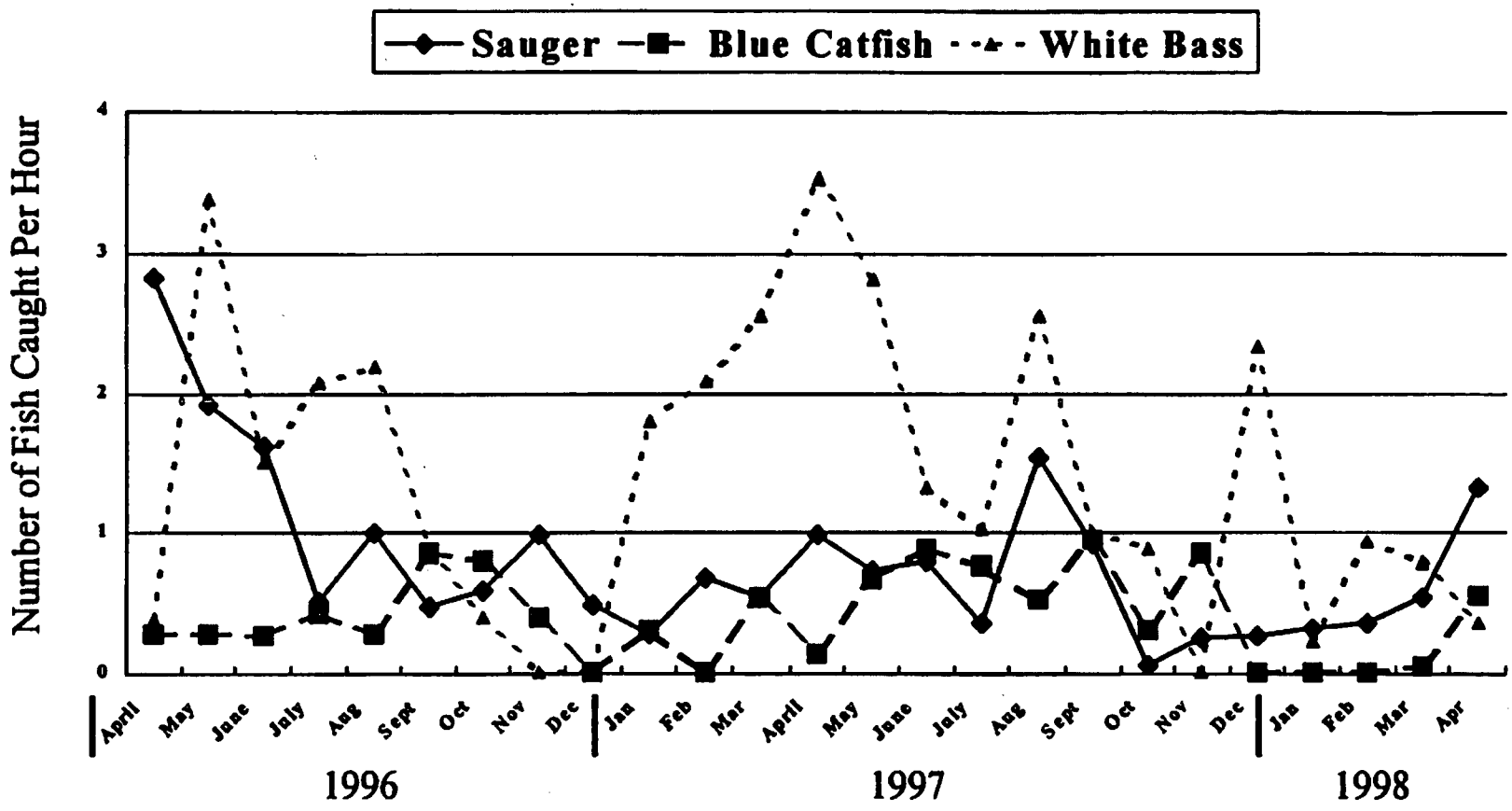


Figure 2-6. Monthly catch rate for selected species from the Watts Bar Tailwater, April 1996 through April 1998.

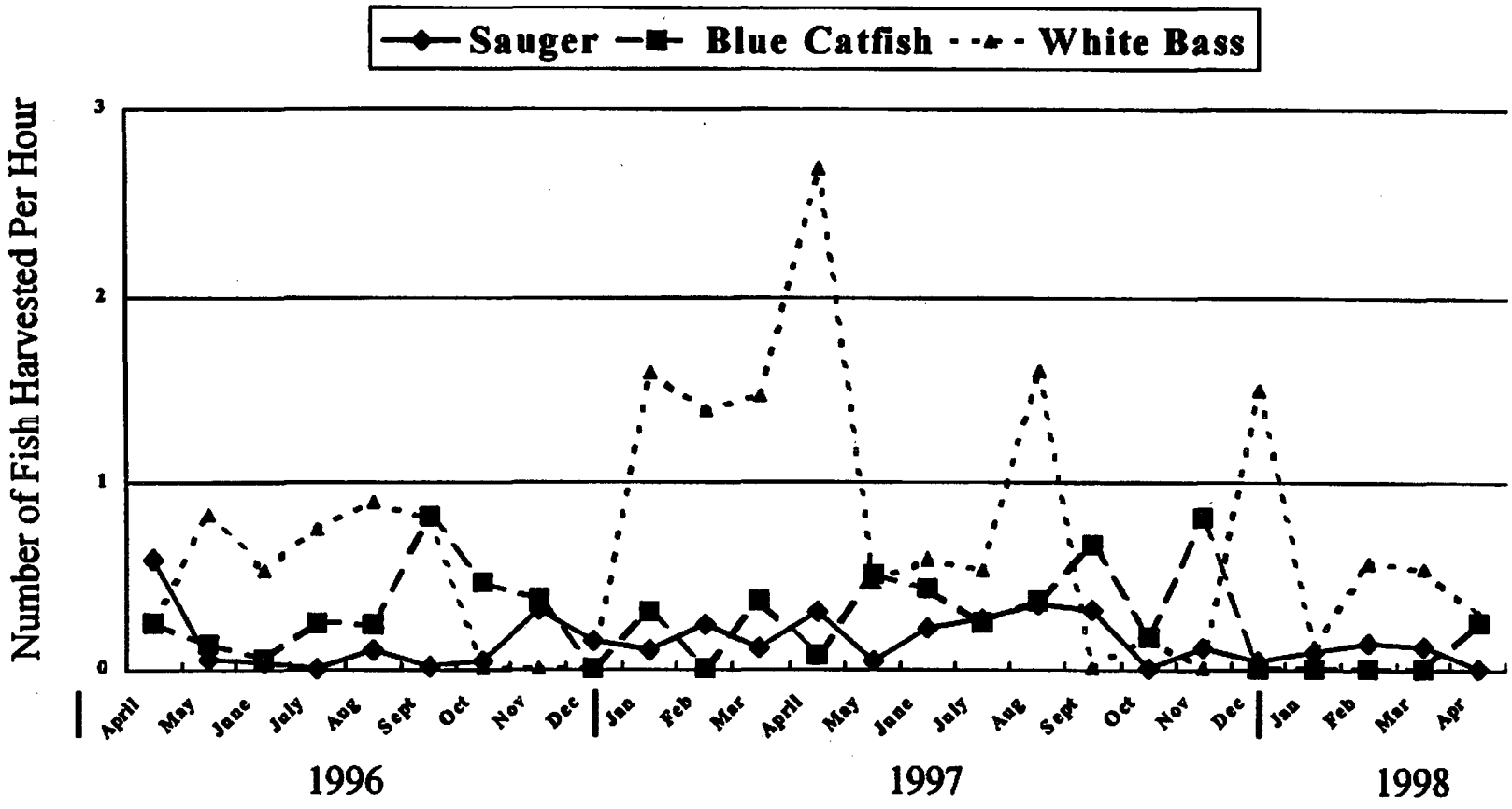


Figure 2-7. Monthly harvest rate for selected species from the Watts Bar Tailwater, April 1996 through April 1998.

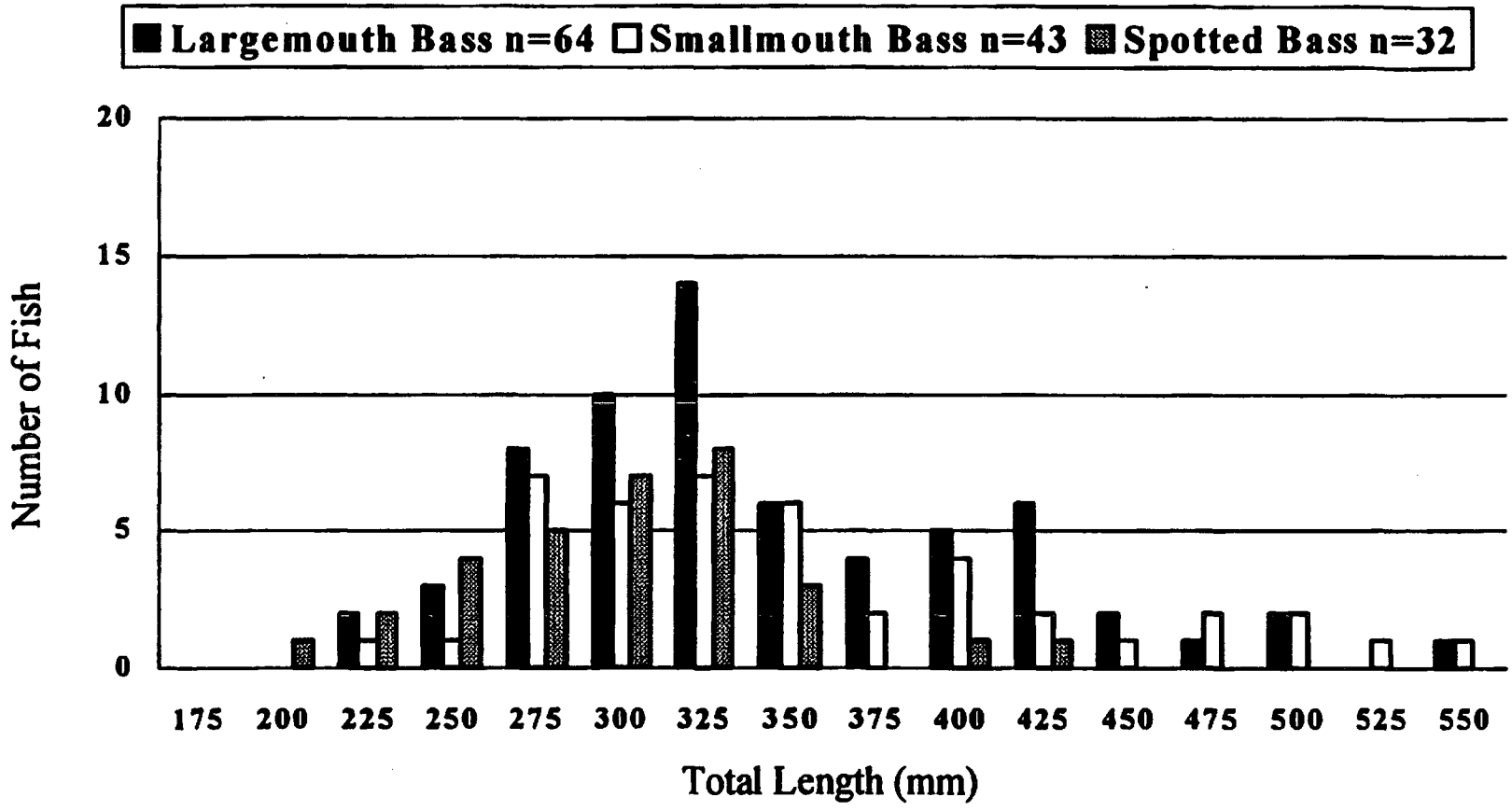


Figure 2-8. Length frequency of angler-harvested black basses sampled during creel surveys in Watts Bar Tailwater, April 1996 through April 1998.

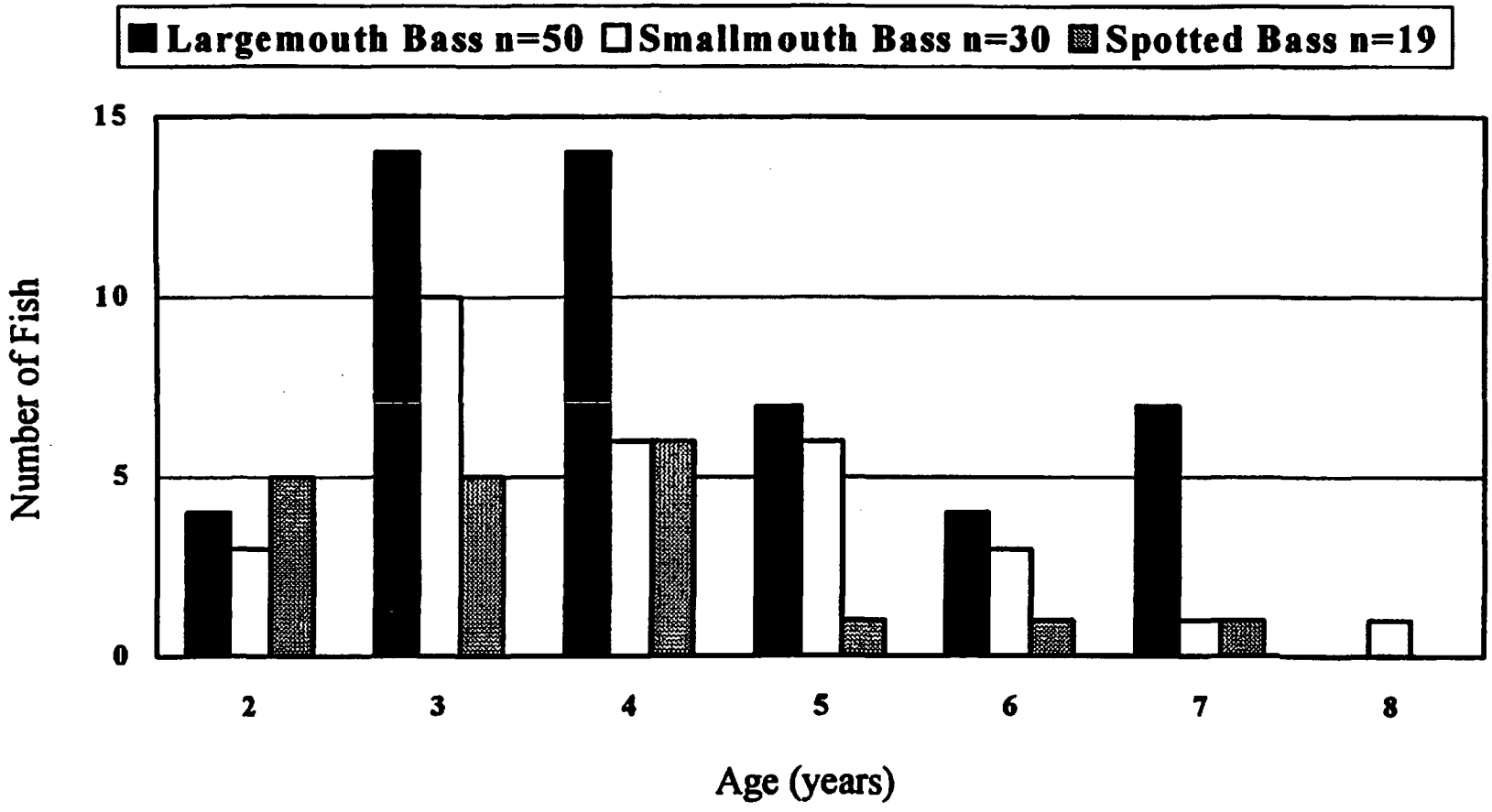


Figure 2-9. Age frequency of harvested black basses from Watts Bar Tailwater, April 1996 through April 1998.

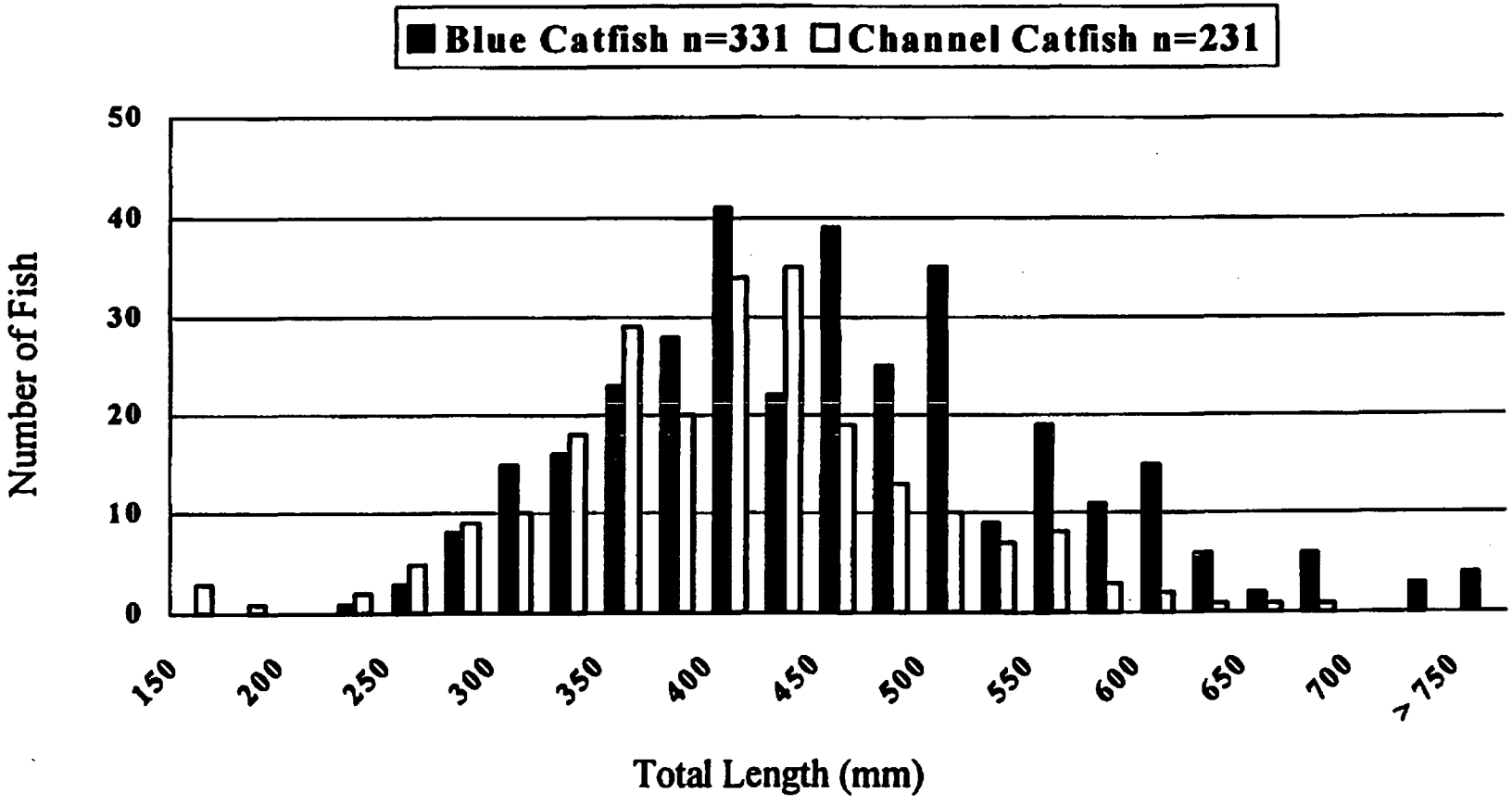


Figure 2-10. Length frequency of angler-harvested blue catfish and channel catfish from the Watts Bar Tailwater, April 1996 through April 1998.

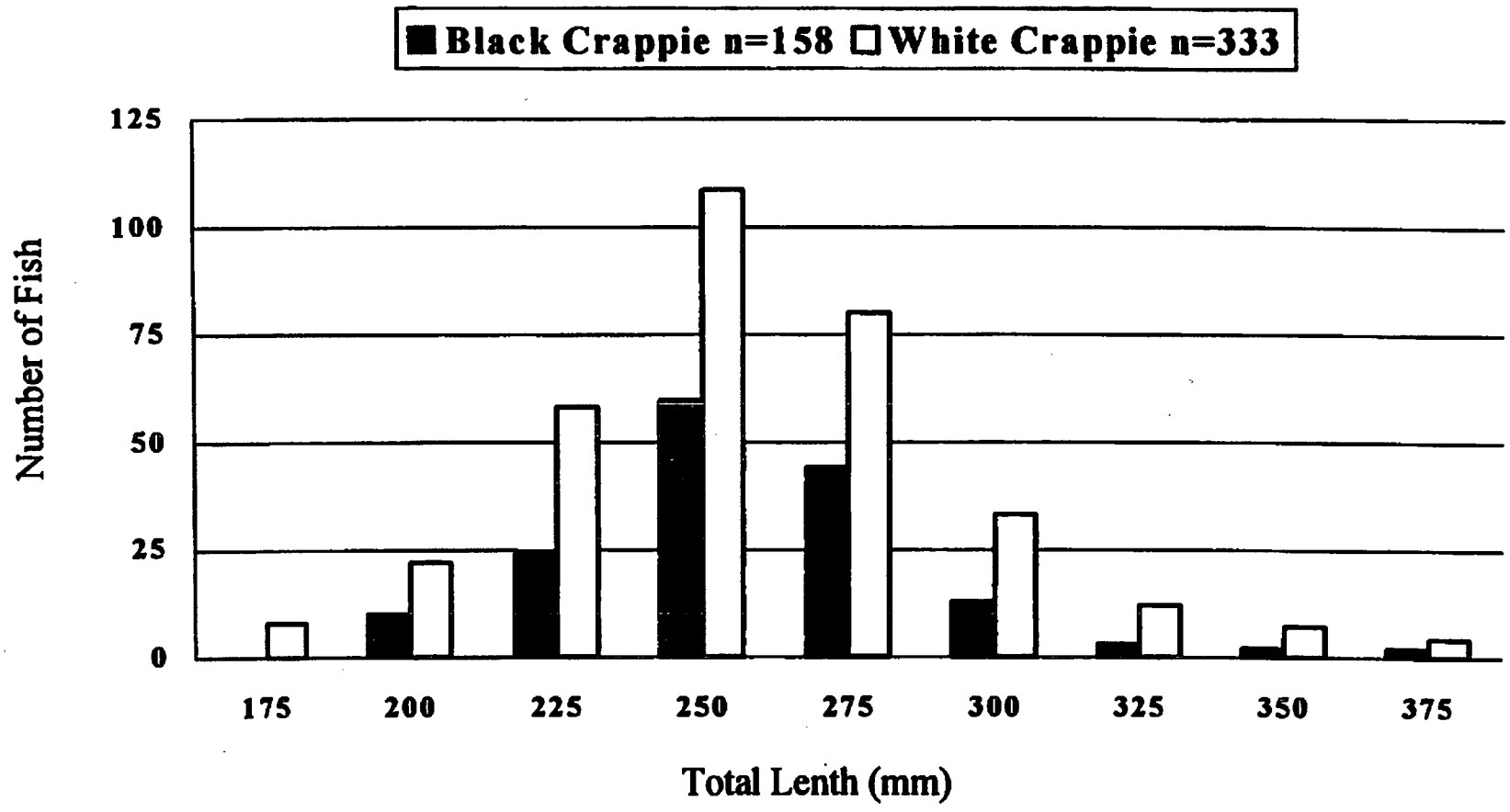


Figure 2-11. Length frequency of angler-harvested black and white crappie from the Watts Bar Tailwater, April 1996 through April 1998.

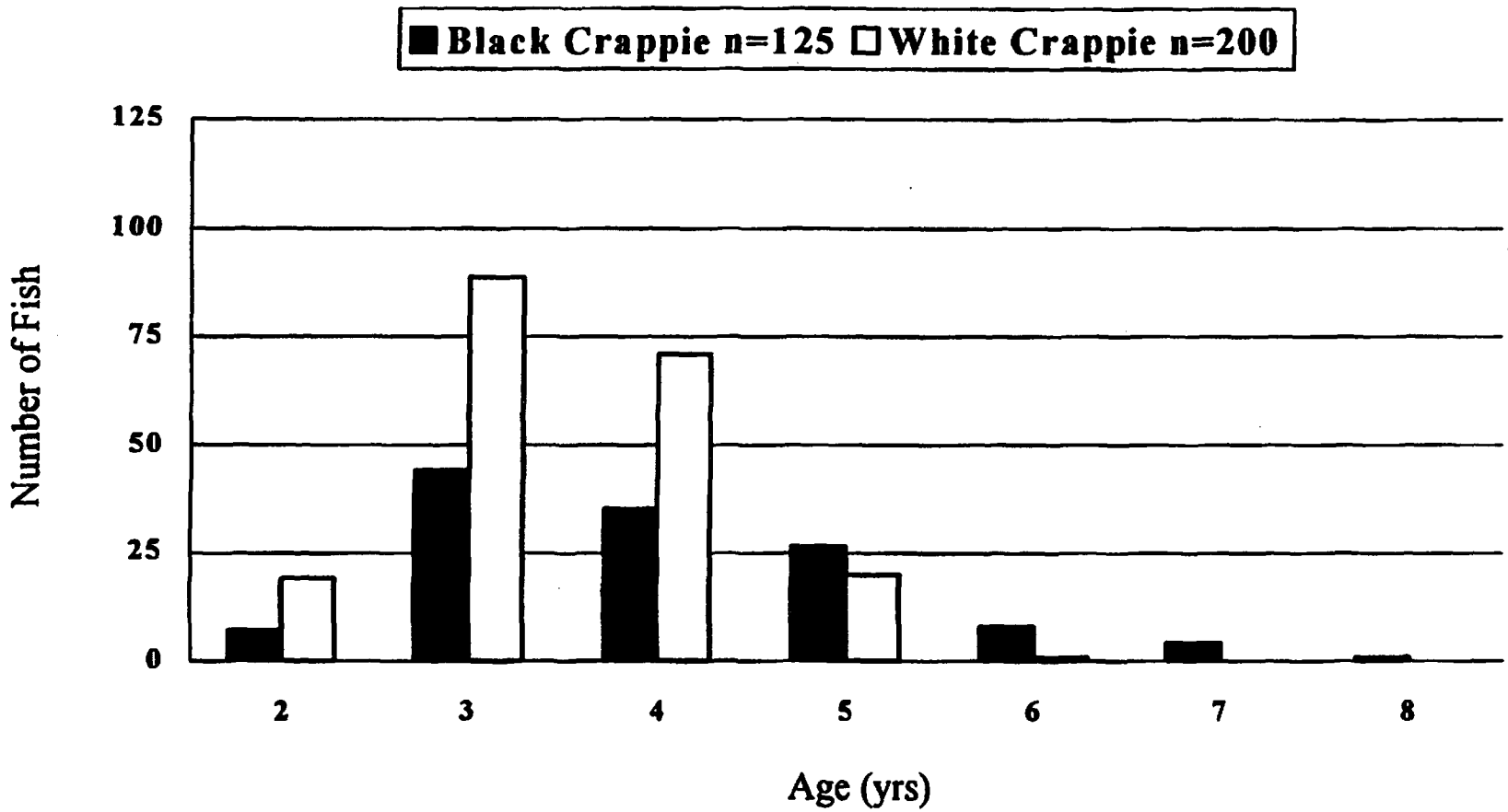


Figure 2-12. Age distribution of angler-harvested black and white crappie from the Watts Bar Tailwater, April 1996 through April 1998.

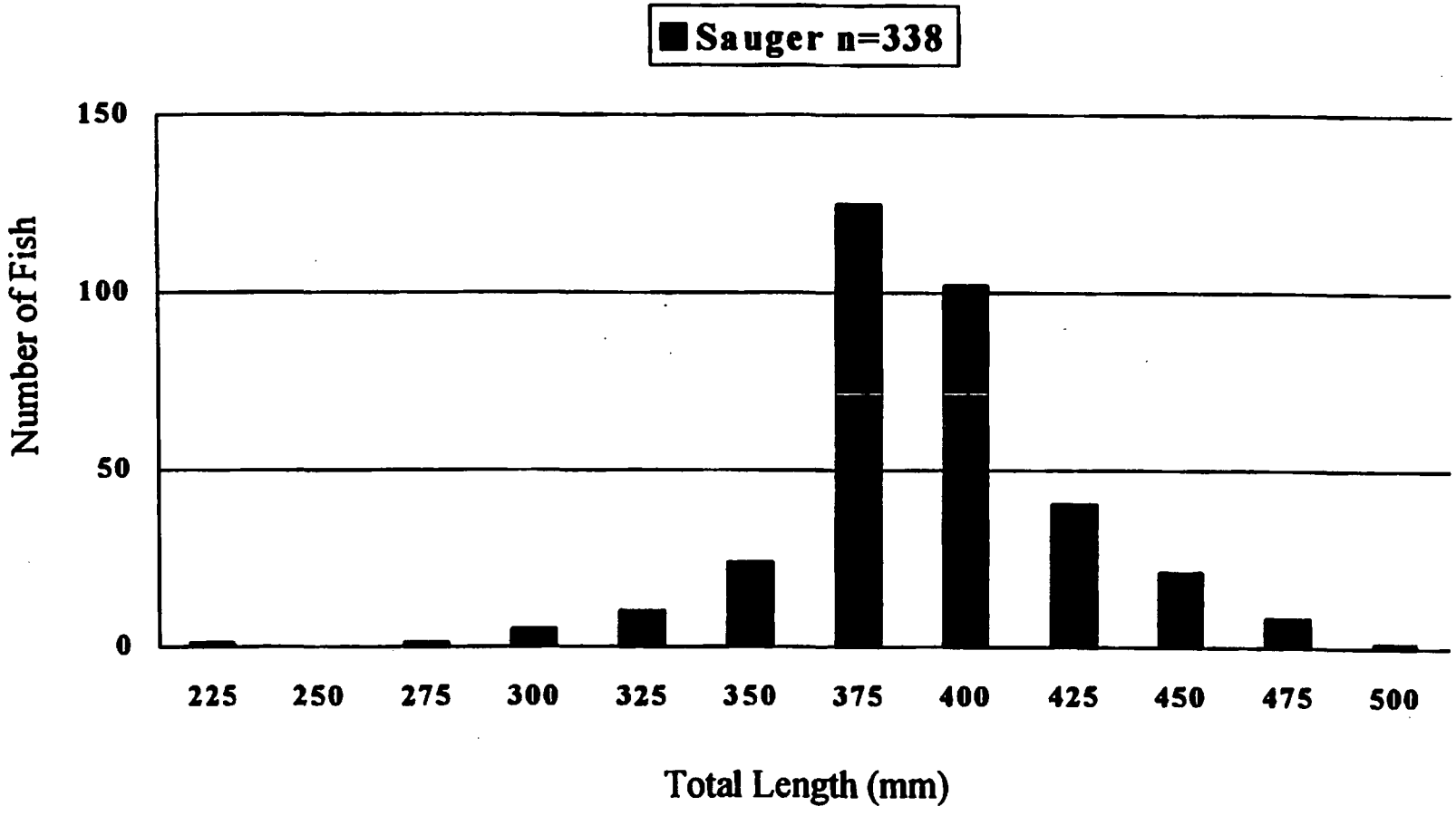


Figure 2-13. Length frequency of angler-harvested sauger from Watts Bar Tailwater, April 1996 through April 1998.

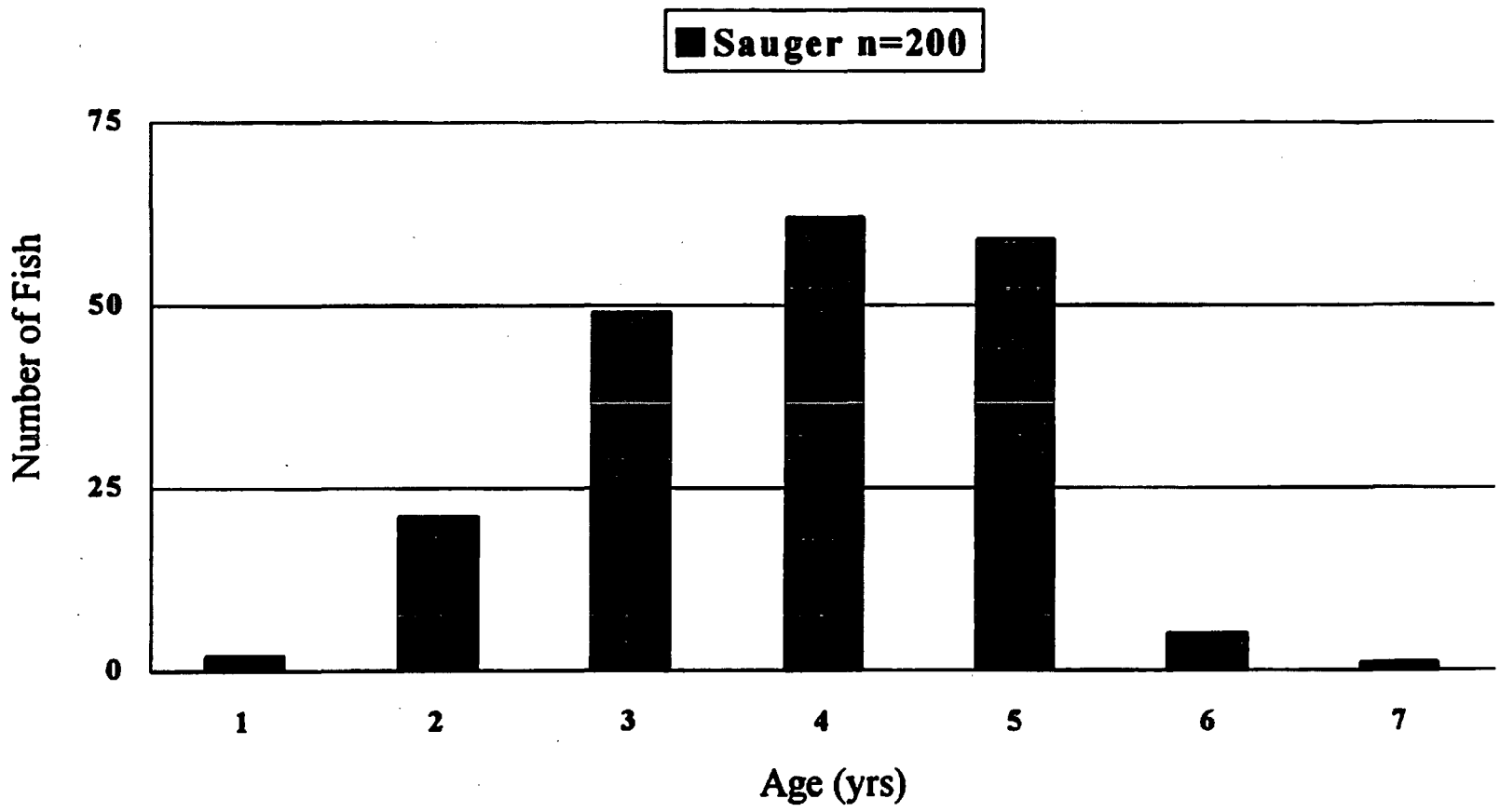


Figure 2-14. Age distribution of angler-harvested sauger from Watts Bar Tailwater, April 1996 through April 1998.

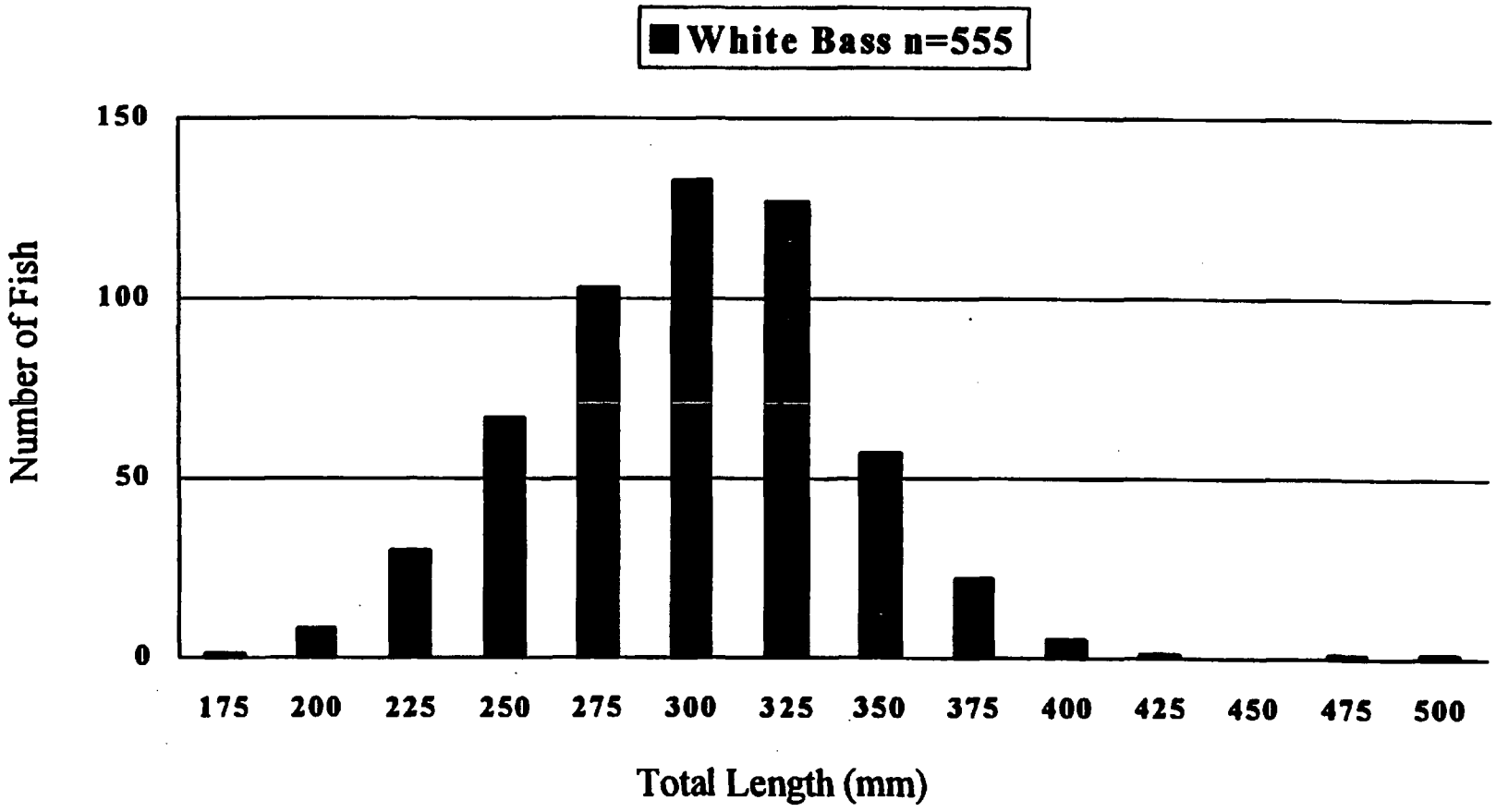


Figure 2-15. Length frequency of angler-harvested white bass from Watts Bar Tailwater, April 1996 through April 1998.

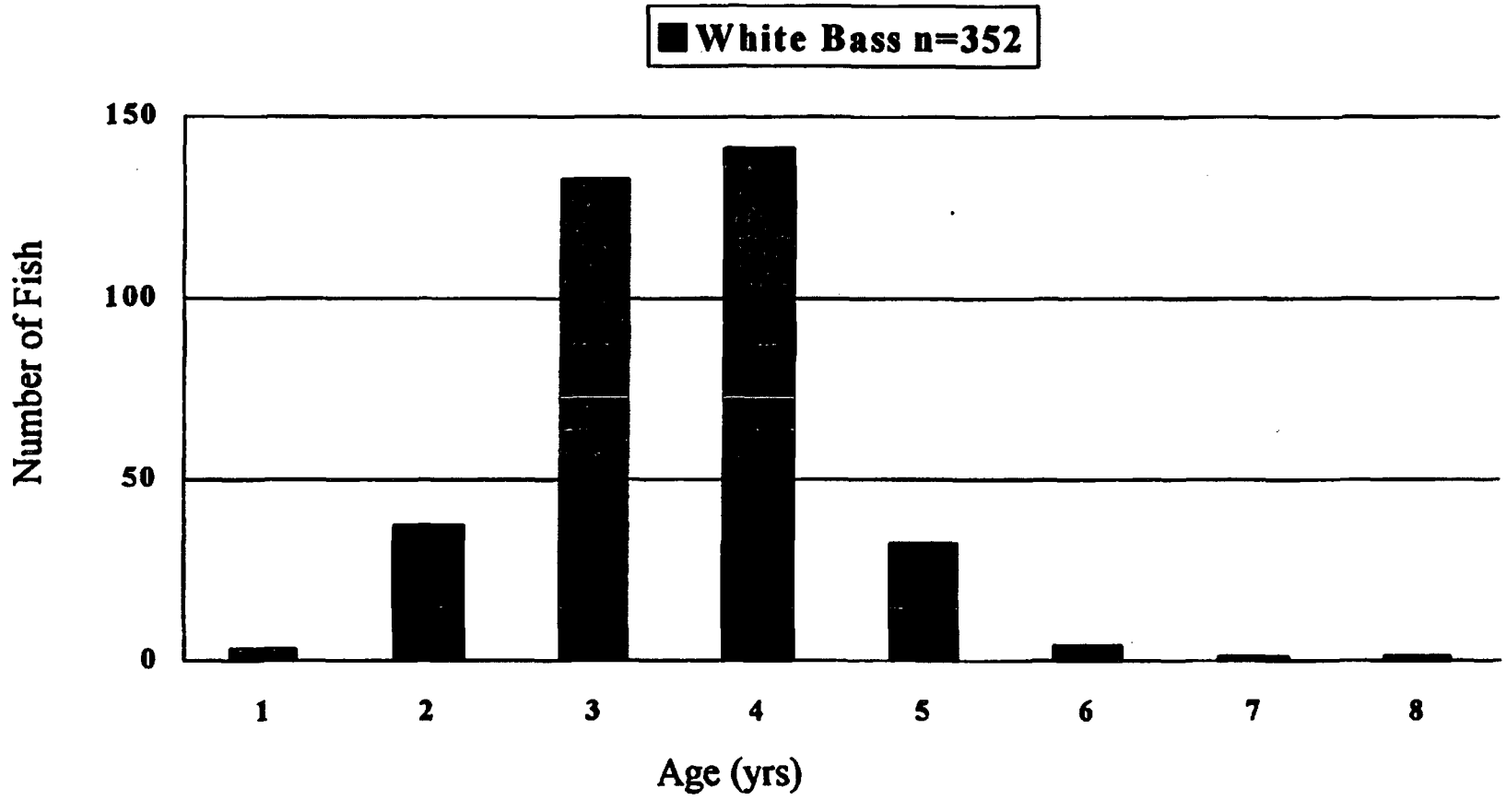


Figure 2-16. Age distribution of angler-harvested white bass from Watts Bar Tailwater, April 1996 through April 1998.

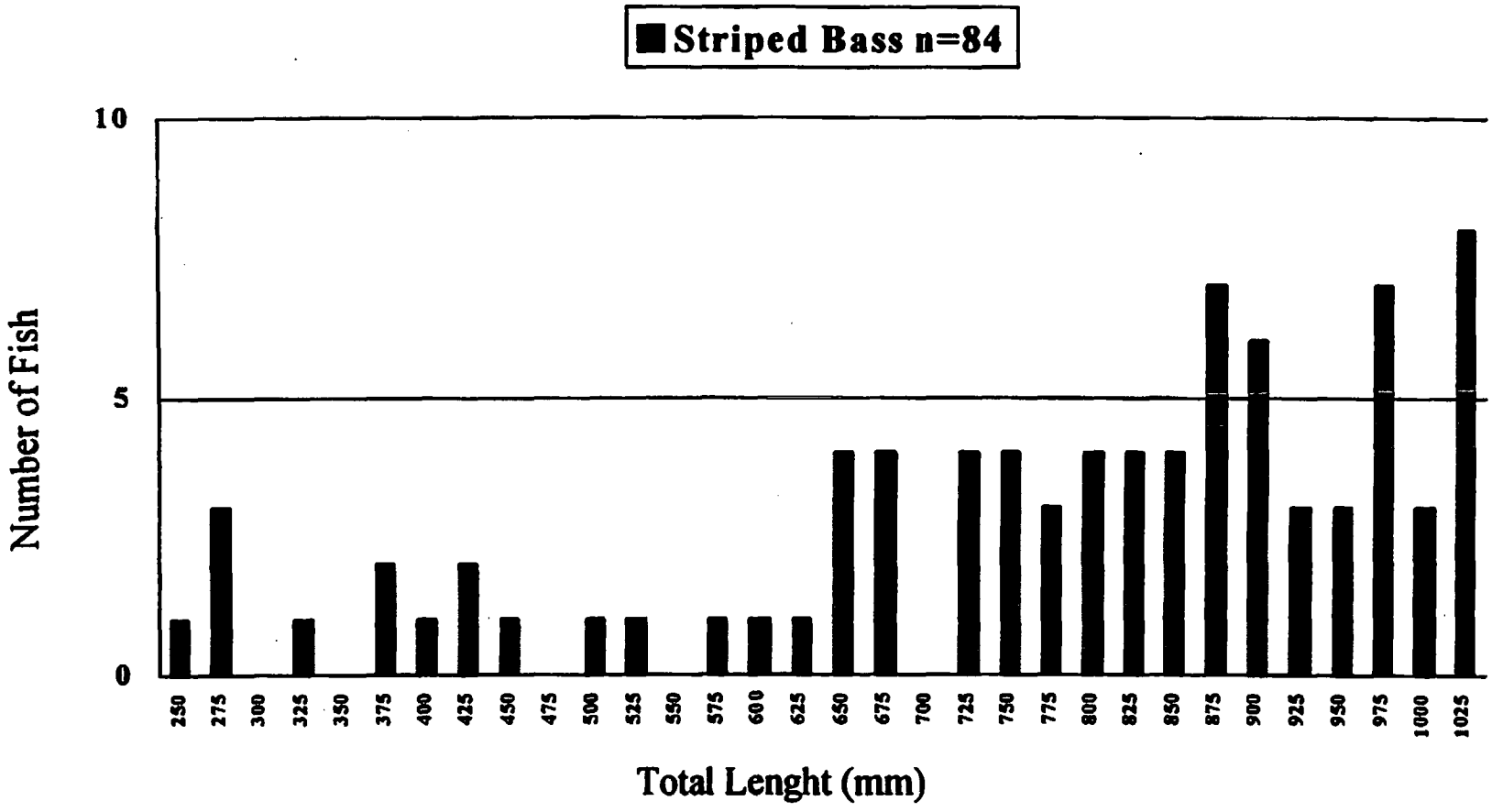


Figure 2-17. Length frequency of angler-harvested striped bass from Watts Bar Tailwater, April 1996 through April 1998.

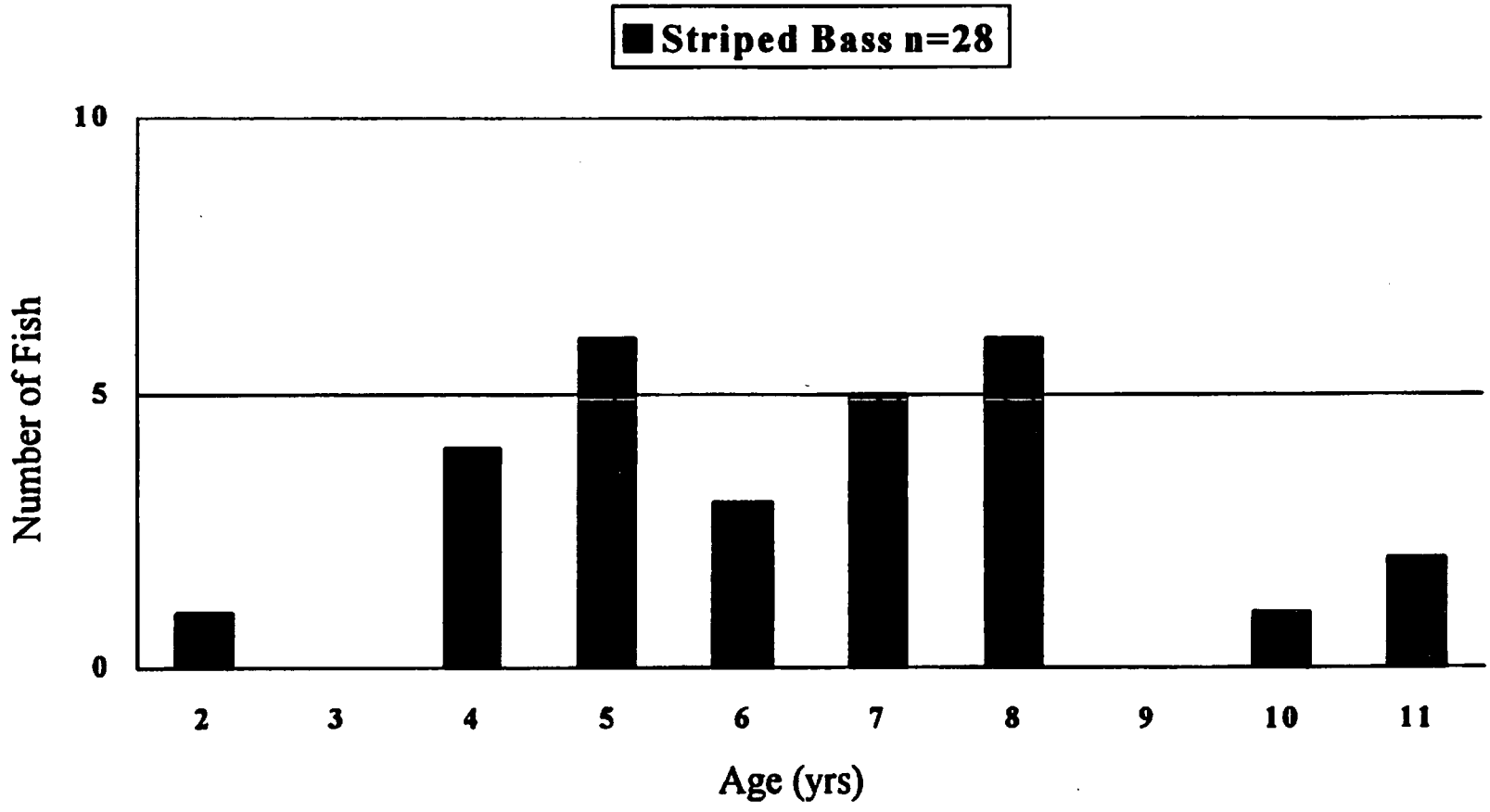


Figure 2-18. Age distribution of angler-harvested striped bass from Watts Bar Tailwater, April 1996 through April 1998.

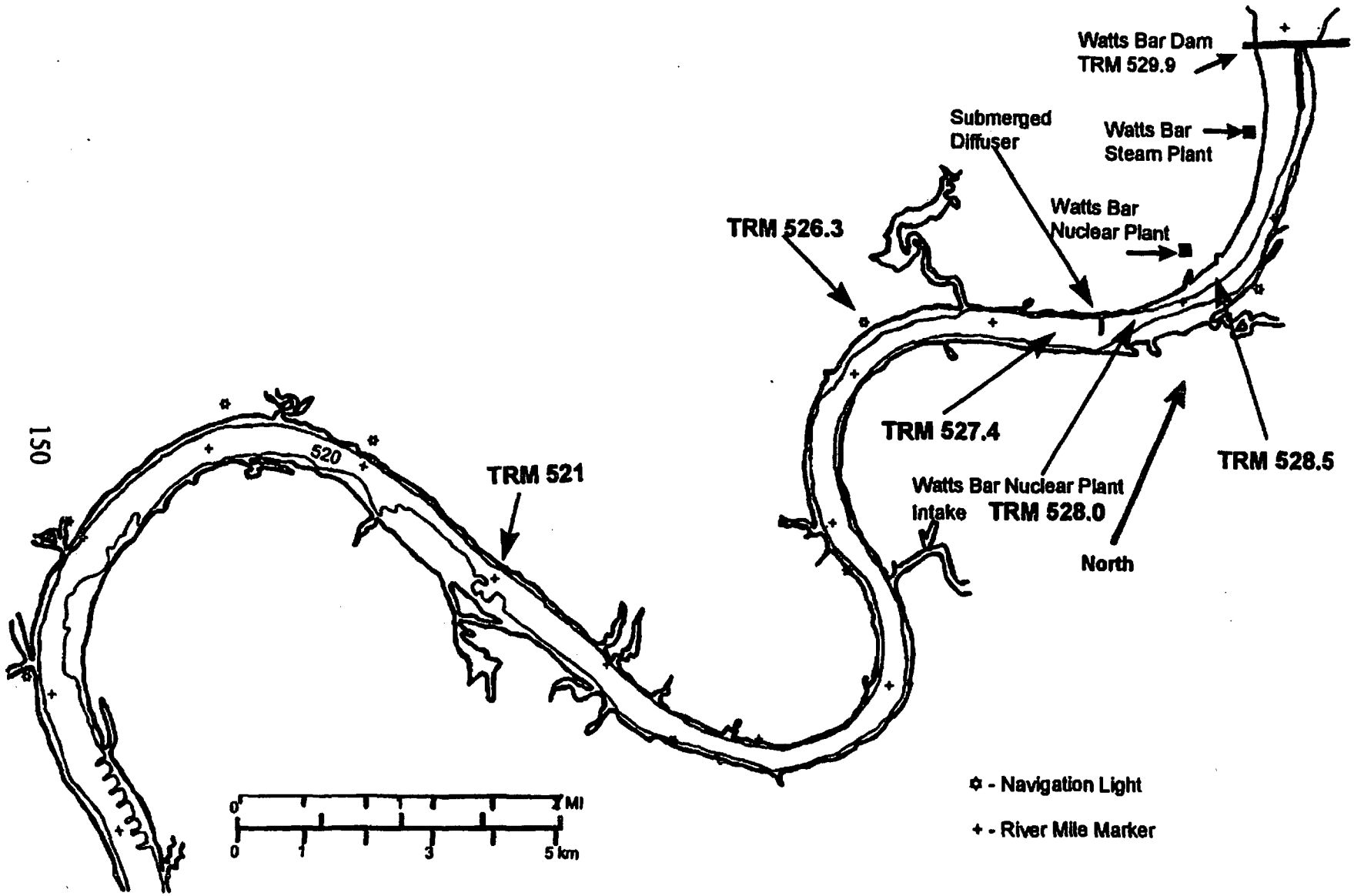


Figure 3-1. Sample locations for benthic macroinvertebrates near Watts Bar Nuclear Plant , 1996-1997.

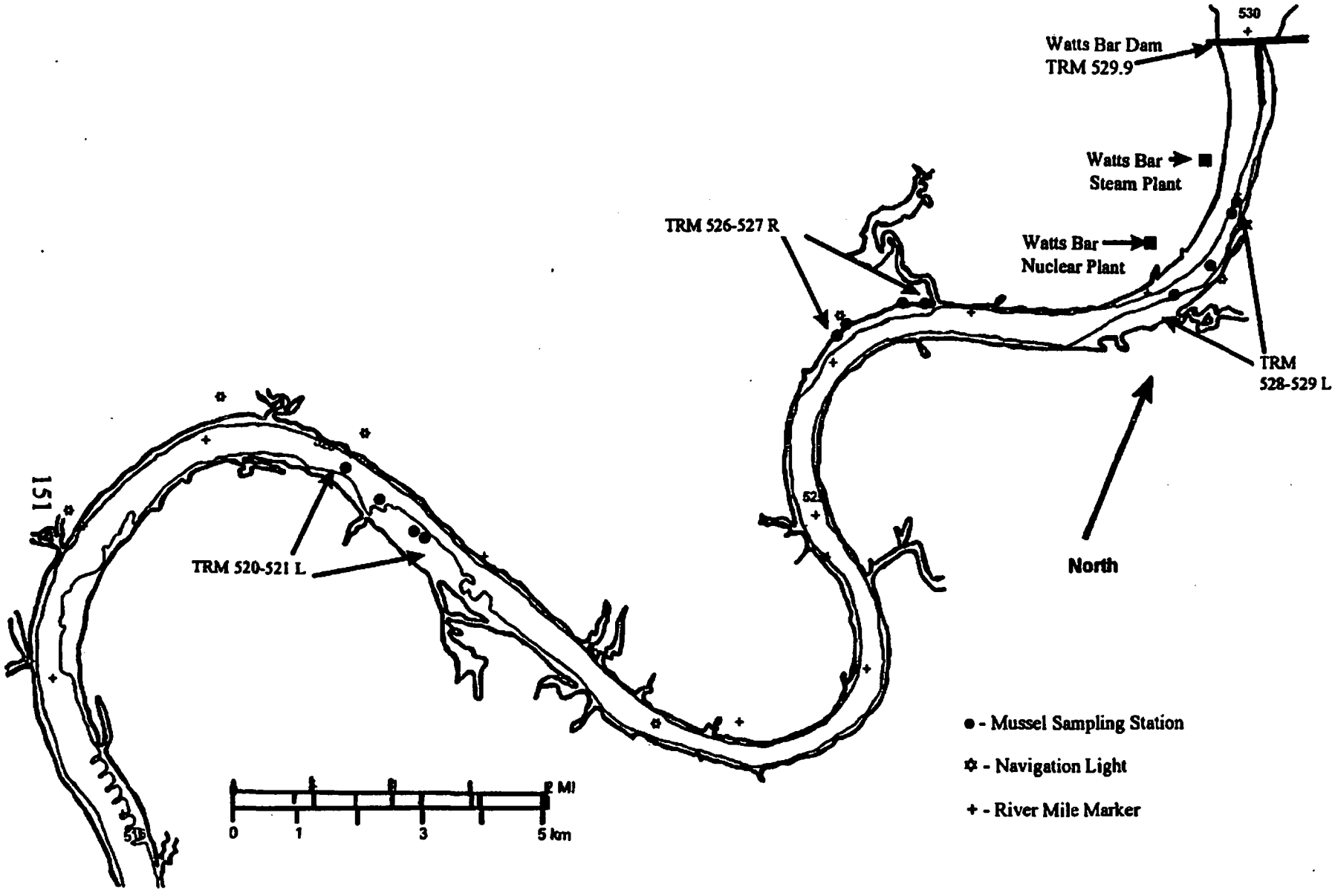


Figure 3-2. Locations of sampling stations at three native mussel beds surveyed during the preoperational (1983-1994) and operational (1996 and 1997) monitoring program for Watts Bar Nuclear Plant.

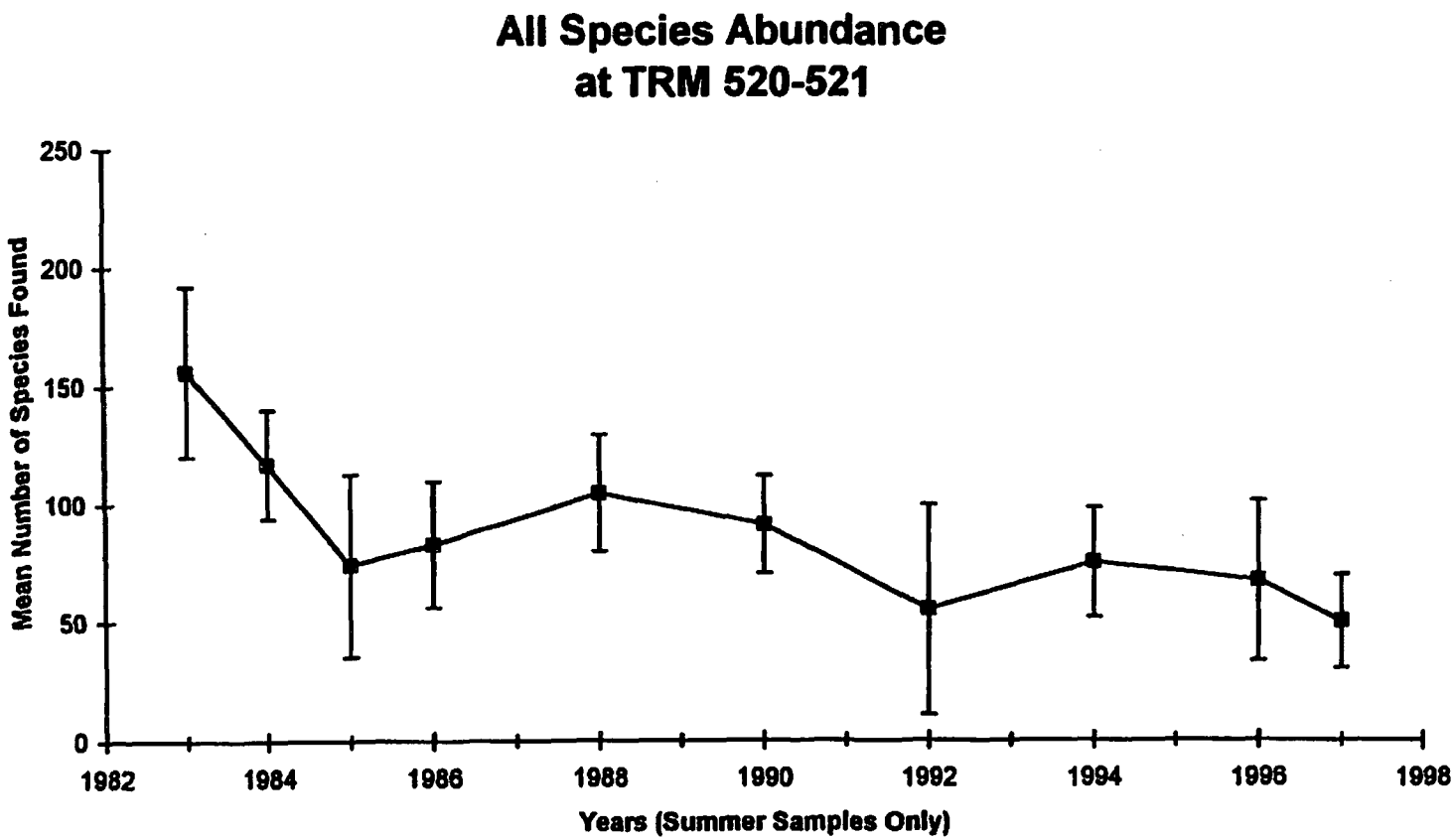


Figure 3-3. Relationships among the mean numbers of all mussel species encountered on the bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values.

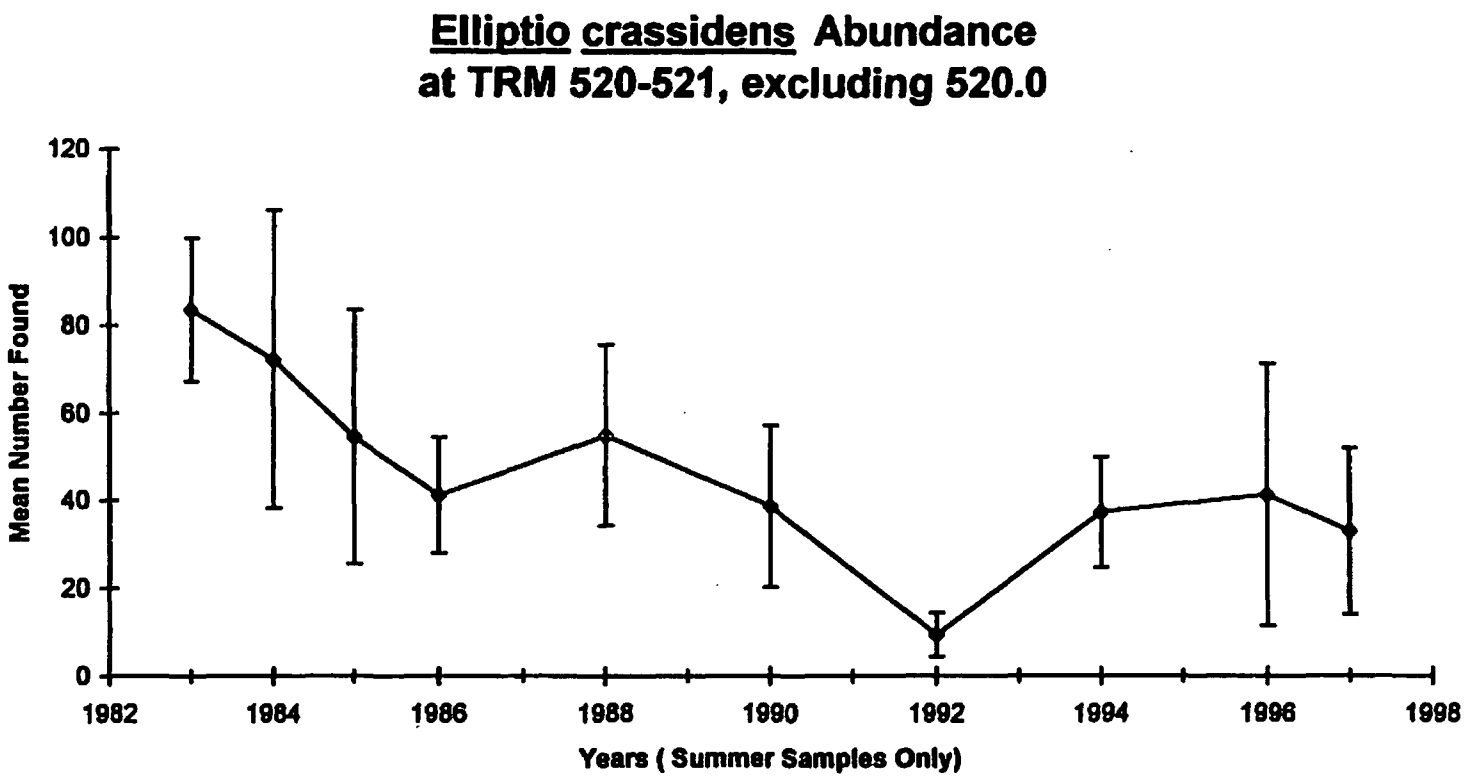


Figure 3-4. Relationships among the mean numbers of Elliptio crassidens encountered on three of the four sampling sites on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values.

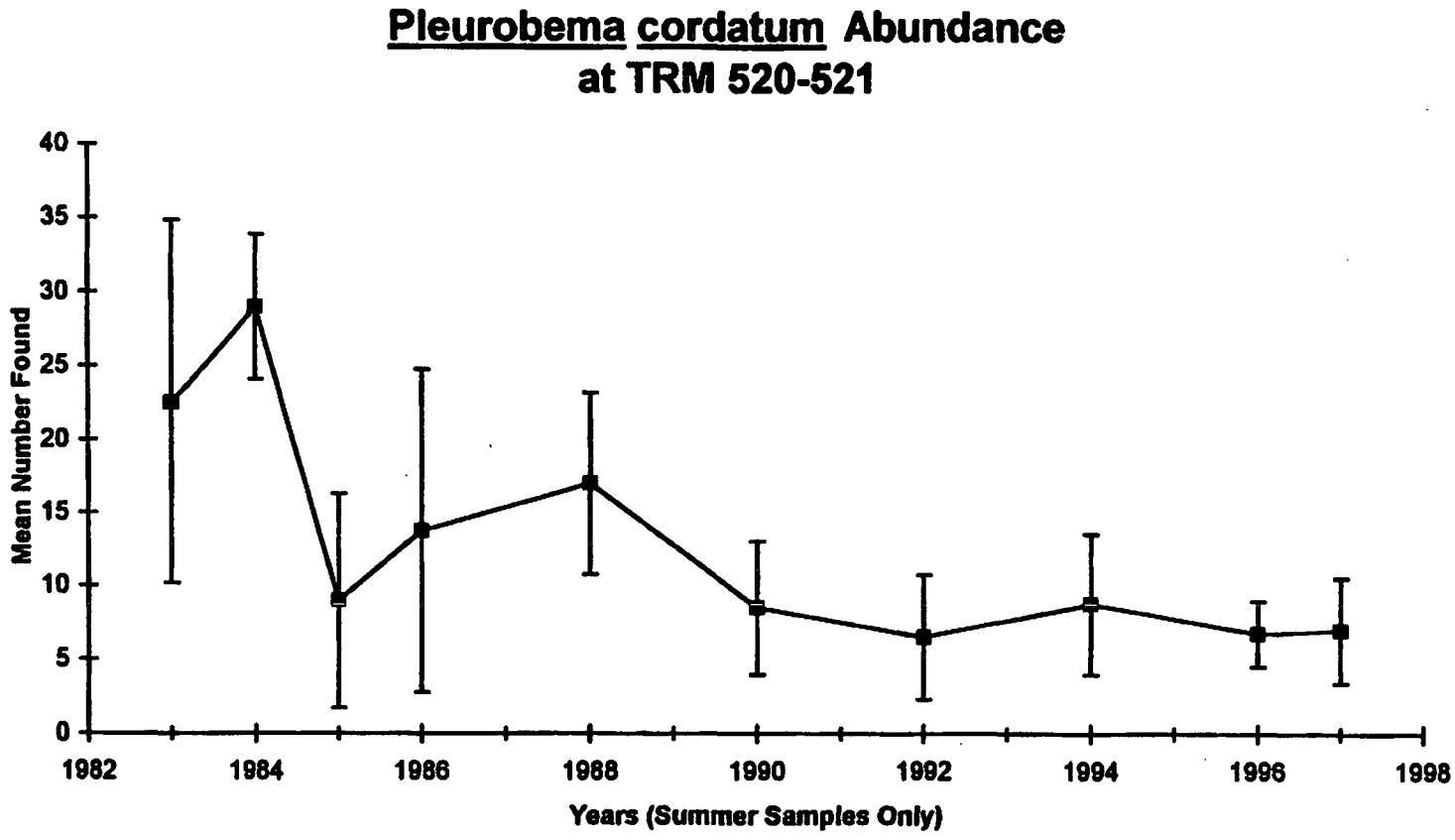


Figure 3-5. Relationships among the mean numbers of Pleurobema cordatum encountered on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values.

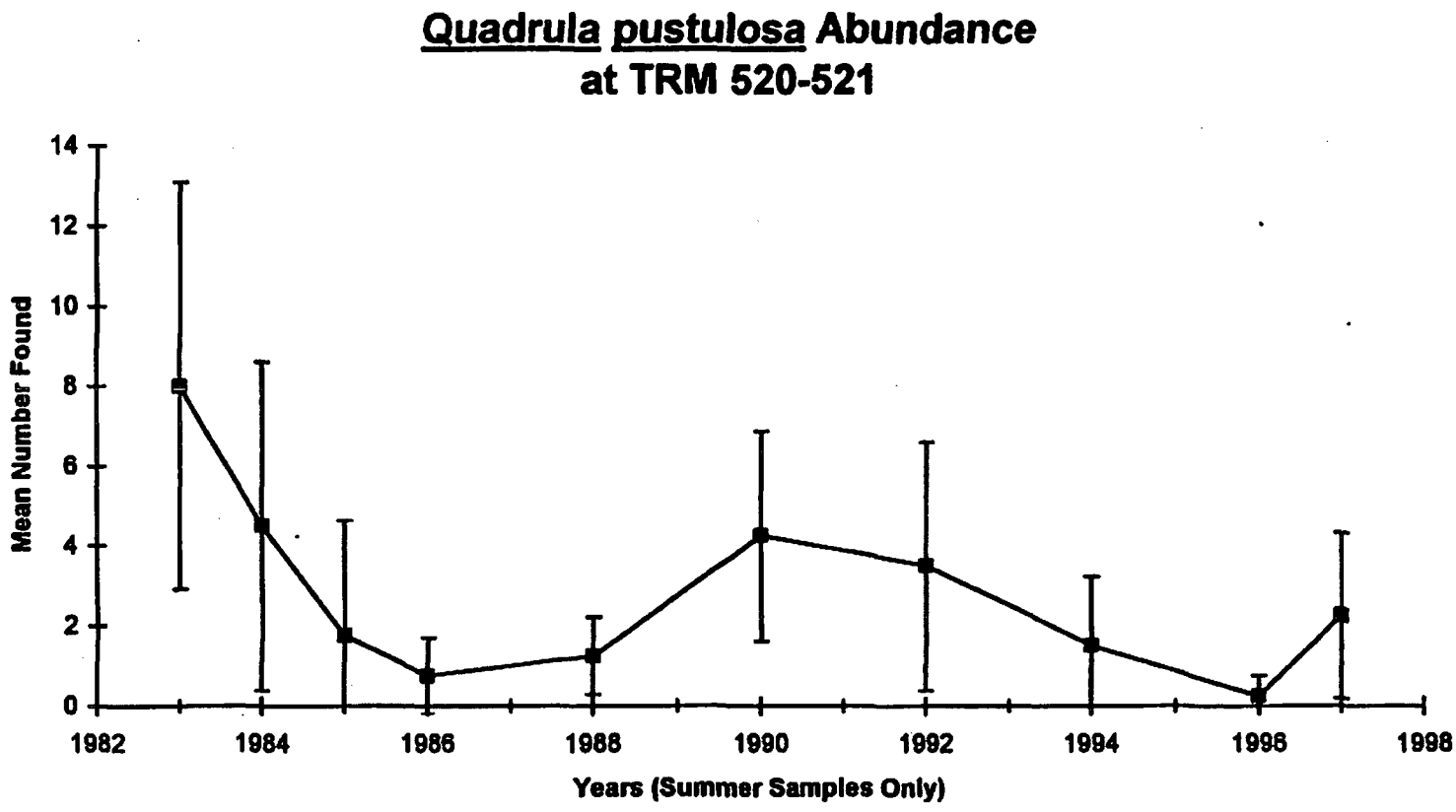


Figure 3-6. Relationships among the mean numbers of Quadrula pustulosa encountered on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values.

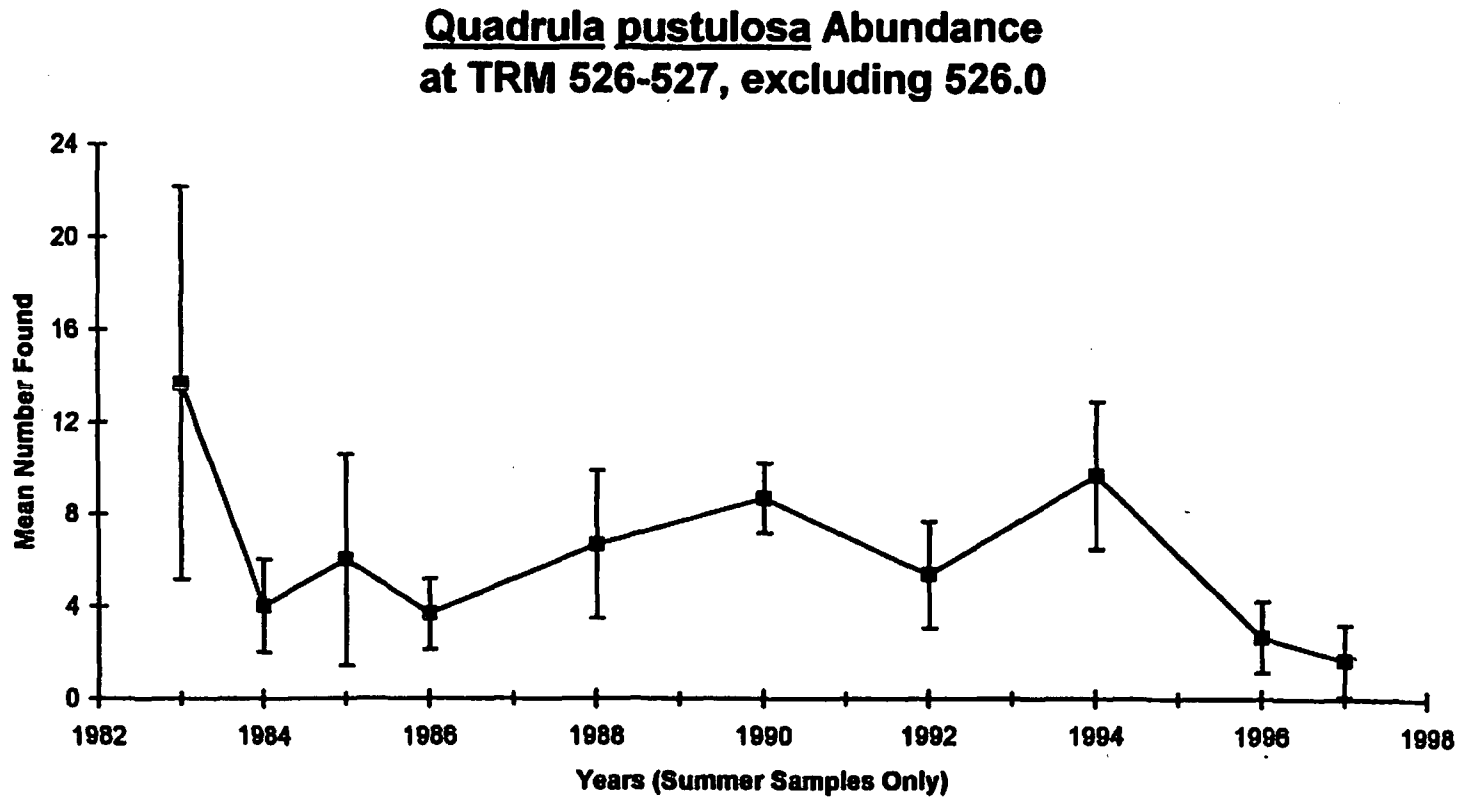


Figure 3-7. Relationships among the mean numbers of Quadrula pustulosa encountered on three of the four sampling sites on the mussel bed at Tennessee River Mile 526-527 during the 10 surveys conducted in the summers of 1983-1997. Vertical bars indicate one standard deviation above and below the mean values.

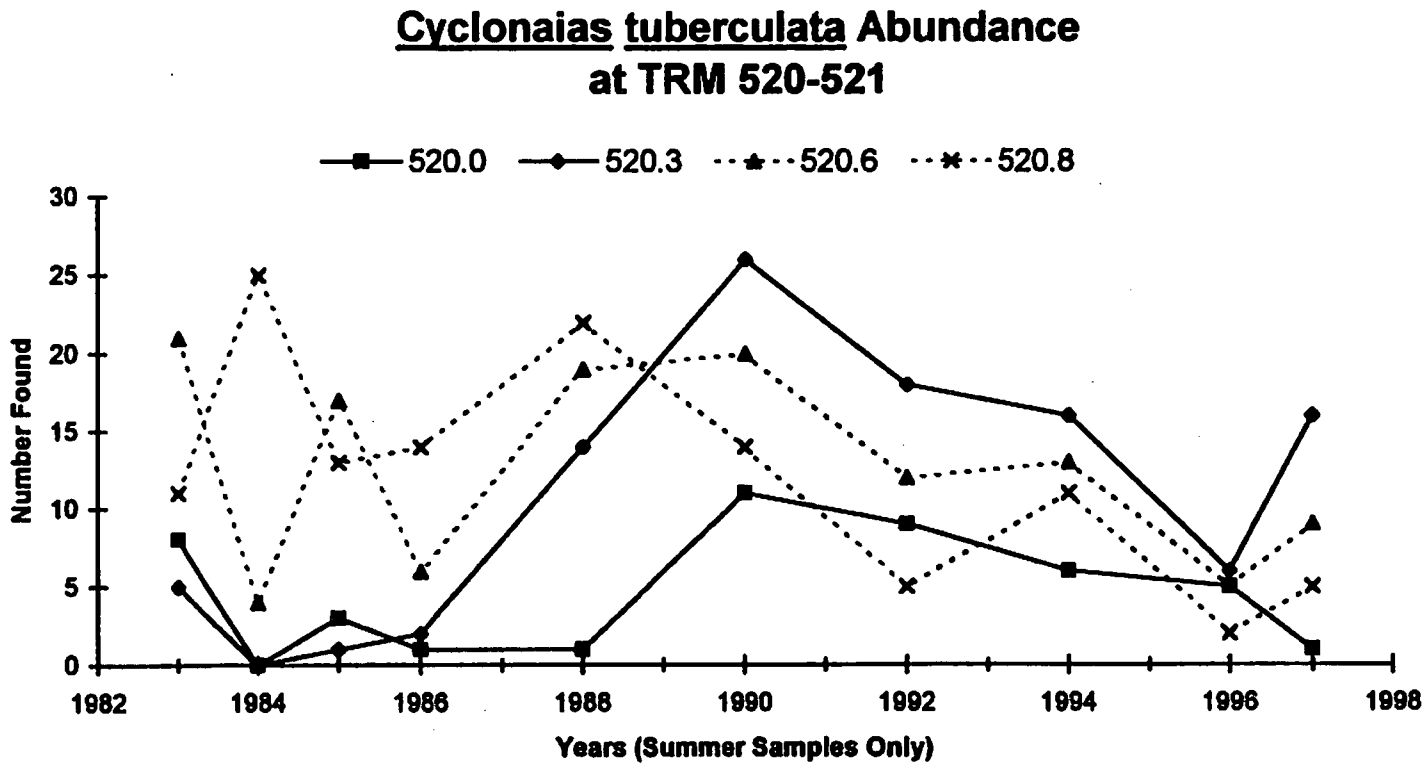


Figure 3-8. Relationships among the numbers of Cyclonaias tuberculata encountered at the four sampling sites on the mussel bed at Tennessee River Mile 520-521 during the 10 surveys conducted in the summers of 1983-1997. While statistically significant trends are present in these data, the slopes of those trends are not parallel with each other.

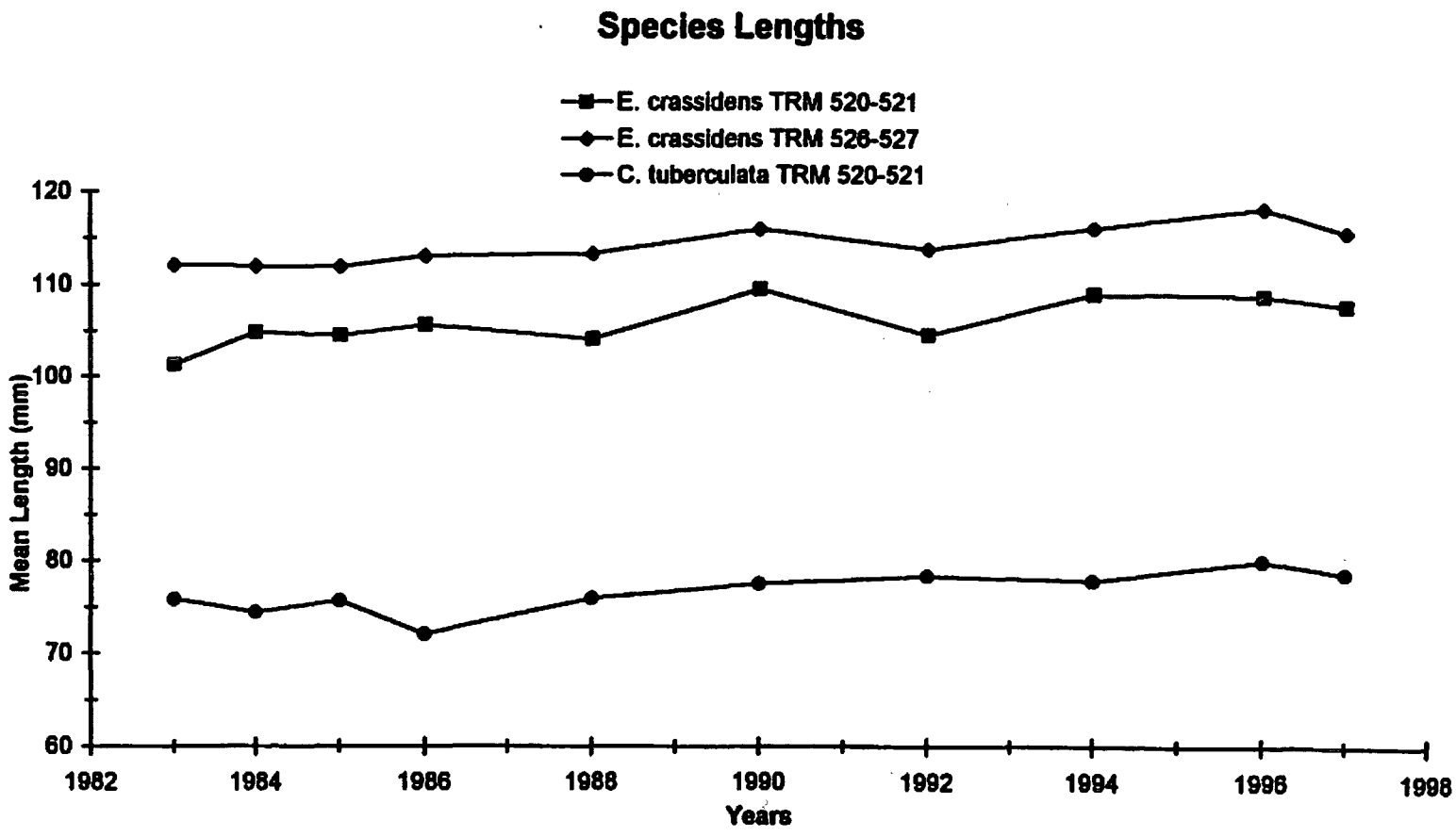


Figure 3-9. Mean lengths of Elliptio crassidens and Cyclonaias tuberculata on the mussel bed at Tennessee River Miles (TRM) 520-521, and Elliptio crassidens on the bed at TRM 526-527 during 1983-1997.

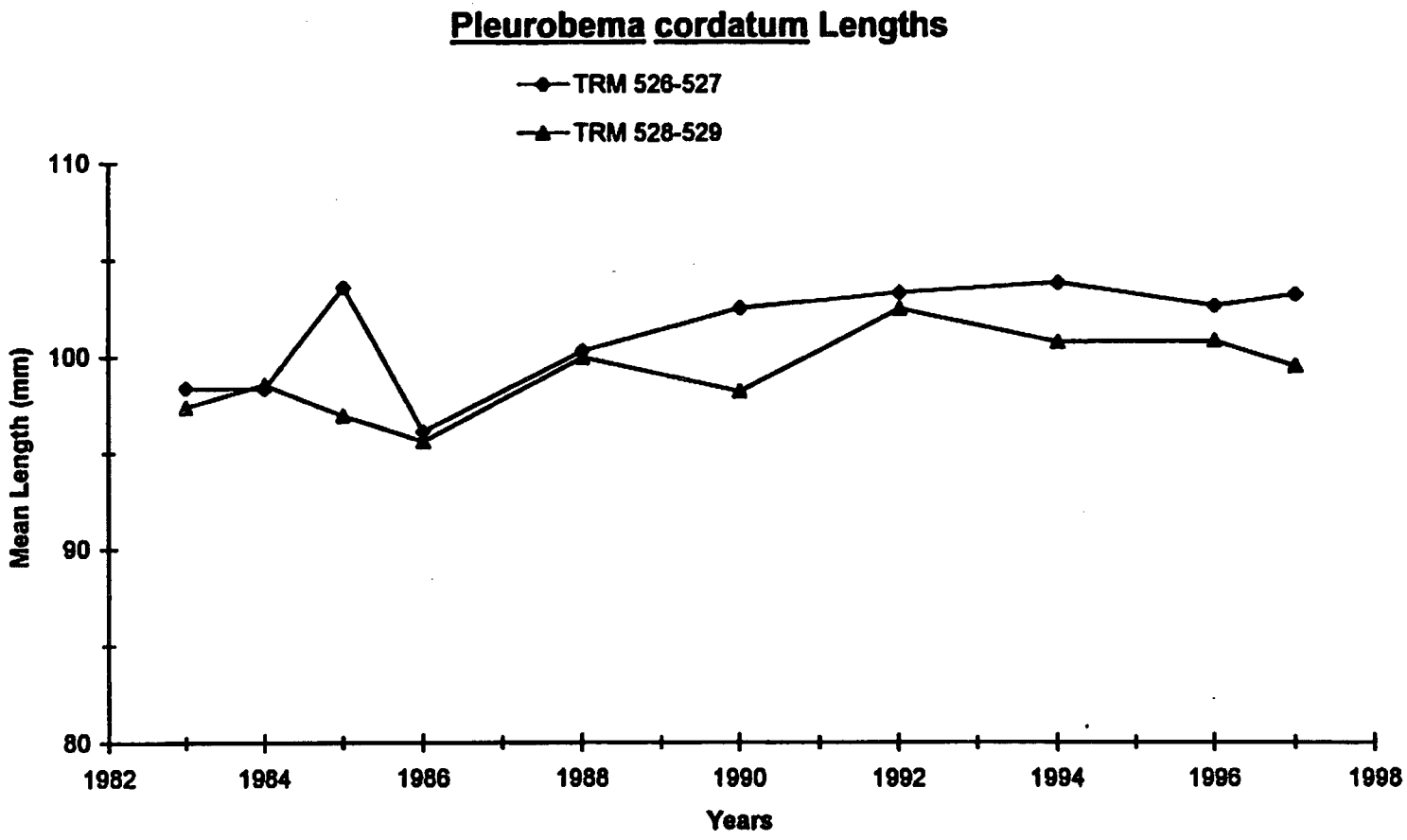


Figure 3-10. Mean lengths of Pleurobema cordatum on two mussel beds, Tennessee River Miles (TRM) 526-527 and TRM 528-529, during 1983-1997.

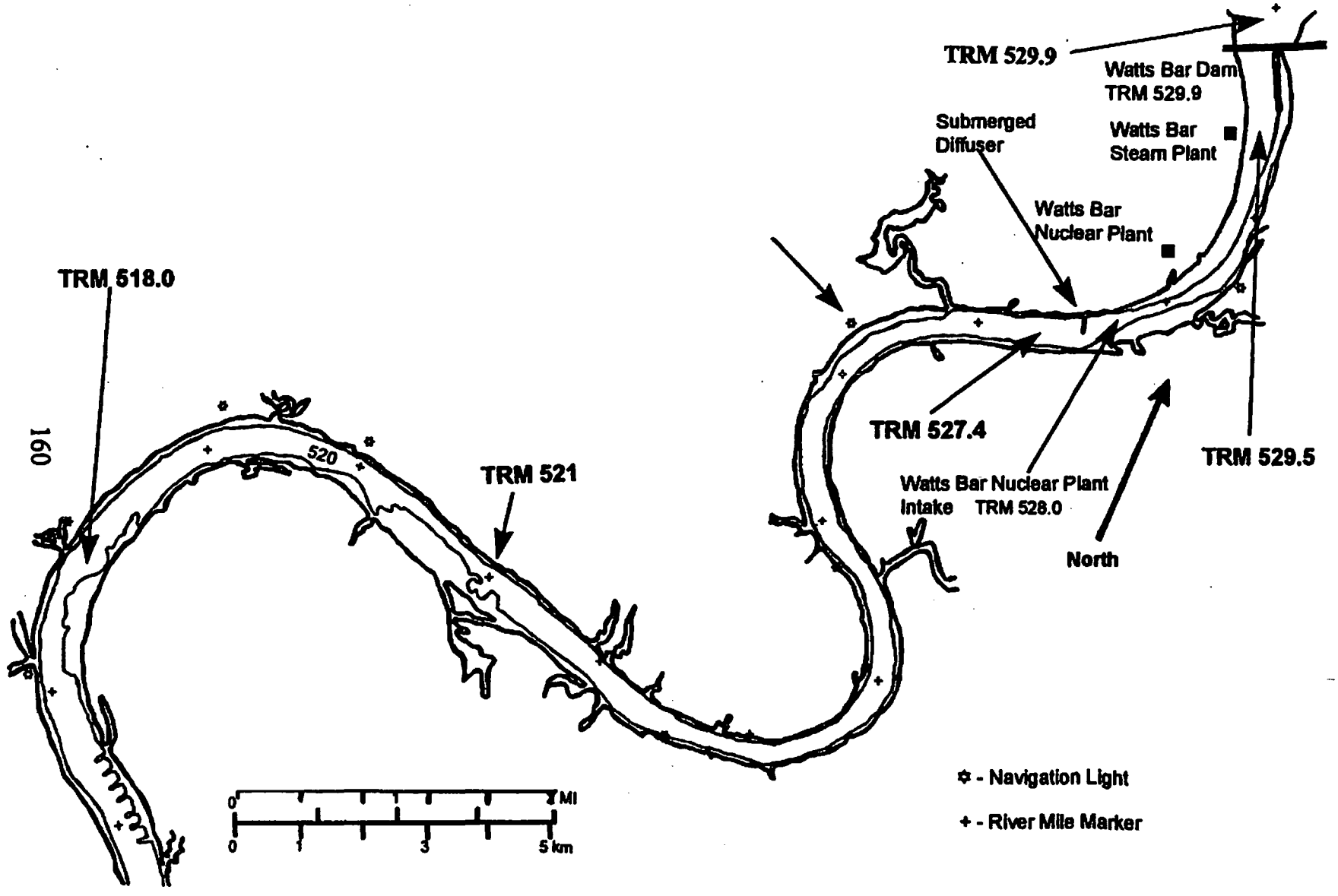


Figure 4-1. Water quality sampling locations during operational monitoring at Watts Bar Nuclear Plant, 1996 and 1997.

Appendices A

Appendix A-1. List of scientific names and densities (number/m^2) of benthic macroinvertebrates collected at five locations in the vicinity of Watts Bar Nuclear Plant during operational monitoring in summer and fall 1996-1997.

Date	July 1996					October 1996				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Nematoda		1								
Hydrozoa										
Hydroida										
Clavidae						6	7	9	7	2
Cordylophora lacustris										
Hydridae										
Hydra americana	4		1	4	3	252	71	2	82	297
Turbellaria										
Tricladida										
Planariidae										
Dugesia tigrina	632	208	1293	962	296	1131	1420	1103	1285	1449
Oligochaeta										
Haplotaxida										
Naididae			1					1	4	2
Dero sp.	41	56	62	37	3	31	6	6	8	34
Nais communis		1	5	1						1
Nais simplex										1
Pristina sp.				2				1	6	4
Slavina appendiculata					1				5	
Tubificidae	243	249	149	70	8	169	21	68	48	383
Branchiura sowerbyi	13	10	6			8	3	3		21
Limnodrilus hoffmeisteri	265	113	106	11		27		8	2	54
Lumbriculida										
Lumbriculidae		1								
Lumbriculus sp.									3	

Appendix A-1. (Continued)

Date	July 1996					October 1996				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Hirudinea	1	6	11	18	4	3		1		
Rhynchobdellida										
Glossiphoniidae										
Helobdella triserialis	14		1	2	2		7	5	2	9
Pharyngobdellida										
Erpobdellidae										
Erpobdella punctata	17		7	1		11	1	21	15	13
Crustacea										
Isopoda										
Asellidae										
Caecidotea sp.		1		31	102			3	40	28
Amphipoda										
Gammaridae										
Gammarus minus	786	307	1066	850	552	279	38	139	141	416
Decapoda										
Cambaridae										
Orconectes sp.	1			2	4			3	1	1
Insecta										
Plecoptera										
Perlidae		1								
Odonata										
Coenagrionidae										
Argia sp.								1	2	
Ephemeroptera										
Baetidae			1							
Baetis amplus						1				

Appendix A-1. (Continued)

Date	July 1996					October 1996				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Heptageniidae				1	1	2			1	1
Stenacron sp.		2							1	
Stenacron interpunctatum	3		1		1	2		7	19	28
Stenonema sp.					1					
Heteroptera										
Corixidae	1									
Trichoptera										
Hydropsychidae										
Cheumatopsyche sp.					2					
Hydroptilidae										
Leptoceridae										
Ceraclea sp.				1		1				
Oecetis sp.	1		1							
Polycentropodidae										
Cyrnellus fraternus	32	215	63	119	63	6	42	279	780	478
Megaloptera										
Corydalidae										
Nigronia sp.			1							
Sialidae										
Sialis sp.		2								
Diptera										
Chironomidae	1	6		1	1	5	5	9	14	13
Ablabesmyia mallochi		4				2			1	
Ablabesmyia parajanta										1
Chironomus sp.			1			1				
Cladotanytarsus sp.		1	1							
Coelotanypus tricolor		1								

Appendix A-1. (Continued)

Date	July 1996					October 1996				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Cryptochironomus fulvus	1	1	2			11	1			3
Dicrotendipes sp.	35	56	67	60	13	23	61	95	77	104
Glyptotendipes sp.	8	122	23	2		1	3	3	5	4
Harnischia sp.	3									
Microtendipes sp.	2	2								
Nanocladius sp.	9	2	5	6	2	109	75	70	129	270
Parachironomus sp.	1			2	1	7	16	9	12	31
Phaenopsectra obediens										2
Polypedilum convictum			1							
Polypedilum halterale	1		3	1						
Pseudochironomus sp.	3									
Rheotanytarsus sp.	2					1	1			
Stenochirohomus sp.										1
Stictochironomus sp.			1							
Synorthocladius semivire										1
Tanytarsus sp.	3	1	1			1	1			
Thienemanniella xena							1			1
Tvetenia discoloripes sp.	1									
Gastropoda										
Mesogastropoda										
Hydrobiidae								1		
Amnicola sp.									1	1
Somatogyrus sp.									1	93
Pleuroceridae										
Leptoxis praerosa						1				
Pleurocera sp.					9					

Appendix A-1. (Continued)

Date	July 1996					October 1996				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Pleurocera canaliculata	115	22	37	12	8	91	49	3	3	1
Basommatophora										
Ancylidae										
Ferrissia rivularis				3		1		1	3	7
Physidae										
Physella sp.	1	1	36	13	16		4	3	5	8
Planorbidae		1			3		3	1	2	
Gyraulus parvus			1		2					
Menetus sp.								1		
Bivalvia										
Unionoida										
Unionidae										
Actinonaias ligamentina							1			
Anodonta imbecillis			1			2				
Elliptio crassidens	4	4		1			1			
Obliquaria reflexa			1							
Quadrula pustulosa pustu			2							
Veneroida										
Corbiculidae										
Corbicula fluminea	713	726	716	767	633	409	353	643	1091	755
Dreissenidae										
Dreissena polymorpha	2	11	28	21	38	8	15	46	60	36
Sphaeriidae					4					
Musculium transversum	4	22	3		2	1	16	7	64	3
Number of samples	10	10	10	10	10	10	10	10	10	10
Sum (Total number)	2963	2156	3705	3001	1775	2603	2222	2552	3920	4558
Number of species	34	32	36	28	28	32	27	32	35	39

Appendix A-1. (Continued)

Date	July 1997					October 1997				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Nematoda				1			1			
Coelenterata						34		2		21
Hydrozoa										
Hydroida										
Hydridae										
Hydra americana	301	66	24	91	1414	209	210	38	24	245
Turbellaria										
Tricladida										
Planariidae										
Dugesia tigrina	611	1141	1643	1489	1414	1457	750	1132	1093	1906
Oligochaeta										
Haplotaxida										
Naididae					1	4		1	9	10
Dero sp.	1	1				11	98	18	12	12
Nais sp.										1
Pristina leidyi										2
Slavina appendiculata				1				1		
Tubificidae	311	69	162	49	68	430	114	21	187	64
Branchiura sowerbyi	2					39	5		3	
Limnodrilus sp.			25		1					
Limnodrilus hoffmeisteri	36	12	150	4	11	49	26	4	17	4
Lumbriculida										
Lumbriculidae	9	14	15	4	4				6	

Appendix A-1. (Continued)

Date	July 1997					October 1997				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Hirudinea		1		1	1					6
Rhynchobdellida										
Glossiphoniidae		1	3	14						
Helobdella sp.				2			1			
Helobdella triserialis				13	3	5	2	1	5	2
Pharyngobdellida										
Erpobdellidae	3	2	7	6	8	67	5	39	21	8
Erpobdella sp.			1	1						
Crustacea										
Isopoda										
Asellidae										
Caecidotea sp.		1	2	12	84				3	8
Amphipoda										
Gammaridae										
Gammarus sp.	734	574	937	1178	1485	492	77	113	110	277
Gammarus minus	138				207					
Insecta										
Odonata										
Coenagrionidae						1			1	
Corduliidae										
Neurocordulia molesta										1
Ephemeroptera										
Heptageniidae						1			1	
Stenacron interpunctatum						1		2		3
Leptophlebiidae										
Paraleptophlebia sp.							1			

Appendix A-1. (Continued)

Date	July 1997					October 1997				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Trichoptera	1									
Hydropsychidae					1				4	1
Cheumatopsyche sp.	3	3	2	7	20				1	3
Leptoceridae					3					
Ceraclea sp.		5	4	2	3	2				
Polycentropodidae										
Cyrnellus fraternus	2			3	5	21	35	548	514	340
Diptera										
Chironomidae	16	5	5	12	8	1	2	2	6	1
Ablabesmyia annulata										1
Ablabesmyia sp.		1							1	
Ablabesmyia mallochi				1						
Ablabesmyia parajanta		1								
Clinotanypus pinguis.					1					
Cricotopus bicinctus	1									
Cryptochironomus fulvus	26	11	7			5	2		1	
Dicrotendipes sp.	60	129	51	29	35	38	56	49	82	46
Glyptotendipes sp.	15	70	15	9	10	1	3	6	18	
Nanocladius sp.	7	9	6	48	83	64	87	85	133	74
Parachironomus sp.	41	10	14	47	50	19	40	15	22	55
Paratanytarsus sp.										6
Paratendipes sp.	4									
Polypedilum sp.		1								
Polypedilum convictum				1						
Polypedilum illinoense	1			1						
Procladius sp.		1	1							
Pseudochironomus sp.		1								
Rheotanytarsus sp.	1		2	5		1		1	1	

Appendix A-1. (Continued)

Date	July 1997					October 1997				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Synorthocladius semivirens	1									
Tanytarsus sp.			1	1		1				
Thienemanniella xena	1	1								
Thienemannimyia sp.				2						
Coleoptera										
Elmidae										
Dubiraphia sp.						1				
Stenelmis sp.									1	
Gastropoda										
Mesogastropoda										
Hydrobiidae										
Amnicola sp.				3	5			9		
Somatogyrus sp.					11	3		1		16
Pleuroceridae										
Pleurocera canaliculata	175	23	27	1	2	71	17	1	22	
Viviparidae										
Campeloma decisum							1			
Basommatophora										
Ancylidae										
Ferrissia rivularis	20	5	2	3	2	5		3		1
Physidae										
Physella sp.	6	12	50	27	68	2	2	2	2	14
Planorbidae										
Micromenetus dilatatus	1	4	4			1		1		

Appendix A-1. (Continued)

Date	July 1997					October 1997				
Tennessee River Mile	521.0	526.3	527.4	528.0	528.5	521.0	526.3	527.4	528.0	528.5
Taxon										
Bivalvia										
Unionoida										
Unionidae										
Elliptio crassidens	5	1	1		1	3	2	1		3
Lampsilis abrupta			1							
Pleurobema cordatum		1		2	1		1			
Potamilus alatus		1								
Quadrula pustulosa pustu			1	1		1				
Veneroida										
Corbiculidae										
Corbicula fluminea	475	724	1018	2440	1138	290	283	835	992	438
Dreissenidae										
Dreissena polymorpha	6	10	26	65	42	4	13	39	17	72
Sphaeriidae										
Musculium transversum		15		20	37		1	11	12	8
Number of samples	10	10	10	10	10	10	10	10	10	10
Sum (Total number)	3014	2926	4207	5596	6226	3335	1835	2981	3321	3649
Number of species	32	35	31	38	33	35	27	29	31	32

Appendix A-2. Results of 14 native mussel surveys at 12 sites in the vicinity of Watts Bar Nuclear Plant, 1983-1997.

September 13-14,1983					Bed					Bed					Bed	Survey	
Species	520.0	520.3	520.6	520.8	Total	526.0	526.3	526.5	526.8	Total	528.2	528.5	528.8	528.9	Total	Total	Percent
Elliptio crassidens	163	71	78	102	414	21	65	12	34	132	53	43	69	43	208	754	56.23
Pleurobema cordatum	17	41	16	16	90	17	82	7	3	109	12	18	20	15	65	264	19.69
Quadrula pustulosa	8	3	6	15	32	4	22	14	5	45	6	5	9	2	22	99	7.38
Cyclonaias tuberculata	8	5	21	11	45	3	7	4	4	18	5	8	8	4	25	88	6.56
Ellipsaria lineolata	2	3	2	8	15	1	4	2	1	8	0	1	0	0	1	24	1.79
Amblema plicata	0	0	1	0	1	0	5	5	5	15	0	1	1	0	2	18	1.34
Anodonta grandis	0	0	0	0	0	4	1	3	6	14	0	0	1	3	4	18	1.34
Obliquaria reflexa	1	0	0	0	1	0	4	6	2	12	0	1	0	0	1	14	1.04
Potamilus alatus	2	1	3	0	6	3	0	1	3	7	0	0	1	0	1	14	1.04
Quadrula metanevra	1	0	5	2	8	2	0	2	0	4	1	1	0	0	2	14	1.04
Ligumia recta	1	1	0	1	3	0	0	0	1	1	0	1	1	0	2	6	0.45
Tritogonia verrucosa	0	0	0	0	0	2	1	0	2	5	0	0	1	0	1	6	0.45
Elliptio dilatata	1	0	1	1	3	0	0	0	0	0	0	0	0	1	1	4	0.30
Actinonaias ligamentina	1	0	0	0	1	0	1	0	0	1	0	1	0	0	1	3	0.22
Lampsilis abrupta	0	0	0	0	0	0	1	0	0	1	0	1	1	0	2	3	0.22
Lampsilis ovata	1	0	1	0	2	0	0	0	0	0	0	0	1	0	1	3	0.22
Cyprogenia stegaria	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	2	0.15
Fusconaia subrotunda	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	2	0.15
Megalonaias nervosa	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	2	0.15
Dromus dromas	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Leptodea fragilis	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0.07
Pleurobema plenum	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Grand Total	206	125	136	158	625	58	194	57	66	375	77	81	115	68	341	1341	100.00
Species Count	12	7	12	10	17	10	12	11	11	16	5	11	13	6	18	22	

Appendix A-2. (Continued)

November 1-2,1983 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	0	145	100	102	347	21	52	26	72	171	54	108	91	65	318	836	58.79
Pleurobema cordatum	32	13	13	24	82	9	24	22	2	57	8	51	46	31	136	275	19.34
Quadrula pustulosa	6	0	6	10	22	4	8	6	0	18	12	7	1	15	35	75	5.27
Cyclonaias tuberculata	5	4	14	15	38	1	8	5	0	14	1	4	4	9	18	70	4.92
Amblema plicata	2	0	3	1	6	6	6	10	2	24	0	1	0	2	3	33	2.32
Ellipsaria lineolata	1	2	4	6	13	1	1	0	3	5	1	7	0	3	11	29	2.04
Potamilus alatus	1	1	3	0	5	7	0	6	7	20	1	1	1	1	4	29	2.04
Quadrula metanevra	5	2	1	2	10	1	2	0	0	3	2	5	1	3	11	24	1.69
Tritogonia verrucosa	0	0	0	0	0	7	0	2	3	12	0	0	0	0	0	12	0.84
Anodonta grandis	0	0	0	0	0	4	0	1	3	8	0	1	1	0	2	10	0.70
Lampsilis abrupta	0	1	1	0	2	0	0	0	0	0	1	1	1	2	5	7	0.49
Obliquaria reflexa	0	0	0	0	0	1	1	2	2	6	0	0	0	0	0	6	0.42
Leptodea fragilis	0	0	1	1	2	0	0	0	0	0	0	0	0	1	1	3	0.21
Ligumia recta	0	1	0	0	1	0	1	0	0	1	0	0	1	0	1	3	0.21
Actinonaias ligamentina	1	0	0	0	1	0	0	0	0	0	0	0	0	1	1	2	0.14
Elliptio dilatata	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0	2	0.14
Plethobasus cyphyus	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	2	0.14
Cyprogenia stegaria	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0.07
Lampsilis ovata	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Megalonaias nervosa	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0.07
Pleurobema plenum	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Grand Total	53	172	146	161	532	65	104	80	94	343	81	186	147	133	547	1422	100.00
Species Count	8	11	10	8	15	13	10	9	8	15	9	10	9	11	14	21	

Appendix A-2. (Continued)

July 11-12, 1984 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	110	63	15	44	232	9	33	21	18	81	11	88	195	172	466	779	61.34
Pleurobema cordatum	33	27	24	23	107	4	7	1	0	12	3	18	55	25	101	220	17.32
Quadrula pustulosa	4	0	13	10	27	8	2	6	4	20	5	13	9	11	38	85	6.69
Cyclonaias tuberculata	0	4	33	25	62	0	0	2	0	2	0	3	6	0	9	73	5.75
Ellipsaria lineolata	1	2	7	3	13	2	1	0	1	4	1	4	2	0	7	24	1.89
Amblema plicata	0	0	4	0	4	4	1	7	0	12	1	1	1	0	3	19	1.50
Potamilus alatus	0	2	3	2	7	2	1	0	6	9	0	1	1	0	2	18	1.42
Quadrula metanevra	0	2	2	2	6	0	0	1	0	1	0	2	2	0	4	11	0.87
Obliquaria reflexa	0	0	1	0	1	1	0	5	1	7	0	0	0	0	0	8	0.63
Lampsilis abrupta	0	1	0	0	1	1	1	0	0	2	0	0	2	1	3	6	0.47
Anodonta grandis	0	0	0	0	0	1	2	2	0	5	0	0	0	0	0	5	0.39
Tritogonia verrucosa	0	0	1	0	1	3	0	0	0	3	0	1	0	0	1	5	0.39
Leptodea fragilis	0	0	0	0	0	0	1	0	2	3	0	1	0	0	1	4	0.31
Ligumia recta	2	0	0	0	2	0	0	0	0	0	0	0	2	0	2	4	0.31
Actinonaias ligamentina	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	2	0.16
Pleurobema oviforme	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0.16
Pleurobema plenum	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	2	0.16
Elliptio dilatata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0.08
Lampsilis ovata	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.08
Ptychobranchus fasciolaris	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0.08
Grand Total	151	101	106	109	467	35	49	45	32	161	23	133	275	211	642	1270	100.00
Species Count	6	7	12	7	15	10	9	8	6	13	7	11	10	5	15	20	

Appendix A-2. (Continued)

November 1-2, 1984 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	128	58	92	102	380	41	60	36	67	204	18	31	200	151	400	984	71.93
Pleurobema cordatum	12	13	25	20	70	3	27	0	1	31	3	12	25	15	55	156	11.40
Cyclonaias tuberculata	2	11	20	10	43	1	3	1	0	5	1	0	11	2	14	62	4.53
Quadrula pustulosa	3	7	7	9	26	0	7	1	1	9	1	0	10	7	18	53	3.87
Potamilus alatus	1	0	2	4	7	4	0	2	8	14	3	4	1	0	8	29	2.12
Ellipsaria lineolata	0	1	6	3	10	2	2	0	4	8	1	1	4	1	7	25	1.83
Quadrula metanevra	0	4	1	3	8	0	0	0	0	0	1	0	4	0	5	13	0.95
Amblema plicata	0	1	0	1	2	1	1	0	2	4	2	0	2	1	5	11	0.80
Ligumia recta	0	0	1	2	3	0	0	0	0	0	0	5	1	1	7	10	0.73
Tritogonia verrucosa	0	0	0	0	0	2	0	1	0	3	1	1	0	0	2	5	0.37
Anodonta grandis	0	0	0	0	0	2	0	0	1	3	0	0	0	1	1	4	0.29
Lampsilis ovata	0	0	0	0	0	0	0	1	0	1	0	3	0	0	3	4	0.29
Obliquaria reflexa	0	0	0	0	0	0	1	1	0	2	0	0	0	1	1	3	0.22
Anodonta imbecillis	0	0	1	0	1	0	1	0	0	1	0	0	0	0	0	2	0.15
Lampsilis abrupta	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	2	0.15
Leptodea fragilis	0	0	0	0	0	0	1	0	1	2	0	0	0	0	0	2	0.15
Cyprogenia stegaria	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Elliptio dilatata	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Megalonaias nervosa	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0.07
Grand Total	146	96	156	154	552	56	104	44	85	289	31	57	259	180	527	1368	100.00
Species Count	5	8	10	9	12	8	10	8	8	15	9	7	10	9	14	19	

Appendix A-2. (Continued)

July 31-August 1, 1985 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	39	41	35	88	203	38	25	8	24	95	44	91	150	155	440	738	69.43
Pleurobema cordatum	1	13	5	17	36	2	18	2	1	23	5	11	13	25	54	113	10.63
Cyclonaias tuberculata	3	1	17	13	34	0	5	1	1	7	0	5	11	3	19	60	5.64
Quadrula pustulosa	0	0	1	6	7	0	11	5	2	18	2	4	15	7	28	53	4.99
Potamilus alatus	0	0	0	3	3	3	0	5	17	25	0	0	5	1	6	34	3.20
Amblema plicata	0	0	0	0	0	0	2	7	0	9	2	0	5	1	8	17	1.60
Ellipsaria lineolata	0	0	3	1	4	0	2	0	0	2	0	0	2	0	2	8	0.75
Anodonta grandis	0	0	0	0	0	1	0	0	0	1	0	1	1	0	2	3	0.28
Obliquaria reflexa	0	0	0	0	0	0	2	4	0	6	0	0	0	1	1	7	0.66
Tritogonia verrucosa	0	0	0	0	0	2	0	2	0	4	0	0	0	0	0	4	0.38
Quadrula metanevra	1	1	2	2	6	0	0	0	0	0	0	0	0	0	0	6	0.56
Lampsilis abrupta	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.09
Leptodea fragilis	0	0	0	0	0	0	0	0	2	2	0	0	1	0	1	3	0.28
Ligumia recta	0	0	0	0	0	0	0	0	0	0	1	1	1	0	3	3	0.28
Megalonaias nervosa	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0.09
Actinonaias ligamentina	0	0	0	1	1	0	0	0	0	0	0	0	3	0	3	4	0.38
Lampsilis ovata	1	0	0	0	1	0	0	0	0	0	2	0	2	0	4	5	0.47
Cyprogenia stegaria	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0.09
Pleurobema plenum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0.09
Lasmigona complanata	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.09
Grand Total	45	56	64	131	296	46	66	34	47	193	56	113	211	194	574	1063	100.00
Species Count	5	4	7	8	10	5	8	8	6	12	6	6	14	8	16	20	

Appendix A-2. (Continued)

October 16-17,1985 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	79	128	73	47	327	23	32	29	32	116	8	70	182	226	486	929	65.10
Pleurobema cordatum	22	17	10	18	67	2	26	3	9	40	0	18	31	21	70	177	12.40
Quadrula pustulosa	2	7	1	9	19	6	5	6	8	25	0	14	16	11	41	85	5.96
Cyclonaias tuberculata	3	7	6	24	40	0	2	1	1	4	2	9	10	1	22	66	4.63
Potamilus alatus	1	1	5	5	12	7	3	14	0	24	0	3	2	2	7	43	3.01
Ellipsaria lineolata	2	0	0	1	3	2	4	2	3	11	0	3	4	6	13	27	1.89
Amblema plicata	1	1	1	0	3	2	1	3	5	11	0	3	5	3	11	25	1.75
Tritogonia verrucosa	0	0	0	1	1	8	1	2	2	13	1	0	0	0	1	15	1.05
Quadrula metanevra	0	0	1	4	5	2	1	0	0	3	0	0	0	2	2	10	0.70
Ligumia recta	0	1	2	1	4	0	0	1	0	1	0	0	2	1	3	8	0.56
Actinonaias ligamentina	2	0	2	0	4	0	0	0	0	0	0	1	2	0	3	7	0.49
Anodonta grandis	0	0	0	0	0	4	0	0	1	5	0	1	0	1	2	7	0.49
Lampsilis abrupta	0	1	1	0	2	0	0	0	0	0	0	1	4	0	5	7	0.49
Obliquaria reflexa	1	0	0	0	1	1	0	1	0	2	1	0	1	0	2	5	0.35
Lampsilis ovata	0	0	0	0	0	0	2	0	0	2	0	0	2	0	2	4	0.28
Megalonaias nervosa	0	1	0	1	2	0	0	0	0	0	0	0	0	2	2	4	0.28
Pleurobema rubrum	0	1	0	0	1	0	0	0	0	0	0	1	1	0	2	3	0.21
Elliptio dilatata	0	0	1	0	1	0	1	0	0	1	0	0	0	0	0	2	0.14
Leptodea fragilis	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	2	0.14
Pleurobema oviforme	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.07
Grand Total	114	165	103	111	493	57	78	63	62	260	12	124	262	276	674	1427	100.00
Species Count	10	10	11	10	17	10	11	11	9	15	4	11	13	11	17	20	

Appendix A-2. (Continued)

July 9-10, 1986 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	100	56	38	30	224	28	23	47	44	142	86	86	34	162	368	734	68.28
Pleurobema cordatum	7	30	7	11	55	2	1	3	2	8	15	16	4	12	47	110	10.23
Cyclonaias tuberculata	1	2	6	14	23	2	2	4	0	8	9	7	2	6	24	55	5.12
Quadrula pustulosa	1	0	0	2	3	1	4	5	2	12	7	6	1	2	16	31	2.88
Potamilus alatus	2	1	0	1	4	3	6	5	9	23	1	1	4	8	14	41	3.81
Amblema plicata	1	0	0	2	3	1	5	7	1	14	4	2	0	0	6	23	2.14
Ellipsaria lineolata	1	0	1	3	5	0	2	4	0	6	1	2	0	5	8	19	1.77
Anodonta grandis	0	0	0	0	0	1	2	1	0	4	0	0	1	4	5	9	0.84
Obliquaria reflexa	0	0	0	0	0	2	2	4	0	8	0	0	0	1	1	9	0.84
Tritogonia verrucosa	0	0	0	0	0	2	4	1	1	8	0	0	0	0	0	8	0.74
Quadrula metanevra	0	0	1	3	4	0	1	0	0	1	1	0	1	0	2	7	0.65
Lampsilis abrupta	1	2	0	0	3	0	0	0	1	1	1	1	0	0	2	6	0.56
Leptodea fragilis	0	0	0	0	0	0	4	1	0	5	0	0	1	0	1	6	0.56
Ligumia recta	1	0	2	0	3	0	0	0	1	1	0	2	1	1	4	8	0.74
Megalonaias nervosa	1	1	1	0	3	0	1	1	0	2	0	0	0	0	0	5	0.47
Lampsilis ovata	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.09
Elliptio dilatata	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	2	0.19
Lasmigona costata	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0.09
Grand Total	116	92	56	67	331	42	57	84	61	244	126	123	50	201	500	1075	100.00
Species Count	10	6	7	9	12	9	13	13	8	16	10	9	10	9	15	18	

Appendix A-2. (Continued)

October 16-17, 1986 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	97	29	73	61	260	14	30	20	28	92	13	100	132	168	413	765	64.83
Pleurobema cordatum	6	18	21	9	54	3	28	1	1	33	1	22	34	25	82	169	14.32
Cyclonaias tuberculata	0	5	28	16	49	0	2	7	0	9	3	1	13	1	18	76	6.44
Quadrula pustulosa	3	0	0	11	14	0	1	6	1	8	4	4	10	1	19	41	3.47
Potamilus alatus	0	1	3	3	7	3	4	4	4	15	5	0	0	0	5	27	2.29
Amblema plicata	0	0	1	1	2	1	6	6	0	13	3	0	4	2	9	24	2.03
Ellipsaria lineolata	2	1	3	4	10	0	0	0	1	1	0	2	3	2	7	18	1.53
Tritogonia verrucosa	0	0	0	0	0	5	2	1	4	12	0	1	0	0	1	13	1.10
Ligumia recta	0	1	2	1	4	0	0	0	1	1	0	3	2	0	5	10	0.85
Actinonaias ligamentina	0	1	1	2	4	0	0	0	0	0	0	2	2	0	4	8	0.68
Anodonta grandis	0	2	0	0	2	2	1	0	1	4	0	0	1	0	1	7	0.59
Quadrula metanevra	1	0	1	3	5	0	0	0	0	0	0	1	1	0	2	7	0.59
Leptodea fragilis	0	0	0	0	0	0	1	0	0	1	0	0	2	0	2	3	0.25
Obliquaria reflexa	0	0	0	0	0	0	1	1	0	2	0	1	0	0	1	3	0.25
Lampsilis abrupta	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	2	0.17
Lampsilis ovata	0	1	0	0	1	0	1	0	0	1	0	0	0	0	0	2	0.17
Pleurobema oviforme	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2	0.17
Anodonta imbecillis	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0.08
Elliptio dilatata	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0.08
Megalonaias nervosa	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0.08
Grand Total	109	59	134	113	415	28	77	46	41	192	29	139	204	201	573	1180	100.00
Species Count	5	9	10	12	15	6	11	8	8	13	6	11	11	8	17	20	

Appendix A-2. (Continued)

July 12 & 14, 1988 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Total	Survey Percent
Elliptio crassidens	71	43	43	79	236	14	28	25	20	87	76	80	248	243	647	970	60.25
Pleurobema cordatum	8	22	18	20	68	10	28	6	0	44	16	22	38	36	112	224	13.91
Cyclonaias tuberculata	1	14	19	22	56	1	1	3	3	8	4	4	17	4	29	93	5.78
Quadrula pustulosa	0	2	1	2	5	1	3	9	8	21	11	9	25	9	54	80	4.97
Potamilus alatus	0	2	5	3	10	5	4	9	12	30	9	3	0	3	15	55	3.42
Amblema plicata	1	4	4	3	12	4	0	10	9	23	10	1	3	0	14	49	3.04
Ellipsaria lineolata	2	1	2	4	9	0	4	0	0	4	3	3	3	1	10	23	1.43
Anodonta grandis	0	1	2	0	3	9	1	4	5	19	2	0	1	4	7	29	1.80
Obliquaria reflexa	0	0	0	0	0	1	0	3	3	7	0	0	0	0	0	7	0.43
Tritogonia verrucosa	0	0	1	2	3	4	5	0	4	13	0	1	0	1	2	18	1.12
Quadrula metanevra	0	2	3	1	6	0	0	0	0	0	0	0	2	0	2	8	0.50
Lampsilis abrupta	0	0	0	0	0	1	0	1	0	2	4	1	3	2	10	12	0.75
Leptodea fragilis	0	0	0	0	0	1	1	1	6	9	2	1	0	0	3	12	0.75
Ligumia recta	1	0	1	0	2	0	0	0	0	0	0	1	3	1	5	7	0.43
Megalonaias nervosa	0	1	1	2	4	0	0	0	0	0	4	0	1	0	5	9	0.56
Actinonaias ligamentina	0	0	0	2	2	0	0	0	1	1	0	0	0	0	0	3	0.19
Lampsilis ovata	0	1	0	0	1	0	0	1	0	1	0	1	0	0	1	3	0.19
Elliptio dilatata	0	0	1	0	1	0	0	0	0	0	0	0	2	0	2	3	0.19
Pleurobema oviforme	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0.12
Anodonta imbecillis	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0.06
Anodonta suborbiculata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0.06
Pleurobema pyramidatum	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0.06
Grand Total	84	93	101	140	418	51	76	72	72	271	142	127	346	306	921	1610	100.00
Species Count	6	11	13	11	15	11	10	11	11	16	12	12	12	11	18	22	

Appendix A-2. (Continued)

July 24-25. 1990 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	79	21	37	58	195	23	17	18	27	85	25	67	84	68	244	524	52.88
Pleurobema cordatum	11	2	12	9	34	3	13	8	0	24	9	33	19	20	81	139	14.03
Cyclonaias tuberculata	11	26	20	14	71	1	2	2	0	5	6	4	4	0	14	90	9.08
Quadrula pustulosa	2	4	8	3	17	0	9	10	7	26	9	9	13	5	36	79	7.97
Potamilus alatus	2	2	5	4	13	8	2	8	10	28	1	0	2	1	4	45	4.54
Amblema plicata	0	1	0	4	5	0	1	2	1	4	0	1	0	0	1	10	1.01
Ellipsaria lineolata	4	1	8	3	16	3	0	0	0	3	3	3	2	1	9	28	2.83
Anodonta grandis	0	0	0	1	1	5	4	3	5	17	0	1	1	0	2	20	2.02
Obliquaria reflexa	0	1	0	1	2	0	1	2	3	6	0	0	2	1	3	11	1.11
Tritogonia verrucosa	0	1	0	0	1	2	3	0	2	7	1	0	0	0	1	9	0.91
Quadrula metanevra	1	1	0	0	2	1	1	0	0	2	0	1	3	0	4	8	0.81
Lampsilis abrupta	0	0	0	0	0	0	0	0	1	1	0	1	2	0	3	4	0.40
Leptodea fragilis	0	0	2	0	2	3	1	1	0	5	0	0	1	0	1	8	0.81
Ligumia recta	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	2	0.20
Megalonaias nervosa	1	0	1	0	2	0	0	0	0	0	0	0	0	1	1	3	0.30
Actinonaias ligamentina	0	2	0	0	2	1	0	0	0	1	1	0	1	0	2	5	0.50
Lampsilis ovata	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0.10
Elliptio dilatata	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.10
Pleurobema oviforme	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0.10
Anodonta imbecillis	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0.10
Anodonta suborbiculata	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0.10
Ptychobranchus fasciolaris	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0.10
Grand Total	111	62	93	98	364	50	54	56	56	216	55	122	135	99	411	991	100.00
Species Count	8	11	8	10	15	10	11	11	8	16	8	11	13	9	20	22	

Appendix A-2. (Continued)

Summer 1992 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	82	15	6	7	110	19	8	13	2	42	6	49	118	99	272	424	59.89
Pleurobema cordatum	11	9	2	4	26	3	7	4	13	27	6	6	8	9	29	82	11.58
Cyclonaias tuberculata	9	18	12	5	44	2	4	6	0	12	1	2	6	3	12	68	9.60
Quadrula pustulosa	3	8	2	1	14	0	8	4	4	16	1	1	14	2	18	48	6.78
Potamilus alatus	2	2	0	2	6	1	0	1	3	5	0	3	1	1	5	16	2.26
Amblema plicata	1	0	0	1	2	1	1	2	2	6	1	1	3	0	5	13	1.84
Ellipsaria lineolata	7	1	0	0	8	3	0	0	0	3	0	0	2	1	3	14	1.98
Anodonta grandis	0	0	0	1	1	1	1	0	2	4	0	0	0	0	0	5	0.71
Obliquaria reflexa	0	1	0	0	1	0	1	1	2	4	0	0	0	1	1	6	0.85
Tritogonia verrucosa	1	0	0	1	2	0	2	4	1	7	0	0	0	0	0	9	1.27
Quadrula metanevra	0	0	2	0	2	0	2	1	0	3	0	0	2	1	3	8	1.13
Lampsilis abrupta	0	0	0	0	0	0	0	1	1	2	0	2	2	0	4	6	0.85
Ligumia recta	2	0	0	0	2	0	0	0	0	0	0	0	1	0	1	3	0.42
Megalonaias nervosa	0	0	0	1	1	0	0	2	1	3	0	0	0	0	0	4	0.56
Actinonaias ligamentina	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0.14
Plethobasus cyphyus	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0.14
Grand Total	118	54	25	23	220	31	34	39	31	135	15	64	157	117	353	708	100.00
Species Count	9	7	6	9	14	8	9	11	10	14	5	7	10	8	11	16	

Appendix A-2. (Continued)

Summer 1994 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	85	31	52	29	197	24	50	11	25	110	23	56	75	122	276	583	66.25
Pleurobema cordatum	14	3	7	11	35	1	13	2	3	19	8	6	12	15	41	95	10.80
Quadrula pustulosa	0	1	1	4	6	1	6	11	12	30	1	14	3	11	29	65	7.39
Cyclonaias tuberculata	6	16	13	11	46	1	2	3	2	8	0	6	1	3	10	64	7.27
Amblema plicata	0	1	0	1	2	3	2	4	2	11	0	0	0	0	0	13	1.48
Ellipsaria lineolata	1	0	4	2	7	0	0	0	1	1	0	2	0	1	3	11	1.25
Obliquaria reflexa	0	0	0	0	0	0	1	7	3	11	0	0	0	0	0	11	1.25
Potamilus alatus	0	1	0	1	2	2	1	1	1	5	1	1	0	1	3	10	1.14
Anodonta grandis	0	0	0	0	0	2	0	1	4	7	0	0	0	0	0	7	0.80
Tritogonia verrucosa	0	0	0	0	0	0	0	1	4	5	0	0	1	1	2	7	0.80
Quadrula metanevra	0	1	1	1	3	0	0	0	0	0	0	0	0	1	1	4	0.45
Leptodea fragilis	0	0	0	0	0	0	1	1	0	2	0	1	0	0	1	3	0.34
Lampsilis abrupta	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	2	0.23
Megalonaias nervosa	0	0	0	1	1	0	0	0	0	0	0	1	0	0	1	2	0.23
Ligumia recta	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0.11
Plethobasus cyphyus	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0.11
Pleurobema oviforme	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0.11
Grand Total	106	54	78	61	299	34	77	43	58	212	33	87	92	157	369	880	100.00
Species Count	4	7	6	9	9	7	9	11	11	14	4	8	5	10	12	17	

Appendix A-2. (Continued)

July 22-23, 1996 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	88	22	76	26	212	10	54	27	23	114	24	71	73	100	268	594	70.21
Pleurobema cordatum	6	4	8	9	27	0	12	7	1	20	9	10	7	21	47	94	11.11
Cyclonaias tuberculata	5	6	5	2	18	0	3	4	0	7	3	6	1	3	13	38	4.49
Potamilus alatus	0	0	2	1	3	8	6	9	5	28	0	0	1	3	4	35	4.14
Quadrula pustulosa	0	0	0	1	1	1	1	3	4	9	8	10	0	2	20	30	3.55
Ellipsaria lineolata	0	0	1	1	2	1	3	0	0	4	0	4	4	1	9	15	1.77
Amblema plicata	0	0	0	2	2	1	4	1	0	6	1	2	0	0	3	11	1.30
Anodonta grandis	0	0	0	0	0	3	0	2	1	6	0	0	0	1	1	7	0.83
Obliquaria reflexa	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0	6	0.71
Lampsilis abrupta	1	0	0	0	1	0	1	1	0	2	0	0	1	0	1	4	0.47
Tritogonia verrucosa	0	0	0	0	0	1	1	0	1	3	0	0	1	0	1	4	0.47
Ligumia recta	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	2	0.24
Quadrula metanevra	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	2	0.24
Elliptio dilatata	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.12
Lasmigona costata	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.12
Leptodea fragilis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0.12
Megalonaias nervosa	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0.12
Grand Total	100	33	92	43	268	25	86	61	35	207	47	104	89	131	371	846	100.00
Species Count	4	4	5	8	10	7	10	10	6	13	7	7	8	7	14	17	

Appendix A-2. (Continued)

July 7-8, 1997 Species	520.0	520.3	520.6	520.8	Bed Total	526.0	526.3	526.5	526.8	Bed Total	528.2	528.5	528.8	528.9	Bed Total	Survey Total	Survey Percent
Elliptio crassidens	24	13	51	35	123	45	33	17	14	109	20	66	126	45	257	489	70.16
Pleurobema cordatum	4	4	9	11	28	2	16	0	0	18	3	33	7	12	55	101	14.49
Cyclonaias tuberculata	1	16	9	5	31	1	2	0	0	3	2	7	4	0	13	47	6.74
Quadrula pustulosa	0	5	2	2	9	1	0	2	3	6	1	7	1	0	9	24	3.44
Potamilus alatus	0	0	1	1	2	0	1	4	1	6	4	0	0	0	4	12	1.72
Ellipsaria lineolata	1	0	2	2	5	0	0	0	1	1	1	0	1	0	2	8	1.15
Amblema plicata	0	0	0	0	0	0	0	3	1	4	0	0	1	0	1	5	0.72
Obliquaria reflexa	0	0	0	1	1	0	0	0	2	2	0	0	0	0	0	3	0.43
Leptodea fragilis	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	2	0.29
Quadrula metanevra	0	0	0	0	0	0	1	0	0	1	1	0	0	0	1	2	0.29
Anodonta grandis	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0.14
Lampsilis ovata	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0.14
Ligumia recta	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0.14
Tritogonia verrucosa	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0.14
Grand Total	30	38	74	57	199	49	53	26	26	154	32	114	141	57	344	697	100.00
Species Count	4	4	6	7	7	4	5	4	9	12	7	5	7	2	10	14	

Appendix A-2. (Continued)

TRM 520-521 and Year 1983	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	2	104.30	102.6	106.0	76.50	72.9	80.1	49.50	46.8	52.2
Amblema plicata	7	85.33	74.4	96.1	64.81	56.8	72.3	40.49	36.1	48.7
Cyclonaias tuberculata	72	75.80	62.1	92.6	65.60	52.1	80.2	38.20	32.4	44.1
Cyprogenia stegaria	1	51.60	51.6	51.6	49.70	49.7	49.7	36.00	36.0	36.0
Dromus dromas	1	60.10	60.1	60.1	58.30	58.3	58.3	32.80	32.8	32.8
Ellipsaria lineolata	20	78.94	56.8	94.5	61.21	44.6	72.0	37.78	30.1	48.8
Elliptio crassidens	102	101.28	87.5	125.5	63.90	54.0	80.5	40.59	21.0	50.3
Elliptio dilatata	3	106.37	102.3	113.3	45.70	42.2	48.8	33.40	30.9	34.7
Lampsilis abrupta	2	91.40	83.7	99.1	67.05	61.4	72.7	44.75	43.4	46.1
Lampsilis ovata	3	122.47	122.0	123.2	84.40	74.7	92.3	65.87	62.0	69.4
Leptodea fragilis	2	71.20	59.6	82.8	41.35	34.6	48.1	23.10	20.1	26.1
Ligumia recta	3	150.60	145.1	154.9	59.70	56.6	63.4	45.93	42.5	48.6
Obliquaria reflexa	1	48.30	48.3	48.3	24.10	24.1	24.1	24.60	24.6	24.6
Pleurobema cordatum	102	90.57	72.1	108.8	72.31	60.6	84.8	45.72	31.4	59.8
Pleurobema plenum	1	58.10	58.1	58.1	52.90	52.9	52.9	36.40	36.4	36.4
Potamilus alatus	11	122.31	46.9	156.9	88.34	71.1	104.9	35.58	30.6	40.9
Quadrula metanevra	16	73.55	63.5	85.3	58.82	52.3	68.0	43.65	38.3	49.2
Quadrula pustulosa	38	52.02	43.7	61.7	49.89	40.5	59.6	31.92	26.3	36.9

Appendix A-2. (Continued)

TRM 520-521 and Year 1984	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	6	96.08	80.5	107.3	72.63	62.6	80.4	42.58	34.6	46.6
Anodonta imbecillis	1	52.50	52.5	52.5	24.70	24.7	24.7	14.30	14.3	14.3
Cyclonaias tuberculata	101	74.39	59.1	92.2	63.86	52.2	76.5	37.48	29.5	44.9
Cyprogenia stegaria	1	52.90	52.9	52.9	51.40	51.4	51.4	36.40	36.4	36.4
Ellipsaria lineolata	23	77.57	56.6	102.2	58.68	44.0	74.2	35.53	26.3	42.0
Elliptio crassidens	101	104.82	89.2	122.7	66.24	56.3	78.4	41.70	24.4	60.9
Elliptio dilatata	1	100.10	100.1	100.1	42.20	42.2	42.2	28.00	28.0	28.0
Lampsilis abrupta	1	90.60	90.6	90.6	60.70	60.7	60.7	48.10	48.1	48.1
Lampsilis ovata	1	102.10	102.1	102.1	72.90	72.9	72.9	56.50	56.5	56.5
Ligumia recta	5	149.30	140.9	155.9	57.52	50.5	60.3	46.68	40.0	49.7
Obliquaria reflexa	1	36.50	36.5	36.5	32.90	32.9	32.9	22.90	22.9	22.9
Pleurobema cordatum	100	90.46	62.1	112.9	71.74	44.7	86.7	44.20	32.8	52.8
Pleurobema plenum	2	60.10	51.3	68.9	57.70	49.4	66.0	44.00	39.4	48.6
Potamilus alatus	14	126.87	96.7	160.0	90.56	74.4	108.0	36.16	30.0	42.5
Ptychobranchus fasciolaris	1	94.40	94.4	94.4	56.70	56.7	56.7	34.80	34.8	34.8
Quadrula metanevra	14	74.78	64.5	82.8	59.29	52.6	66.6	40.09	32.4	50.6
Quadrula pustulosa	53	53.28	40.0	74.1	50.63	39.5	64.1	31.69	22.0	40.1
Tritogonia verrucosa	1	76.70	76.7	76.7	42.70	42.7	42.7	19.70	19.7	19.7

Appendix A-2. (Continued)

TRM 520-521 and Year 1985	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	5	105.42	97.4	112.3	75.42	70.6	78.9	52.78	50.2	54.9
Amblema plicata	3	94.77	92.1	97.9	69.83	69.1	70.3	39.80	36.6	42.8
Cyclonaias tuberculata	72	75.62	60.5	86.6	65.14	54.7	74.5	36.95	30.6	43.1
Cyprogenia stegaria	1	57.70	57.7	57.7	55.60	55.6	55.6	44.10	44.1	44.1
Ellipsaria lineolata	7	79.13	62.3	92.5	61.27	46.9	69.9	34.84	32.0	36.2
Elliptio crassidens	101	104.43	90.1	122.5	65.82	54.1	88.5	41.43	29.5	50.9
Elliptio dilatata	1	96.80	96.8	96.8	44.20	44.2	44.2	29.80	29.8	29.8
Lampsilis abrupta	2	96.45	82.3	110.6	71.65	69.8	73.5	51.95	43.5	60.4
Lampsilis ovata	1	121.20	121.2	121.2	86.50	86.5	86.5	62.30	62.3	62.3
Ligumia recta	4	158.93	142.2	170.2	59.88	57.2	60.8	45.15	41.3	48.5
Megalonaias nervosa	2	165.15	160.1	170.2	109.35	102.3	116.4	54.45	52.4	56.5
Obliquaria reflexa	1	46.60	46.6	46.6	36.10	36.1	36.1	23.40	23.4	23.4
Pleurobema cordatum	88	91.57	70.4	108.5	73.40	58.2	89.5	43.91	30.2	52.7
Pleurobema oviforme	1	72.90	72.9	72.9	56.50	56.5	56.5	40.20	40.2	40.2
Pleurobema rubrum	1	80.70	80.7	80.7	64.30	64.3	64.3	44.50	44.5	44.5
Potamilus alatus	15	128.51	98.0	150.7	87.92	76.5	106.7	36.53	30.9	40.7
Quadrula metanevra	11	75.45	67.3	88.2	60.21	56.1	70.3	40.83	36.8	46.2
Quadrula pustulosa	26	54.20	46.3	72.8	51.48	44.7	64.3	31.89	25.7	37.4
Tritogonia verrucosa	1	104.10	104.1	104.1	52.80	52.8	52.8	36.10	36.1	36.1

Appendix A-2. (Continued)

TRM 520-521 and Year 1986	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	4	94.93	91.3	97.5	68.15	65.3	71.6	46.03	40.3	53.8
Amblema plicata	5	102.18	90.3	112.9	72.96	66.4	78.2	44.38	39.3	52.1
Anodonta grandis	2	123.05	119.4	126.7	70.00	63.3	76.7	47.05	43.4	50.7
Anodonta imbecillis	1	39.20	39.2	39.2	17.40	17.4	17.4	7.10	7.1	7.1
Cyclonaias tuberculata	72	72.03	56.9	85.1	61.53	47.6	76.6	34.82	23.7	44.9
Ellipsaria lineolata	15	73.42	51.8	86.9	54.71	39.2	65.3	30.81	22.6	42.0
Elliptio crassidens	100	105.59	87.2	151.8	64.88	55.9	82.5	40.83	31.1	51.4
Elliptio dilatata	1	109.40	109.4	109.4	45.50	45.5	45.5	39.90	39.9	39.9
Lampsilis abrupta	4	98.43	86.1	104.7	72.45	66.3	80.7	50.15	48.3	52.2
Lampsilis ovata	1	139.10	139.1	139.1	90.30	90.3	90.3	55.90	55.9	55.9
Lasmigona costata	1	122.10	122.1	122.1	69.90	69.9	69.9	25.50	25.5	25.5
Ligumia recta	7	133.40	107.7	150.2	51.84	45.0	55.9	40.80	33.1	48.6
Megalonaias nervosa	3	148.97	146.9	150.3	102.27	97.6	109.3	57.37	53.9	63.2
Pleurobema cordatum	94	88.69	54.9	109.6	70.34	49.7	88.5	42.39	25.2	54.6
Potamilus alatus	11	127.29	93.4	144.9	84.49	67.9	95.8	32.73	26.8	40.0
Quadrula metanevra	9	69.98	54.9	80.9	54.79	42.4	64.3	37.06	31.0	42.4
Quadrula pustulosa	17	48.40	38.2	55.9	45.26	37.2	52.8	27.30	20.5	35.7

Appendix A-2. (Continued)

TRM 520-521 and Year 1988	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	2	93.00	90.9	95.1	71.65	71.3	72.0	49.35	47.6	51.1
Amblema plicata	12	97.95	73.2	115.3	72.45	53.0	86.1	43.01	33.3	52.1
Anodonta grandis	3	101.60	81.7	119.9	59.83	53.6	65.3	44.00	34.5	50.4
Cyclonaias tuberculata	50	75.88	64.3	88.6	64.96	55.2	75.2	38.08	32.2	44.9
Ellipsaria lineolata	9	79.49	65.1	100.0	59.98	47.5	70.6	37.53	32.7	50.3
Elliptio crassidens	52	104.08	92.4	124.5	66.17	60.1	84.9	42.50	34.1	50.7
Elliptio dilatata	1	96.80	96.8	96.8	45.40	45.4	45.4	26.90	26.9	26.9
Lampsilis ovata	1	110.70	110.7	110.7	76.90	76.9	76.9	61.80	61.8	61.8
Ligumia recta	2	156.05	144.4	167.7	57.45	54.2	60.7	48.65	44.4	52.9
Megalonaias nervosa	4	155.25	144.2	170.2	109.25	100.8	117.2	59.88	53.3	65.6
Pleurobema cordatum	52	91.03	68.5	110.1	73.16	54.9	83.6	46.47	38.2	54.8
Potamilus alatus	10	132.07	114.9	151.0	96.46	76.3	113.4	39.75	34.4	48.3
Quadrula metanevra	6	80.70	66.7	92.1	63.15	54.2	70.1	43.43	38.4	47.3
Quadrula pustulosa	5	57.08	52.2	68.8	52.20	46.9	61.3	34.66	31.3	37.3
Tritogonia verrucosa	3	101.07	91.8	109.4	55.10	50.5	57.4	27.93	23.2	34.0

TRM 520-521 and Year 1990	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	2	97.35	96.0	98.7	72.15	71.4	72.9	49.60	47.6	51.6
Amblema plicata	5	100.30	76.6	120.1	71.08	54.5	87.2	41.74	33.6	47.2
Anodonta grandis	1	136.30	136.3	136.3	76.70	76.7	76.7	51.00	51.0	51.0
Anodonta imbecillis	1	52.00	52.0	52.0	24.80	24.8	24.8	14.30	14.3	14.3
Cyclonaias tuberculata	50	77.43	62.0	111.0	65.32	52.1	92.1	37.12	28.0	46.5
Ellipsaria lineolata	16	85.20	64.2	94.8	63.94	51.6	71.3	37.67	32.1	44.6
Elliptio crassidens	50	109.49	87.5	130.1	68.71	62.4	79.9	42.94	36.3	50.2
Leptodea fragilis	2	100.15	89.9	110.4	67.65	62.7	72.6	37.85	36.5	39.2
Megalonaias nervosa	2	164.85	155.6	174.1	115.65	110.7	120.6	56.20	56.2	56.2
Obliquaria reflexa	2	45.40	44.5	46.3	36.80	36.7	36.9	26.60	25.4	27.8
Pleurobema cordatum	34	91.89	75.6	110.1	71.37	59.5	82.4	42.27	32.9	52.0
Potamilus alatus	13	141.24	131.6	152.9	105.18	83.3	120.9	55.30	37.2	139.8
Quadrula metanevra	2	73.35	65.2	81.5	53.60	48.1	59.1	39.40	35.5	43.3
Quadrula pustulosa	17	52.47	45.7	64.1	49.12	42.8	55.7	31.34	25.3	37.5
Tritogonia verrucosa	1	94.00	94.0	94.0	52.20	52.2	52.2	32.50	32.5	32.5

Appendix A-2. (Continued)

TRM 520-521 and Year 1992	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	1	94.80	94.8	94.8	65.40	65.4	65.4	49.60	49.6	49.6
Amblema plicata	2	119.45	114.2	124.7	85.55	84.7	86.4	51.95	49.1	54.8
Anodonta grandis	1	131.50	131.5	131.5	84.90	84.9	84.9	57.20	57.2	57.2
Cyclonaias tuberculata	44	78.27	63.2	89.0	65.77	53.4	87.1	37.92	30.8	44.7
Ellipsaria lineolata	8	86.17	69.6	95.5	65.55	49.7	75.1	38.46	31.3	44.8
Elliptio crassidens	43	104.55	88.4	116.5	65.75	55.6	74.3	42.35	27.2	51.7
Ligumia recta	2	153.05	148.0	158.1	59.65	56.9	62.4	48.50	47.3	49.7
Megalonaias nervosa	1	182.10	182.1	182.1	116.20	116.2	116.2	58.40	58.4	58.4
Obliquaria reflexa	1	52.70	52.7	52.7	41.60	41.6	41.6	29.80	29.8	29.8
Pleurobema cordatum	26	89.13	64.7	104.0	70.92	60.9	82.9	43.46	37.5	51.2
Potamilus alatus	6	141.35	124.8	155.3	105.82	98.1	114.8	42.15	35.2	45.4
Quadrula metanevra	2	82.65	82.5	82.8	62.55	61.7	63.4	42.80	42.0	43.6
Quadrula pustulosa	14	52.09	45.3	57.4	48.60	40.2	54.9	31.74	25.2	37.9
Tritogonia verrucosa	2	108.60	100.9	116.3	60.15	59.4	60.9	33.45	31.3	35.6

TRM 520-521 and Year 1994	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	2	97.85	84.7	111.0	65.95	59.2	72.7	43.10	35.0	51.2
Cyclonaias tuberculata	46	77.77	66.2	91.1	65.59	58.4	74.3	38.82	32.9	48.9
Ellipsaria lineolata	7	82.13	76.1	89.6	63.57	57.7	69.0	37.46	32.9	42.1
Elliptio crassidens	65	108.95	96.8	128.7	68.19	61.3	88.6	43.51	36.6	50.4
Megalonaias nervosa	1	180.20	180.2	180.2	119.70	119.7	119.7	69.00	69.0	69.0
Pleurobema cordatum	35	90.84	59.8	107.7	72.35	58.1	86.8	45.37	35.5	53.0
Potamilus alatus	2	129.80	128.3	131.3	103.60	99.6	107.6	38.90	38.5	39.3
Quadrula metanevra	3	71.60	68.4	75.5	56.63	54.4	59.5	40.67	39.9	42.2
Quadrula pustulosa	6	55.28	52.1	57.3	51.02	46.6	54.5	32.85	28.9	35.1

Appendix A-2. (Continued)

TRM 520-521 and Year 1996	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	2	101.80	78.2	125.4	68.60	52.4	84.9	36.70	26.7	46.7
Cyclonaias tuberculata	18	79.90	73.0	91.3	67.10	58.4	75.6	39.30	34.6	45.3
Ellipsaria lineolata	2	79.50	69.7	89.3	59.90	48.0	71.9	37.60	30.8	44.3
Elliptio crassidens	61	108.80	97.8	127.2	66.30	56.9	75.2	43.50	34.2	50.2
Elliptio dilatata	1	95.40	95.4	95.4	41.00	41.0	41.0	29.70	29.7	29.7
Lampsilis abrupta	1	99.40	99.4	99.4	73.10	73.1	73.1	55.30	55.3	55.3
Ligumia recta	1	160.00	160.0	160.0	61.10	61.1	61.1	49.40	49.4	49.4
Pleurobema cordatum	27	94.50	82.8	107.7	72.50	67.2	79.2	46.20	39.0	53.0
Potamilus alatus	3	117.10	98.2	133.0	70.40	60.1	79.9	36.80	28.9	45.5
Quadrula pustulosa	1	56.60	56.6	56.6	54.90	54.9	54.9	34.50	34.5	34.5

TRM 520-521 and Year 1997	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Cyclonaias tuberculata	31	78.50	67.0	91.4	65.40	56.5	73.7	41.60	35.6	49.8
Ellipsaria lineolata	5	83.10	56.4	105.5	61.00	45.9	71.6	41.60	33.8	52.6
Elliptio crassidens	52	107.70	92.2	120.8	64.90	53.7	73.1	44.40	34.7	51.1
Obliquaria reflexa	1	50.60	50.6	50.6	34.70	34.7	34.7	33.90	33.9	33.9
Pleurobema cordatum	28	93.40	83.1	117.2	71.70	60.2	92.3	47.50	41.7	52.8
Potamilus alatus	2	113.60	105.7	121.4	70.00	63.3	76.6	36.00	33.3	38.8
Quadrula pustulosa	9	56.60	49.7	65.2	51.50	45.2	57.9	36.00	30.9	45.6

Appendix A-2. (Continued)

TRM 520-521 and Years 1983-1997	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	16	99.43	90.9	112.3	72.23	65.3	80.1	49.66	40.3	54.9
Amblema plicata	44	97.36	73.2	125.4	71.11	52.4	87.2	42.46	26.7	54.8
Anodonta grandis	7	116.96	81.7	136.3	68.73	53.6	84.9	47.76	34.5	57.2
Anodonta imbecillis	3	47.90	39.2	52.5	22.30	17.4	24.8	11.90	7.1	14.3
Cyclonaias tuberculata	556	75.83	56.9	111.0	64.66	47.6	92.1	37.61	23.7	49.8
Cyprogenia stegaria	3	54.07	51.6	57.7	52.23	49.7	55.6	38.83	36.0	44.1
Dromus dromas	1	60.10	60.1	60.1	58.30	58.3	58.3	32.80	32.8	32.8
Ellipsaria lineolata	112	79.78	51.8	105.5	60.54	39.2	75.1	36.80	22.6	52.6
Elliptio crassidens	727	105.54	87.2	151.8	65.89	53.7	88.6	42.08	21.0	60.9
Elliptio dilatata	8	102.20	95.4	113.3	44.42	41.0	48.8	31.81	26.9	39.9
Lampsilis abrupta	10	95.94	82.3	110.6	70.10	60.7	80.7	49.74	43.4	60.4
Lampsilis ovata	7	120.07	102.1	139.1	82.83	72.9	92.3	62.01	55.9	69.4
Lasmigona costata	1	122.10	122.1	122.1	69.90	69.9	69.9	25.50	25.5	25.5
Leptodea fragilis	4	85.67	59.6	110.4	54.50	34.6	72.6	30.48	20.1	39.2
Ligumia recta	24	147.75	107.7	170.2	56.85	45.0	63.4	45.05	33.1	52.9
Megalonaias nervosa	13	160.78	144.2	182.1	109.98	97.6	120.6	58.48	52.4	69.0
Obliquaria reflexa	7	46.50	36.5	52.7	34.72	24.1	41.6	26.83	22.9	33.9
Pleurobema cordatum	586	90.78	54.9	117.2	72.00	44.7	92.3	44.50	25.2	59.8
Pleurobema oviforme	1	72.90	72.9	72.9	56.50	56.5	56.5	40.20	40.2	40.2
Pleurobema plenum	3	59.43	51.3	68.9	56.10	49.4	66.0	41.47	36.4	48.6
Pleurobema rubrum	1	80.70	80.7	80.7	64.30	64.3	64.3	44.50	44.5	44.5
Potamilus alatus	87	129.80	46.9	160.0	92.11	60.1	120.9	39.49	26.8	139.8
Ptychobranchus fasciolaris	1	94.40	94.4	94.4	56.70	56.7	56.7	34.80	34.8	34.8
Quadrula metanevra	63	74.52	54.9	92.1	58.85	42.4	70.3	41.10	31.0	50.6
Quadrula pustulosa	186	52.89	38.2	74.1	49.94	37.2	64.3	31.68	20.5	45.6
Tritogonia verrucosa	8	99.40	76.7	116.3	54.16	42.7	60.9	29.87	19.7	36.1

Appendix A-2. (Continued)

TRM 526-527 and Year 1983	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	1	105.50	105.5	105.5	70.30	70.3	70.3	53.60	53.6	53.6
Amblema plicata	41	98.06	76.5	121.1	73.71	56.6	99.7	46.80	34.8	56.9
Anodonta grandis	22	124.84	101.6	154.6	68.28	55.3	89.6	53.76	39.6	67.9
Cyclonaias tuberculata	32	82.55	66.4	94.7	70.40	60.8	78.1	40.98	34.2	49.8
Ellipsaria lineolata	13	90.57	71.1	96.5	71.33	61.5	78.6	42.22	36.6	50.9
Elliptio crassidens	104	112.07	93.1	134.2	69.83	59.4	79.1	44.82	36.3	52.5
Elliptio dilatata	1	102.20	102.2	102.2	46.30	46.3	46.3	31.20	31.2	31.2
Lampsilis abrupta	1	103.10	103.1	103.1	84.40	84.4	84.4	58.20	58.2	58.2
Leptodea fragilis	1	112.40	112.4	112.4	66.40	66.4	66.4	32.70	32.7	32.7
Ligumia recta	2	162.50	160.0	165.0	66.05	63.8	68.3	55.35	54.0	56.7
Megalonaias nervosa	3	173.83	164.4	180.6	117.43	111.7	120.7	60.50	57.2	63.0
Obliquaria reflexa	18	54.35	45.1	64.1	44.40	35.3	51.5	34.88	25.5	41.4
Plethobasus cyphyus	2	91.80	89.3	94.3	64.55	62.8	66.3	45.00	43.6	46.4
Pleurobema cordatum	94	98.39	81.1	129.1	78.17	62.2	99.5	49.67	39.0	62.9
Potamilus alatus	27	142.29	96.6	162.8	104.00	79.3	120.9	38.95	24.1	46.5
Quadrula metanevra	7	84.54	75.1	92.2	64.21	60.1	71.1	47.81	44.0	50.9
Quadrula pustulosa	63	57.01	46.2	66.0	55.09	46.3	66.0	35.49	28.2	43.8
Tritogonia verrucosa	17	110.26	96.0	128.7	58.53	54.3	64.1	36.48	30.1	42.7

Appendix A-2. (Continued)

TRM 526-527 and Year 1984	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	16	100.54	84.8	120.1	73.24	62.3	88.0	44.96	38.9	52.4
Anodonta grandis	8	127.31	104.3	144.3	68.77	56.6	74.1	50.76	42.1	54.6
Anodonta imbecillis	1	54.70	54.7	54.7	23.20	23.2	23.2	16.90	16.9	16.9
Cyclonaias tuberculata	7	80.50	66.6	92.6	70.53	60.5	80.9	37.67	31.5	43.1
Ellipsaria lineolata	12	90.98	62.7	109.7	70.40	50.4	86.0	40.49	31.3	50.2
Elliptio crassidens	100	111.95	96.9	130.8	70.98	60.5	82.4	44.64	38.2	53.1
Lampsilis abrupta	3	98.63	96.4	100.2	70.80	66.1	74.8	57.07	54.7	60.2
Lampsilis ovata	1	139.80	139.8	139.8	92.60	92.6	92.6	68.80	68.8	68.8
Leptodea fragilis	5	109.62	104.5	118.1	65.02	62.1	68.4	35.10	30.9	38.4
Megalonaias nervosa	1	180.00	180.0	180.0	130.20	130.2	130.2	63.00	63.0	63.0
Obliquaria reflexa	9	55.80	49.2	64.0	43.27	36.1	52.3	34.44	26.3	39.8
Pleurobema cordatum	31	98.37	82.0	119.1	77.38	69.3	99.8	47.24	40.6	58.7
Potamilus alatus	23	153.90	132.3	182.1	105.20	80.5	134.5	41.12	36.8	46.5
Quadrula metanevra	1	79.10	79.1	79.1	64.60	64.6	64.6	54.90	54.9	54.9
Quadrula pustulosa	29	59.12	50.2	66.8	55.92	49.5	61.7	34.46	29.4	40.8
Tritogonia verrucosa	6	118.87	94.2	134.9	61.53	56.1	66.8	38.98	29.3	44.8

Appendix A-2. (Continued)

TRM 526-527		Length			Height			Thickness		
and Year 1985	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	20	100.06	84.1	119.5	71.56	58.2	84.8	43.86	36.1	56.7
Anodonta grandis	6	122.98	108.7	142.6	72.18	62.9	80.4	50.47	41.9	58.7
Cyclonaias tuberculata	11	82.09	73.5	91.5	70.28	62.1	76.6	39.97	35.6	42.7
Ellipsaria lineolata	13	89.20	80.9	100.4	69.52	62.3	76.9	39.52	34.9	46.8
Elliptio crassidens	105	111.88	90.7	134.8	70.36	60.1	82.9	43.96	34.2	53.7
Elliptio dilatata	1	100.80	100.8	100.8	44.20	44.2	44.2	34.80	34.8	34.8
Lampsilis ovata	2	127.20	120.8	133.6	81.15	76.1	86.2	63.05	61.5	64.6
Leptodea fragilis	4	103.30	86.9	114.7	61.30	55.4	66.8	34.38	30.2	39.8
Ligumia recta	1	170.10	170.1	170.1	72.40	72.4	72.4	50.10	50.1	50.1
Megalonaias nervosa	1	190.80	190.8	190.8	121.10	121.1	121.1	57.10	57.1	57.1
Obliquaria reflexa	8	57.25	52.4	66.9	43.74	40.1	50.8	33.39	30.1	36.6
Pleurobema cordatum	52	103.59	83.6	160.2	81.47	66.5	134.9	46.31	34.3	54.4
Potamilus alatus	49	143.15	104.7	170.2	103.43	81.6	125.6	40.52	28.4	49.6
Quadrula metanevra	3	85.90	80.6	88.9	67.27	64.7	70.3	43.80	40.2	50.3
Quadrula pustulosa	43	60.61	46.3	72.3	57.34	32.1	68.1	36.61	28.9	44.2
Tritogonia verrucosa	17	125.20	92.3	148.8	61.35	40.6	70.0	40.43	34.1	48.7

Appendix A-2. (Continued)

TRM 526-527 and Year 1986	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	27	97.68	66.7	121.4	69.54	50.6	84.9	44.09	26.8	57.4
Anodonta grandis	8	125.85	80.9	147.8	70.95	50.7	82.0	52.32	35.1	63.2
Cyclonaias tuberculata	17	79.26	63.2	96.7	67.04	55.9	80.2	39.89	33.1	51.0
Ellipsaria lineolata	7	96.04	83.6	112.3	70.80	61.5	78.2	43.99	34.1	52.5
Elliptio crassidens	105	113.05	92.3	145.2	68.73	59.1	87.1	43.35	35.1	54.1
Elliptio dilatata	1	107.10	107.1	107.1	50.00	50.0	50.0	35.40	35.4	35.4
Lampsilis abrupta	1	114.80	114.8	114.8	77.70	77.7	77.7	57.20	57.2	57.2
Lampsilis ovata	1	132.90	132.9	132.9	91.30	91.3	91.3	72.60	72.6	72.6
Leptodea fragilis	6	100.25	80.1	112.1	57.62	46.6	67.5	31.87	25.3	36.0
Ligumia recta	2	158.55	153.1	164.0	67.00	66.4	67.6	49.75	48.8	50.7
Megalonaias nervosa	2	145.80	124.6	167.0	103.25	87.2	119.3	58.35	57.0	59.7
Obliquaria reflexa	10	55.84	46.6	66.7	44.39	34.1	52.4	34.92	25.7	41.2
Pleurobema cordatum	38	96.12	75.7	117.9	75.20	63.2	83.5	47.08	42.4	56.3
Potamilus alatus	38	142.16	79.8	174.0	90.65	56.7	112.8	40.22	26.7	57.9
Quadrula metanevra	1	81.40	81.4	81.4	70.40	70.4	70.4	55.30	55.3	55.3
Quadrula pustulosa	20	57.10	42.4	67.0	54.51	42.4	66.1	33.57	25.7	40.0
Tritogonia verrucosa	20	111.93	87.1	133.0	56.05	47.6	66.7	33.90	24.7	42.9

Appendix A-2. (Continued)

TRM 526-527 and Year 1988	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	1	107.60	107.6	107.6	76.80	76.8	76.8	55.40	55.4	55.4
Amblema plicata	22	105.73	64.8	117.6	77.38	51.1	89.3	49.21	34.8	56.9
Anodonta grandis	19	131.44	101.0	155.1	72.65	56.1	89.9	55.26	43.5	71.2
Anodonta imbecillis	1	54.00	54.0	54.0	24.10	24.1	24.1	16.20	16.2	16.2
Cyclonaias tuberculata	8	82.56	63.4	94.7	71.49	60.7	78.1	41.26	31.3	45.0
Ellipsaria lineolata	4	88.22	81.7	94.3	68.20	61.5	72.8	40.80	38.4	42.3
Elliptio crassidens	51	113.30	100.1	129.2	70.47	44.2	79.3	45.82	39.9	55.3
Lampsilis abrupta	2	96.10	93.4	98.8	69.75	69.5	70.0	57.50	51.4	63.6
Lampsilis ovata	1	139.90	139.9	139.9	90.40	90.4	90.4	77.30	77.3	77.3
Leptodea fragilis	9	98.76	70.4	126.3	61.44	44.9	76.0	32.27	23.8	39.8
Obliquaria reflexa	7	54.84	44.2	62.7	43.20	36.2	49.6	32.27	24.4	36.0
Pleurobema cordatum	31	100.33	83.4	113.9	79.15	70.3	89.2	49.45	43.1	54.5
Pleurobema rubrum	1	88.30	88.3	88.3	69.50	69.5	69.5	46.70	46.7	46.7
Potamilus alatus	29	147.89	110.3	187.7	109.59	86.7	131.2	41.57	31.0	50.3
Quadrula pustulosa	21	58.90	52.6	64.0	55.89	46.6	64.1	36.14	30.0	40.6
Tritogonia verrucosa	13	114.88	96.3	140.8	64.74	50.1	76.3	41.53	29.7	50.7

Appendix A-2. (Continued)

TRM 526-527 and Year 1990	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	1	115.40	115.4	115.4	82.60	82.6	82.6	58.30	58.3	58.3
Amblema plicata	4	102.48	87.2	112.4	73.68	66.7	80.7	48.68	43.4	50.9
Anodonta grandis	17	136.27	108.7	159.1	76.23	61.5	99.9	56.54	44.4	68.8
Anodonta suborbiculata	1	126.20	126.2	126.2	96.40	96.4	96.4	48.30	48.3	48.3
Cyclonaias tuberculata	5	80.92	73.5	86.7	69.12	64.2	72.2	39.28	35.8	43.2
Ellipsaria lineolata	3	87.13	64.7	101.6	67.33	53.1	76.9	41.37	39.5	42.3
Elliptio crassidens	50	115.95	104.0	149.3	71.21	61.4	82.1	45.56	38.3	51.0
Lampsilis abrupta	1	98.10	98.1	98.1	83.70	83.7	83.7	62.10	62.1	62.1
Leptodea fragilis	5	111.74	101.8	130.1	69.30	61.0	89.5	36.24	32.8	40.0
Ligumia recta	1	173.10	173.1	173.1	73.50	73.5	73.5	59.90	59.9	59.9
Obliquaria reflexa	6	57.62	48.5	64.6	45.73	39.6	49.9	36.08	29.9	45.1
Pleurobema cordatum	24	102.52	90.2	120.7	78.21	69.0	90.6	48.51	41.7	52.8
Potamilus alatus	28	146.09	120.1	169.1	108.90	88.4	126.3	40.99	33.1	47.7
Quadrula metanevra	2	84.35	77.9	90.8	66.20	62.3	70.1	50.65	49.9	51.4
Quadrula pustulosa	26	60.05	50.1	74.4	55.38	44.9	66.9	35.37	28.0	42.1
Tritogonia verrucosa	7	105.43	78.1	130.1	56.16	43.4	65.9	35.67	26.6	42.5

Appendix A-2. (Continued)

TRM 526-527		Length			Height			Thickness		
and Year 1992	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	6	99.72	94.7	105.1	73.83	65.5	82.1	47.28	44.7	51.6
Anodonta grandis	4	129.70	122.0	136.8	73.85	67.3	79.2	58.88	54.0	65.1
Cyclonaias tuberculata	12	84.87	75.5	92.4	70.85	64.1	75.4	40.52	36.5	43.2
Ellipsaria lineolata	3	95.83	94.6	96.7	73.90	71.1	77.2	41.23	36.1	44.5
Elliptio crassidens	42	113.78	100.1	126.7	71.49	63.2	81.6	45.96	39.1	52.3
Lampsilis abrupta	2	107.55	99.8	115.3	72.35	66.3	78.4	52.55	52.2	52.9
Megalonaias nervosa	3	170.43	155.9	183.2	122.43	112.2	128.2	61.77	53.1	69.3
Obliquaria reflexa	4	57.75	52.0	61.5	44.05	40.9	47.9	33.78	30.9	36.7
Plethobasus cyphyus	1	91.40	91.4	91.4	64.80	64.8	64.8	50.30	50.3	50.3
Pleurobema cordatum	27	103.31	82.5	127.9	78.67	68.5	90.7	45.82	39.5	49.7
Potamilus alatus	5	142.44	116.6	161.2	106.72	94.0	116.9	40.20	35.1	47.4
Quadrula metanevra	3	79.53	75.7	87.2	61.43	58.3	66.5	44.37	40.9	48.2
Quadrula pustulosa	16	58.32	51.5	64.7	54.97	50.1	62.7	35.34	30.3	44.8
Tritogonia verrucosa	7	105.57	77.0	127.3	58.67	43.1	66.7	37.10	21.7	48.3

TRM 526-527		Length			Height			Thickness		
and Year 1994	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	11	108.42	97.6	119.1	78.67	72.2	89.7	49.41	45.2	54.7
Anodonta grandis	7	135.29	121.4	142.7	79.13	66.7	85.1	57.84	47.6	64.6
Cyclonaias tuberculata	8	79.01	72.0	85.1	68.94	63.7	73.5	38.94	34.8	41.6
Ellipsaria lineolata	1	96.10	96.1	96.1	76.70	76.7	76.7	42.30	42.3	42.3
Elliptio crassidens	85	116.05	96.5	129.8	72.99	62.5	82.4	46.66	39.4	52.9
Lampsilis abrupta	1	101.20	101.2	101.2	86.10	86.1	86.1	65.40	65.4	65.4
Leptodea fragilis	2	117.15	112.2	122.1	74.05	71.2	76.9	39.70	39.4	40.0
Ligumia recta	1	161.40	161.4	161.4	73.30	73.3	73.3	61.20	61.2	61.2
Obliquaria reflexa	11	57.30	52.8	69.5	45.68	41.4	51.7	35.04	29.6	42.7
Plethobasus cyphyus	1	88.60	88.6	88.6	59.40	59.4	59.4	46.20	46.2	46.2
Pleurobema cordatum	19	103.80	83.1	116.5	79.25	69.1	90.1	48.48	37.4	57.6
Potamilus alatus	5	153.00	131.9	168.6	117.24	109.4	128.5	43.88	38.4	46.5
Quadrula pustulosa	30	57.93	49.5	66.0	54.34	45.7	64.1	35.61	27.1	49.9
Tritogonia verrucosa	5	113.86	95.8	127.7	56.80	52.4	60.6	36.54	30.7	39.9

Appendix A-2. (Continued)

TRM 526-527 and Year 1996	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	6	103.30	84.0	117.1	73.70	59.1	86.5	49.20	41.0	57.3
Anodonta grandis	6	144.90	130.6	160.0	84.20	71.9	102.4	58.50	52.1	64.2
Cyclonaias tuberculata	7	84.50	75.5	87.9	69.80	67.8	71.5	42.30	40.0	46.5
Ellipsaria lineolata	4	94.40	89.0	100.9	71.10	66.5	75.6	43.30	42.0	44.4
Elliptio crassidens	29	118.20	101.4	151.1	73.10	63.5	82.5	48.40	42.3	56.9
Lampsilis abrupta	2	115.70	109.1	122.4	84.30	83.0	85.5	63.00	59.1	66.9
Megalonaias nervosa	1	180.00	180.0	180.0	123.60	123.6	123.6	66.00	66.0	66.0
Obliquaria reflexa	6	56.10	51.8	59.6	43.90	39.8	50.1	36.40	33.4	40.3
Pleurobema cordatum	20	102.60	77.1	120.9	79.30	65.2	91.2	50.20	41.2	56.0
Potamilus alatus	28	148.90	125.9	180.0	83.90	70.8	97.3	41.30	32.2	51.5
Quadrula metanevra	1	77.80	77.8	77.8	61.00	61.0	61.0	51.60	51.6	51.6
Quadrula pustulosa	9	59.60	50.6	68.6	55.40	48.9	60.0	38.10	31.3	47.7
Tritogonia verrucosa	3	101.60	88.5	127.5	54.20	49.4	60.8	35.50	29.6	40.3

TRM 526-527 and Year 1997	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	4	100.60	73.5	123.0	71.90	57.0	78.9	47.40	35.1	53.2
Anodonta grandis	1	147.00	147.0	147.0	81.00	81.0	81.0	63.40	63.4	63.4
Cyclonaias tuberculata	3	86.20	75.3	96.8	71.10	60.4	78.8	42.70	37.8	49.4
Ellipsaria lineolata	1	85.10	85.1	85.1	71.60	71.6	71.6	41.50	41.5	41.5
Elliptio crassidens	50	115.60	96.7	131.5	71.50	58.8	80.5	46.90	39.6	59.8
Leptodea fragilis	2	92.20	69.3	115.0	56.10	40.5	71.7	26.90	21.5	37.3
Obliquaria reflexa	2	55.80	54.2	57.4	45.70	44.6	46.7	34.80	33.0	36.6
Pleurobema cordatum	18	103.20	93.5	112.6	77.60	70.5	83.9	52.40	43.8	57.3
Potamilus alatus	6	154.00	142.4	166.9	87.10	78.4	95.8	43.20	39.7	48.9
Quadrula metanevra	1	85.00	85.0	85.0	65.70	65.7	65.7	45.40	45.4	45.4
Quadrula pustulosa	6	60.50	53.7	65.3	55.80	51.6	58.9	37.20	31.9	42.0
Tritogonia verrucosa	1	109.60	109.6	109.6	52.80	52.8	52.8	38.30	38.3	38.3

Appendix A-2. (Continued)

TRM 526-527 and Years 1983-1997	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	3	109.50	105.5	115.4	76.57	70.3	82.6	55.77	53.6	58.3
Amblema plicata	157	100.74	64.8	123.0	73.92	50.6	99.7	46.47	26.8	57.4
Anodonta grandis	98	130.67	80.9	160.0	73.11	50.7	102.4	54.85	35.1	71.2
Anodonta imbecillis	2	54.35	54.0	54.7	23.65	23.2	24.1	16.55	16.2	16.9
Anodonta suborbiculata	1	126.20	126.2	126.2	96.40	96.4	96.4	48.30	48.3	48.3
Cyclonaias tuberculata	110	82.01	63.2	96.8	69.81	55.9	80.9	40.37	31.3	51.0
Ellipsaria lineolata	61	91.17	62.7	112.3	70.50	50.4	86.0	41.38	31.3	52.5
Elliptio crassidens	721	113.59	90.7	151.1	70.76	44.2	87.1	45.15	34.2	59.8
Elliptio dilatata	3	103.37	100.8	107.1	46.83	44.2	50.0	33.80	31.2	35.4
Lampsilis abrupta	13	103.98	93.4	122.4	76.00	66.1	86.1	58.47	51.4	65.4
Lampsilis ovata	5	133.40	120.8	139.9	87.32	76.1	92.6	68.96	61.5	77.3
Leptodea fragilis	34	104.16	69.3	130.1	63.01	40.5	89.5	33.58	21.5	40.0
Ligumia recta	7	163.81	153.1	173.1	69.33	63.8	73.5	54.49	48.8	61.2
Megalonaias nervosa	11	170.47	124.6	190.8	118.27	87.2	130.2	60.87	53.1	69.3
Obliquaria reflexa	81	56.00	44.2	69.5	44.35	34.1	52.4	34.63	24.4	45.1
Plethobasus cyphyus	4	90.90	88.6	94.3	63.33	59.4	66.3	46.63	43.6	50.3
Pleurobema cordatum	354	100.51	75.7	160.2	78.49	62.2	134.9	48.39	34.3	62.9
Pleurobema rubrum	1	88.30	88.3	88.3	69.50	69.5	69.5	46.70	46.7	46.7
Potamilus alatus	238	145.99	79.8	187.7	91.15	56.7	134.5	40.76	24.1	57.9
Quadrula metanevra	19	83.16	75.1	92.2	64.72	58.3	71.1	47.77	40.2	55.3
Quadrula pustulosa	263	58.64	42.4	74.4	55.53	32.1	68.1	35.59	25.7	49.9
Tritogonia verrucosa	96	113.63	77.0	148.8	59.09	40.6	76.3	37.46	21.7	50.7

Appendix A-2. (Continued)

TRM 528-529 and Year 1983	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	2	102.95	92.5	113.4	72.95	69.3	76.6	53.40	48.3	58.5
Amblema plicata	5	103.20	84.7	132.3	75.74	64.1	94.6	40.42	30.4	51.3
Anodonta grandis	6	111.01	83.0	128.0	63.24	46.1	72.3	46.23	35.4	54.9
Cyclonaias tuberculata	43	82.19	66.8	96.5	69.89	57.3	79.9	40.56	32.6	46.6
Cyprogenia stegaria	2	56.45	52.9	60.0	51.14	50.9	51.4	38.71	36.8	40.6
Ellipsaria lineolata	12	90.16	66.4	108.8	67.22	52.4	76.8	42.40	36.6	51.3
Elliptio crassidens	105	110.49	86.8	134.6	68.14	54.4	89.9	43.39	34.9	56.1
Elliptio dilatata	1	95.30	95.3	95.3	44.10	44.1	44.1	30.50	30.5	30.5
Fusconaia subrotunda	1	66.09	66.1	66.1	53.56	53.6	53.6	36.58	36.6	36.6
Lampsilis abrupta	7	94.00	70.5	106.4	70.46	59.4	80.4	51.68	39.8	60.1
Lampsilis ovata	1	132.30	132.3	132.3	91.64	91.6	91.6	76.30	76.3	76.3
Leptodea fragilis	1	81.70	81.7	81.7	48.20	48.2	48.2	29.50	29.5	29.5
Ligumia recta	3	155.31	145.8	160.1	62.95	60.3	65.1	51.84	50.6	53.8
Obliquaria reflexa	1	49.00	49.0	49.0	39.70	39.7	39.7	34.30	34.3	34.3
Pleurobema cordatum	105	97.39	73.3	114.2	76.61	59.3	86.7	49.44	32.3	61.2
Potamilus alatus	5	126.89	110.3	141.8	88.62	69.1	119.8	39.26	34.5	44.1
Quadrula metanevra	13	75.86	46.9	92.6	59.96	42.2	74.4	42.98	26.2	54.7
Quadrula pustulosa	57	57.27	44.8	69.9	54.45	42.1	66.9	35.05	28.8	43.5
Tritogonia verrucosa	1	106.72	106.7	106.7	62.81	62.8	62.8	32.64	32.6	32.6

Appendix A-2. (Continued)

TRM 528-529 and Year 1984	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	2	109.55	99.4	119.7	81.00	74.0	88.0	53.25	53.1	53.4
Amblema plicata	8	95.05	73.6	113.8	71.76	59.5	84.3	37.02	26.8	48.4
Anodonta grandis	1	102.70	102.7	102.7	56.90	56.9	56.9	39.60	39.6	39.6
Cyclonaias tuberculata	23	82.19	69.4	99.1	69.40	60.3	79.1	39.06	33.5	46.3
Ellipsaria lineolata	14	84.82	63.6	108.7	63.59	50.1	78.3	39.51	34.1	46.3
Elliptio crassidens	101	112.00	94.7	129.8	69.07	58.0	78.5	43.58	36.0	54.5
Elliptio dilatata	1	92.60	92.6	92.6	43.70	43.7	43.7	21.50	21.5	21.5
Lampsilis abrupta	4	96.70	86.8	106.8	68.78	64.6	74.0	57.80	52.9	62.4
Lampsilis ovata	3	132.67	118.5	142.7	88.90	82.0	102.7	70.83	63.5	76.7
Leptodea fragilis	1	119.90	119.9	119.9	66.50	66.5	66.5	40.80	40.8	40.8
Ligumia recta	9	162.78	146.6	185.2	60.77	56.1	66.6	51.30	44.0	54.9
Obliquaria reflexa	1	51.20	51.2	51.2	40.20	40.2	40.2	30.80	30.8	30.8
Pleurobema cordatum	103	98.58	76.1	132.6	77.42	52.1	90.6	47.97	34.2	79.9
Pleurobema oviforme	2	69.80	63.5	76.1	55.70	50.6	60.8	40.35	40.0	40.7
Potamilus alatus	10	139.25	110.2	163.2	91.64	72.5	102.3	40.80	34.3	44.8
Quadrula metanevra	9	84.71	72.5	94.8	67.19	56.9	76.1	46.33	39.7	50.9
Quadrula pustulosa	56	58.80	46.4	72.0	55.34	44.4	64.8	34.54	20.2	40.9
Tritogonia verrucosa	3	104.83	84.6	121.4	59.37	49.5	64.4	29.40	24.3	32.4

Appendix A-2. (Continued)

TRM 528-529 and Year 1985	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	6	104.13	92.7	113.4	72.30	66.8	80.3	50.88	46.6	54.6
Amblema plicata	19	108.21	76.3	132.5	79.99	62.9	94.9	42.61	30.5	54.4
Anodonta grandis	4	123.38	107.9	130.1	65.80	60.9	69.6	46.20	40.7	50.1
Cyclonaias tuberculata	41	82.26	70.5	94.6	68.68	59.5	78.4	38.85	32.0	44.9
Ellipsaria lineolata	15	90.71	70.1	98.4	68.05	52.2	76.1	40.40	36.4	44.7
Elliptio crassidens	100	114.33	99.1	130.5	69.92	20.1	84.7	44.20	36.1	52.4
Lampsilis abrupta	6	103.77	92.6	113.3	75.07	64.4	81.1	56.83	50.6	64.4
Lampsilis ovata	6	128.43	114.0	142.0	84.58	70.0	103.4	62.65	57.3	70.2
Lasmigona complanata	1	180.20	180.2	180.2	114.30	114.3	114.3	40.30	40.3	40.3
Leptodea fragilis	1	88.20	88.2	88.2	50.20	50.2	50.2	28.60	28.6	28.6
Ligumia recta	6	168.92	154.4	180.3	64.07	60.2	72.4	53.33	49.9	60.4
Megalonaias nervosa	2	173.70	172.2	175.2	118.25	116.8	119.7	66.15	60.9	71.4
Obliquaria reflexa	3	54.67	50.5	58.8	43.13	40.2	46.8	33.50	30.9	36.7
Pleurobema cordatum	105	96.94	76.3	112.2	76.82	60.6	89.9	46.09	34.1	59.1
Pleurobema plenum	1	84.60	84.6	84.6	70.20	70.2	70.2	50.60	50.6	50.6
Pleurobema rubrum	2	91.60	90.4	92.8	73.20	71.6	74.8	50.60	49.8	51.4
Potamilus alatus	13	140.13	102.6	155.2	102.73	80.6	119.5	41.25	30.6	46.8
Quadrula metanevra	2	80.70	76.9	84.5	63.45	62.8	64.1	48.90	43.6	54.2
Quadrula pustulosa	69	57.78	48.5	80.5	54.68	44.8	68.8	34.83	26.3	42.8
Tritogonia verrucosa	1	136.10	136.1	136.1	72.00	72.0	72.0	34.00	34.0	34.0

Appendix A-2. (Continued)

TRM 528-529 and Year 1986	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	4	103.52	88.2	116.3	71.28	63.2	75.7	48.63	43.4	52.8
Amblema plicata	15	113.97	80.9	137.4	79.28	58.0	94.9	43.03	27.8	55.3
Anodonta grandis	6	117.00	102.2	135.2	64.53	57.0	79.4	46.35	37.2	56.7
Cyclonaias tuberculata	42	81.98	68.4	94.3	69.32	57.0	79.3	39.83	33.0	48.1
Ellipsaria lineolata	15	89.69	63.9	110.8	66.99	50.1	78.8	41.21	35.1	53.3
Elliptio crassidens	99	112.84	93.4	136.2	68.64	53.8	85.2	42.61	31.0	55.5
Elliptio dilatata	1	111.20	111.2	111.2	52.60	52.6	52.6	42.20	42.2	42.2
Lampsilis abrupta	3	98.33	90.3	108.6	72.07	66.4	76.2	53.30	50.7	56.7
Lampsilis ovata	1	152.20	152.2	152.2	101.40	101.4	101.4	72.00	72.0	72.0
Leptodea fragilis	3	90.10	79.4	111.1	51.33	47.3	59.1	29.23	26.7	33.1
Ligumia recta	9	155.47	135.3	173.1	58.03	48.0	64.5	50.77	44.5	55.9
Megalonaias nervosa	1	175.60	175.6	175.6	117.90	117.9	117.9	58.00	58.0	58.0
Obliquaria reflexa	2	51.45	50.7	52.2	36.15	32.0	40.3	25.75	21.6	29.9
Pleurobema cordatum	99	95.61	74.4	116.0	74.47	57.4	84.8	46.86	36.2	61.9
Pleurobema oviforme	2	68.90	68.4	69.4	50.70	48.6	52.8	35.60	33.0	38.2
Potamilus alatus	19	141.82	112.8	164.1	90.17	72.9	123.6	41.89	30.9	79.6
Quadrula metanevra	4	83.83	75.7	91.2	68.80	61.1	84.2	50.20	46.4	54.1
Quadrula pustulosa	35	56.95	46.5	71.6	53.18	43.4	64.2	33.65	24.7	42.1
Tritogonia verrucosa	1	78.80	78.8	78.8	41.40	41.4	41.4	26.70	26.7	26.7

Appendix A-2. (Continued)

TRM 528-529 and Year 1988	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Amblema plicata	14	101.22	82.3	119.8	74.19	63.5	89.8	44.59	32.1	52.0
Anodonta grandis	7	125.20	109.7	136.1	66.87	57.6	81.3	52.64	48.4	58.7
Anodonta suborbiculata	1	107.80	107.8	107.8	79.20	79.2	79.2	38.70	38.7	38.7
Cyclonaias tuberculata	29	83.77	67.2	97.5	69.95	58.9	97.7	41.00	36.1	49.3
Ellipsaria lineolata	10	93.77	83.5	102.8	69.20	62.1	77.4	41.00	36.1	44.5
Elliptio crassidens	51	112.93	99.6	136.4	69.48	61.3	76.2	44.49	36.3	54.6
Elliptio dilatata	2	103.25	95.6	110.9	45.45	40.8	50.1	29.15	27.5	30.8
Lampsilis abrupta	10	101.72	86.8	119.8	72.11	62.7	79.8	57.43	51.9	60.9
Lampsilis ovata	1	140.50	140.5	140.5	87.70	87.7	87.7	58.00	58.0	58.0
Leptodea fragilis	3	102.97	98.2	106.4	60.70	56.7	63.0	31.67	28.8	34.0
Ligumia recta	5	161.96	146.6	175.1	64.36	62.0	68.7	53.08	50.2	55.1
Megalonaias nervosa	5	164.90	155.1	170.8	118.14	110.4	126.6	61.18	53.6	68.7
Pleurobema cordatum	50	99.99	86.1	119.1	78.51	69.2	87.5	48.33	39.4	58.6
Pleurobema oviforme	2	72.20	70.2	74.2	55.00	54.0	56.0	40.70	40.7	40.7
Potamilus alatus	15	139.96	118.6	155.2	107.58	90.1	120.9	40.10	34.8	49.3
Quadrula metanevra	2	91.25	90.7	91.8	67.40	67.2	67.6	52.10	50.6	53.6
Quadrula pustulosa	51	58.83	36.1	81.1	55.00	40.7	98.4	35.02	26.2	43.1
Tritogonia verrucosa	2	115.75	98.3	133.2	56.80	51.4	62.2	43.55	26.7	60.4

Appendix A-2. (Continued)

TRM 528-529 and Year 1990	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	2	120.90	120.8	121.0	81.30	80.1	82.5	60.95	60.1	61.8
Amblema plicata	1	110.20	110.2	110.2	75.70	75.7	75.7	38.50	38.5	38.5
Anodonta grandis	2	127.75	126.4	129.1	74.10	69.2	79.0	52.95	46.8	59.1
Cyclonaias tuberculata	14	87.13	76.3	94.9	73.68	66.8	83.3	40.56	34.1	49.6
Ellipsaria lineolata	9	85.23	72.7	102.3	64.28	53.2	74.6	41.13	36.2	47.4
Elliptio crassidens	60	119.35	104.6	134.7	72.48	61.1	82.7	46.00	38.2	51.6
Elliptio dilatata	1	94.60	94.6	94.6	46.90	46.9	46.9	28.60	28.6	28.6
Lampsilis abrupta	3	108.57	101.0	120.6	83.23	81.8	86.0	62.17	55.7	67.7
Lampsilis ovata	1	121.70	121.7	121.7	78.10	78.1	78.1	68.30	68.3	68.3
Leptodea fragilis	1	124.70	124.7	124.7	69.60	69.6	69.6	39.70	39.7	39.7
Ligumia recta	1	172.10	172.1	172.1	68.30	68.3	68.3	58.70	58.7	58.7
Megalonaias nervosa	1	170.10	170.1	170.1	118.40	118.4	118.4	57.10	57.1	57.1
Obliquaria reflexa	3	56.40	54.8	58.0	42.90	40.3	46.4	30.37	28.5	31.7
Pleurobema cordatum	74	98.21	85.4	116.8	76.30	67.2	90.1	47.50	39.6	56.9
Pleurobema oviforme	1	72.80	72.8	72.8	56.00	56.0	56.0	41.70	41.7	41.7
Potamilus alatus	4	124.70	83.2	147.6	101.20	72.6	116.9	36.65	21.5	43.5
Ptychobranchus fasciolaris	1	116.80	116.8	116.8	61.40	61.4	61.4	44.70	44.7	44.7
Quadrula metanevra	4	89.70	85.3	100.7	66.98	60.2	71.5	48.43	46.3	51.8
Quadrula pustulosa	35	58.17	44.1	82.8	54.31	43.3	67.4	34.77	25.2	45.4
Tritogonia verrucosa	1	136.30	136.3	136.3	70.90	70.9	70.9	34.70	34.7	34.7

Appendix A-2. (Continued)

TRM 528-529		Length			Height			Thickness		
and Year 1992	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	5	106.76	89.9	118.2	78.08	68.4	88.8	39.76	24.9	50.4
Cyclonaias tuberculata	12	82.04	70.3	97.1	70.42	59.6	79.4	39.90	29.5	44.5
Ellipsaria lineolata	3	96.67	90.8	99.6	68.43	67.9	69.1	40.80	39.6	42.2
Elliptio crassidens	52	117.40	99.7	136.6	71.86	63.2	83.3	45.77	39.2	53.3
Lampsilis abrupta	4	109.50	96.8	116.3	75.78	68.8	83.4	55.78	50.7	59.8
Ligumia recta	1	165.70	165.7	165.7	60.70	60.7	60.7	59.90	59.9	59.9
Obliquaria reflexa	1	59.30	59.3	59.3	42.90	42.9	42.9	28.90	28.9	28.9
Pleurobema cordatum	29	102.50	86.8	119.8	78.50	72.0	94.2	49.27	39.3	59.8
Potamilus alatus	5	145.50	139.3	150.1	103.32	90.6	109.4	42.50	39.0	46.8
Quadrula metanevra	3	75.00	61.9	84.7	61.57	60.7	62.0	44.23	37.4	47.7
Quadrula pustulosa	18	57.97	52.2	66.9	53.86	47.6	59.7	33.30	28.2	40.3

TRM 528-529		Length			Height			Thickness		
and Year 1994	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Cyclonaias tuberculata	10	81.57	58.4	91.2	67.30	50.3	72.9	39.50	28.3	46.9
Ellipsaria lineolata	3	97.83	94.0	100.2	71.60	69.5	73.1	46.57	44.4	48.6
Elliptio crassidens	66	115.95	104.6	129.2	71.54	62.5	84.7	45.53	39.2	50.8
Lampsilis abrupta	1	108.90	108.9	108.9	82.30	82.3	82.3	65.90	65.9	65.9
Leptodea fragilis	1	118.70	118.7	118.7	70.50	70.5	70.5	39.40	39.4	39.4
Megalonaias nervosa	1	168.70	168.7	168.7	119.20	119.2	119.2	58.70	58.7	58.7
Pleurobema cordatum	41	100.75	84.4	110.7	77.52	68.1	86.3	47.35	34.3	62.7
Pleurobema oviforme	1	71.90	71.9	71.9	59.80	59.8	59.8	41.70	41.7	41.7
Potamilus alatus	3	158.20	145.7	172.3	119.43	108.8	128.6	45.40	43.6	46.5
Quadrula metanevra	1	81.90	81.9	81.9	60.20	60.2	60.2	39.30	39.3	39.3
Quadrula pustulosa	29	58.69	46.2	66.6	54.43	43.8	64.8	35.44	29.8	42.5
Tritogonia verrucosa	2	119.95	99.6	140.3	64.15	58.7	69.6	36.90	31.8	42.0

Appendix A-2. (Continued)

TRM 528-529 and Year 1996	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	3	109.90	100.4	122.5	76.50	72.1	79.0	46.30	38.0	52.3
Anodonta grandis	1	118.10	118.1	118.1	67.70	67.7	67.7	47.40	47.4	47.4
Cyclonaias tuberculata	13	86.50	75.3	94.9	71.90	65.1	80.8	42.50	35.5	47.7
Ellipsaria lineolata	9	94.00	72.6	107.5	68.30	49.7	80.7	44.70	34.5	50.7
Elliptio crassidens	50	114.90	88.9	131.3	68.90	53.5	85.7	46.30	39.4	61.7
Lampsilis abrupta	1	110.10	110.1	110.1	75.70	75.7	75.7	60.30	60.3	60.3
Lasmigona costata	1	118.40	118.4	118.4	60.60	60.6	60.6	35.20	35.2	35.2
Leptodea fragilis	1	126.20	126.2	126.2	71.30	71.3	71.3	40.70	40.7	40.7
Ligumia recta	1	155.00	155.0	155.0	61.90	61.9	61.9	49.50	49.5	49.5
Pleurobema cordatum	46	100.80	85.3	112.5	78.90	65.4	90.5	49.60	38.3	59.6
Potamilus alatus	4	145.90	135.5	154.1	110.60	86.7	131.7	44.20	39.2	46.8
Quadrula metanevra	1	86.10	86.1	86.1	66.10	66.1	66.1	47.70	47.7	47.7
Quadrula pustulosa	19	61.60	53.0	77.3	56.00	49.6	62.5	38.20	31.1	49.5
Tritogonia verrucosa	1	134.10	134.1	134.1	61.30	61.3	61.3	31.60	31.6	31.6

Appendix A-2. (Continued)

TRM 528-529		Length			Height			Thickness		
and Year 1997	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	1	77.60	77.6	77.6	57.10	57.1	57.1	31.50	31.5	31.5
Cyclonaias tuberculata	13	87.40	79.3	96.2	72.70	65.4	78.8	44.10	38.5	51.9
Ellipsaria lineolata	2	77.00	69.4	84.6	57.70	54.3	61.0	38.80	35.5	42.2
Elliptio crassidens	50	116.10	101.7	134.5	68.40	59.1	83.4	45.80	33.5	65.0
Lampsilis ovata	1	115.30	115.3	115.3	74.10	74.1	74.1	69.50	69.5	69.5
Ligumia recta	1	160.00	160.0	160.0	71.50	71.5	71.5	59.60	59.6	59.6
Pleurobema cordatum	36	99.50	87.1	107.9	77.30	68.7	88.4	50.50	42.9	57.1
Potamilus alatus	4	151.50	122.0	168.8	85.00	74.6	92.9	44.90	42.4	46.6
Quadrula metanevra	1	91.00	91.0	91.0	63.50	63.5	63.5	46.40	46.4	46.4
Quadrula pustulosa	9	60.50	49.2	67.3	55.60	48.7	60.7	35.80	28.4	41.8

Appendix A-2. (Continued)

TRM 528-529 and Years 1983-1997	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	16	106.61	88.2	121.0	74.34	63.2	88.0	52.19	43.4	61.8
Amblema plicata	71	105.77	73.6	137.4	76.80	57.1	94.9	42.13	24.9	55.3
Anodonta grandis	27	119.14	83.0	136.1	65.58	46.1	81.3	48.21	35.4	59.1
Anodonta suborbiculata	1	107.80	107.8	107.8	79.20	79.2	79.2	38.70	38.7	38.7
Cyclonaias tuberculata	240	83.12	58.4	99.1	69.95	50.3	97.7	40.27	28.3	51.9
Cyprogenia stegaria	2	56.45	52.9	60.0	51.14	50.9	51.4	38.71	36.8	40.6
Ellipsaria lineolata	92	89.83	63.6	110.8	66.77	50.1	80.7	41.39	34.1	53.3
Elliptio crassidens	734	114.11	86.8	136.6	69.70	20.1	89.9	44.44	31.0	65.0
Elliptio dilatata	6	100.03	92.6	111.2	46.37	40.8	52.6	30.18	21.5	42.2
Fusconaia subrotunda	1	66.09	66.1	66.1	53.56	53.6	53.6	36.58	36.6	36.6
Lampsilis abrupta	39	101.59	70.5	120.6	73.51	59.4	86.0	56.51	39.8	67.7
Lampsilis ovata	14	130.76	114.0	152.2	86.23	70.0	103.4	66.60	57.3	76.7
Lasmigona complanata	1	180.20	180.2	180.2	114.30	114.3	114.3	40.30	40.3	40.3
Lasmigona costata	1	118.40	118.4	118.4	60.60	60.6	60.6	35.20	35.2	35.2
Leptodea fragilis	12	103.22	79.4	126.2	59.36	47.3	71.3	33.45	26.7	40.8
Ligumia recta	36	161.29	135.3	185.2	61.85	48.0	74.1	52.42	44.0	60.4
Megalonaias nervosa	10	168.63	155.1	175.6	118.27	110.4	126.6	61.20	53.6	71.4
Obliquaria reflexa	11	54.15	49.0	59.3	41.20	32.0	46.8	30.65	21.6	36.7
Pleurobema cordatum	688	98.28	73.3	132.6	76.89	52.1	94.2	47.97	32.3	79.9
Pleurobema oviforme	8	70.81	63.5	76.1	54.82	48.6	60.8	39.59	33.0	41.7
Pleurobema plenum	1	84.60	84.6	84.6	70.20	70.2	70.2	50.60	50.6	50.6
Pleurobema rubrum	2	91.60	90.4	92.8	73.20	71.6	74.8	50.60	49.8	51.4
Potamilus alatus	82	140.65	83.2	172.3	98.58	69.1	131.7	41.34	21.5	79.6
Ptychobranchus fasciolaris	1	116.80	116.8	116.8	61.40	61.4	61.4	44.70	44.7	44.7
Quadrula metanevra	40	81.77	46.9	100.7	64.09	42.2	84.2	45.96	26.2	54.7
Quadrula pustulosa	378	58.29	36.1	82.8	54.64	40.7	98.4	34.90	20.2	49.5
Tritogonia verrucosa	12	114.82	78.8	140.3	60.70	41.4	72.0	34.06	24.3	60.4

Appendix A-2. (Continued)

Three Bed Composite and Year 1983	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	5	104.00	92.5	113.4	73.84	69.3	80.1	51.88	46.8	58.5
Amblema plicata	53	96.86	74.4	132.3	72.73	56.6	99.7	45.37	30.4	56.9
Anodonta grandis	28	121.88	83.0	154.6	67.20	46.1	89.6	52.15	35.4	67.9
Cyclonaias tuberculata	147	79.14	62.1	96.5	67.90	52.1	80.2	39.50	32.4	49.8
Cyprogenia stegaria	3	54.83	51.6	60.0	50.66	49.7	51.4	37.81	36.0	40.6
Dromus dromas	1	60.10	60.1	60.1	58.30	58.3	58.3	32.80	32.8	32.8
Ellipsaria lineolata	45	85.29	56.8	108.8	65.74	44.6	78.6	40.30	30.1	51.3
Elliptio crassidens	311	107.96	86.8	134.6	67.29	54.0	89.9	42.93	21.0	56.1
Elliptio dilatata	5	103.32	95.3	113.3	45.50	42.2	48.8	32.38	30.5	34.7
Fusconaia subrotunda	1	66.09	66.1	66.1	53.56	53.6	53.6	36.58	36.6	36.6
Lampsilis abrupta	10	94.39	70.5	106.4	71.17	59.4	84.4	50.94	39.8	60.1
Lampsilis ovata	4	124.93	122.0	132.3	86.21	74.7	92.3	68.48	62.0	76.3
Leptodea fragilis	4	84.13	59.6	112.4	49.33	34.6	66.4	27.10	20.1	32.7
Ligumia recta	8	155.34	145.1	165.0	62.50	56.6	68.3	50.50	42.5	56.7
Megalonaias nervosa	3	173.83	164.4	180.6	117.43	111.7	120.7	60.50	57.2	63.0
Obliquaria reflexa	20	53.78	45.1	64.1	43.15	24.1	51.5	34.33	24.6	41.4
Plethobasus cyphyus	2	91.80	89.3	94.3	64.55	62.8	66.3	45.00	43.6	46.4
Pleurobema cordatum	301	95.39	72.1	129.1	75.65	59.3	99.5	48.25	31.4	62.9
Pleurobema plenum	1	58.10	58.1	58.1	52.90	52.9	52.9	36.40	36.4	36.4
Potamilus alatus	43	135.39	46.9	162.8	98.20	69.1	120.9	38.12	24.1	46.5
Quadrula metanevra	36	76.52	46.9	92.6	60.28	42.2	74.4	44.22	26.2	54.7
Quadrula pustulosa	158	55.91	43.7	69.9	53.61	40.5	66.9	34.47	26.3	43.8
Tritogonia verrucosa	18	110.06	96.0	128.7	58.77	54.3	64.1	36.27	30.1	42.7

Appendix A-2. (Continued)

Three Bed Composite and Year 1984	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	2	109.55	99.4	119.7	81.00	74.0	88.0	53.25	53.1	53.4
Amblema plicata	30	98.18	73.6	120.1	72.73	59.5	88.0	42.37	26.8	52.4
Anodonta grandis	9	124.58	102.7	144.3	67.46	56.6	74.1	49.52	39.6	54.6
Anodonta imbecillis	2	53.60	52.5	54.7	23.95	23.2	24.7	15.60	14.3	16.9
Cyclonaias tuberculata	131	76.09	59.1	99.1	65.19	52.2	80.9	37.77	29.5	46.3
Cyprogenia stegaria	1	52.90	52.9	52.9	51.40	51.4	51.4	36.40	36.4	36.4
Ellipsaria lineolata	49	82.92	56.6	109.7	62.95	44.0	86.0	37.88	26.3	50.2
Elliptio crassidens	302	109.58	89.2	130.8	68.75	56.3	82.4	43.30	24.4	60.9
Elliptio dilatata	2	96.35	92.6	100.1	42.95	42.2	43.7	24.75	21.5	28.0
Lampsilis abrupta	8	96.66	86.8	106.8	68.52	60.7	74.8	56.31	48.1	62.4
Lampsilis ovata	5	127.98	102.1	142.7	86.44	72.9	102.7	67.56	56.5	76.7
Leptodea fragilis	6	111.33	104.5	119.9	65.27	62.1	68.4	36.05	30.9	40.8
Ligumia recta	14	157.96	140.9	185.2	59.61	50.5	66.6	49.65	40.0	54.9
Megalonaias nervosa	1	180.00	180.0	180.0	130.20	130.2	130.2	63.00	63.0	63.0
Obliquaria reflexa	11	53.63	36.5	64.0	42.05	32.9	52.3	33.06	22.9	39.8
Pleurobema cordatum	234	95.08	62.1	132.6	74.99	44.7	99.8	46.26	32.8	79.9
Pleurobema oviforme	2	69.80	63.5	76.1	55.70	50.6	60.8	40.35	40.0	40.7
Pleurobema plenum	2	60.10	51.3	68.9	57.70	49.4	66.0	44.00	39.4	48.6
Potamilus alatus	47	142.73	96.7	182.1	97.96	72.5	134.5	39.57	30.0	46.5
Ptychobranchus fasciolaris	1	94.40	94.4	94.4	56.70	56.7	56.7	34.80	34.8	34.8
Quadrula metanevra	24	78.68	64.5	94.8	62.47	52.6	76.1	43.05	32.4	54.9
Quadrula pustulosa	138	56.75	40.0	74.1	53.65	39.5	64.8	33.43	20.2	40.9
Tritogonia verrucosa	10	110.44	76.7	134.9	59.00	42.7	66.8	34.18	19.7	44.8

Appendix A-2. (Continued)

Three Bed Composite and Year 1985	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	11	104.72	92.7	113.4	73.72	66.8	80.3	51.75	46.6	54.9
Amblema plicata	42	103.37	76.3	132.5	75.25	58.2	94.9	43.01	30.5	56.7
Anodonta grandis	10	123.14	107.9	142.6	69.63	60.9	80.4	48.76	40.7	58.7
Cyclonaias tuberculata	124	78.39	60.5	94.6	66.76	54.7	78.4	37.85	30.6	44.9
Cyprogenia stegaria	1	57.70	57.7	57.7	55.60	55.6	55.6	44.10	44.1	44.1
Ellipsaria lineolata	35	87.83	62.3	100.4	67.24	46.9	76.9	38.96	32.0	46.8
Elliptio crassidens	306	110.22	90.1	134.8	68.72	20.1	88.5	43.21	29.5	53.7
Elliptio dilatata	2	98.80	96.8	100.8	44.20	44.2	44.2	32.30	29.8	34.8
Lampsilis abrupta	8	101.94	82.3	113.3	74.21	64.4	81.1	55.61	43.5	64.4
Lampsilis ovata	9	127.36	114.0	142.0	84.03	70.0	103.4	62.70	57.3	70.2
Lasmigona complanata	1	180.20	180.2	180.2	114.30	114.3	114.3	40.30	40.3	40.3
Leptodea fragilis	5	100.28	86.9	114.7	59.08	50.2	66.8	33.22	28.6	39.8
Ligumia recta	11	165.39	142.2	180.3	63.30	57.2	72.4	50.06	41.3	60.4
Megalonaias nervosa	5	173.70	160.1	190.8	115.26	102.3	121.1	59.66	52.4	71.4
Obliquaria reflexa	12	55.72	46.6	66.9	42.95	36.1	50.8	32.58	23.4	36.7
Pleurobema cordatum	245	96.42	70.4	160.2	76.58	58.2	134.9	45.35	30.2	59.1
Pleurobema oviforme	1	72.90	72.9	72.9	56.50	56.5	56.5	40.20	40.2	40.2
Pleurobema plenum	1	84.60	84.6	84.6	70.20	70.2	70.2	50.60	50.6	50.6
Pleurobema rubrum	3	87.97	80.7	92.8	70.23	64.3	74.8	48.57	44.5	51.4
Potamilus alatus	77	139.79	98.0	170.2	100.29	76.5	125.6	39.87	28.4	49.6
Quadrula metanevra	16	78.07	67.3	88.9	61.94	56.1	70.3	42.39	36.8	54.2
Quadrula pustulosa	138	57.98	46.3	80.5	54.91	32.1	68.8	34.83	25.7	44.2
Tritogonia verrucosa	19	124.66	92.3	148.8	61.46	40.6	72.0	39.86	34.0	48.7

Appendix A-2. (Continued)

Three Bed Composite and Year 1986	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	8	99.23	88.2	116.3	69.71	63.2	75.7	47.32	40.3	53.8
Amblema plicata	47	103.36	66.7	137.4	73.01	50.6	94.9	43.79	26.8	57.4
Anodonta grandis	16	122.18	80.9	147.8	68.42	50.7	82.0	49.42	35.1	63.2
Anodonta imbecillis	1	39.20	39.2	39.2	17.40	17.4	17.4	7.10	7.1	7.1
Cyclonaias tuberculata	131	76.16	56.9	96.7	64.74	47.6	80.2	37.08	23.7	51.0
Ellipsaria lineolata	37	84.30	51.8	112.3	62.73	39.2	78.8	37.52	22.6	53.3
Elliptio crassidens	304	110.53	87.2	151.8	67.43	53.8	87.1	42.28	31.0	55.5
Elliptio dilatata	3	109.23	107.1	111.2	49.37	45.5	52.6	39.17	35.4	42.2
Lampsilis abrupta	8	100.44	86.1	114.8	72.96	66.3	80.7	52.21	48.3	57.2
Lampsilis ovata	3	141.40	132.9	152.2	94.33	90.3	101.4	66.83	55.9	72.6
Lasmigona costata	1	122.10	122.1	122.1	69.90	69.9	69.9	25.50	25.5	25.5
Leptodea fragilis	9	96.87	79.4	112.1	55.52	46.6	67.5	30.99	25.3	36.0
Ligumia recta	18	147.23	107.7	173.1	56.62	45.0	67.6	46.78	33.1	55.9
Megalonaias nervosa	6	152.35	124.6	175.6	105.20	87.2	119.3	57.80	53.9	63.2
Obliquaria reflexa	12	55.11	46.6	66.7	43.02	32.0	52.4	33.39	21.6	41.2
Pleurobema cordatum	231	92.87	54.9	117.9	72.90	49.7	88.5	45.07	25.2	61.9
Pleurobema oviforme	2	68.90	68.4	69.4	50.70	48.6	52.8	35.60	33.0	38.2
Potamilus alatus	68	139.66	79.8	174.0	89.52	56.7	123.6	39.47	26.7	79.6
Quadrula metanevra	14	74.75	54.9	91.2	59.91	42.4	84.2	42.11	31.0	55.3
Quadrula pustulosa	72	54.97	38.2	71.6	51.68	37.2	66.1	32.13	20.5	42.1
Tritogonia verrucosa	21	110.36	78.8	133.0	55.36	41.4	66.7	33.56	24.7	42.9

Appendix A-2. (Continued)

Three Bed Composite and Year 1988	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	3	97.87	90.9	107.6	73.37	71.3	76.8	51.37	47.6	55.4
Amblema plicata	48	102.47	64.8	119.8	75.22	51.1	89.8	46.31	32.1	56.9
Anodonta grandis	29	126.85	81.7	155.1	69.93	53.6	89.9	53.46	34.5	71.2
Anodonta imbecillis	1	54.00	54.0	54.0	24.10	24.1	24.1	16.20	16.2	16.2
Anodonta suborbiculata	1	107.80	107.8	107.8	79.20	79.2	79.2	38.70	38.7	38.7
Cyclonaias tuberculata	87	79.12	63.4	97.5	67.22	55.2	97.7	39.34	31.3	49.3
Ellipsaria lineolata	23	87.22	65.1	102.8	65.42	47.5	77.4	39.61	32.7	50.3
Elliptio crassidens	154	110.06	92.4	136.4	68.69	44.2	84.9	44.26	34.1	55.3
Elliptio dilatata	3	101.10	95.6	110.9	45.43	40.8	50.1	28.40	26.9	30.8
Lampsilis abrupta	12	100.78	86.8	119.8	71.72	62.7	79.8	57.44	51.4	63.6
Lampsilis ovata	3	130.37	110.7	140.5	85.00	76.9	90.4	65.70	58.0	77.3
Leptodea fragilis	12	99.81	70.4	126.3	61.26	44.9	76.0	32.12	23.8	39.8
Ligumia recta	7	160.27	144.4	175.1	62.39	54.2	68.7	51.81	44.4	55.1
Megalonaias nervosa	9	160.61	144.2	170.8	114.19	100.8	126.6	60.60	53.3	68.7
Obliquaria reflexa	7	54.84	44.2	62.7	43.20	36.2	49.6	32.27	24.4	36.0
Pleurobema cordatum	133	96.57	68.5	119.1	76.57	54.9	89.2	47.87	38.2	58.6
Pleurobema oviforme	2	72.20	70.2	74.2	55.00	54.0	56.0	40.70	40.7	40.7
Pleurobema rubrum	1	88.30	88.3	88.3	69.50	69.5	69.5	46.70	46.7	46.7
Potamilus alatus	54	142.76	110.3	187.7	106.60	76.3	131.2	40.82	31.0	50.3
Quadrula metanevra	8	83.34	66.7	92.1	64.21	54.2	70.1	45.60	38.4	53.6
Quadrula pustulosa	77	58.73	36.1	81.1	55.06	40.7	98.4	35.31	26.2	43.1
Tritogonia verrucosa	18	112.68	91.8	140.8	62.25	50.1	76.3	39.49	23.2	60.4

Appendix A-2. (Continued)

Three Bed Composite and Year 1990	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	5	110.38	96.0	121.0	77.90	71.4	82.6	55.88	47.6	61.8
Amblema plicata	10	102.16	76.6	120.1	72.58	54.5	87.2	44.19	33.6	50.9
Anodonta grandis	20	135.42	108.7	159.1	76.04	61.5	99.9	55.90	44.4	68.8
Anodonta imbecillis	1	52.00	52.0	52.0	24.80	24.8	24.8	14.30	14.3	14.3
Anodonta suborbiculata	1	126.20	126.2	126.2	96.40	96.4	96.4	48.30	48.3	48.3
Cyclonaias tuberculata	69	79.65	62.0	111.0	67.29	52.1	92.1	37.97	28.0	49.6
Ellipsaria lineolata	28	85.42	64.2	102.3	64.41	51.6	76.9	39.18	32.1	47.4
Elliptio crassidens	160	115.21	87.5	149.3	70.91	61.1	82.7	44.91	36.3	51.6
Elliptio dilatata	1	94.60	94.6	94.6	46.90	46.9	46.9	28.60	28.6	28.6
Lampsilis abrupta	4	105.95	98.1	120.6	83.35	81.8	86.0	62.15	55.7	67.7
Lampsilis ovata	1	121.70	121.7	121.7	78.10	78.1	78.1	68.30	68.3	68.3
Leptodea fragilis	8	110.46	89.9	130.1	68.93	61.0	89.5	37.08	32.8	40.0
Ligumia recta	2	172.60	172.1	173.1	70.90	68.3	73.5	59.30	58.7	59.9
Megalonaias nervosa	3	166.60	155.6	174.1	116.57	110.7	120.6	56.50	56.2	57.1
Obliquaria reflexa	11	55.06	44.5	64.6	43.34	36.7	49.9	32.80	25.4	45.1
Pleurobema cordatum	132	97.37	75.6	120.7	75.38	59.5	90.6	46.34	32.9	56.9
Pleurobema oviforme	1	72.80	72.8	72.8	56.00	56.0	56.0	41.70	41.7	41.7
Potamilus alatus	45	142.78	83.2	169.1	107.14	72.6	126.3	44.74	21.5	139.8
Ptychobranchus fasciolaris	1	116.80	116.8	116.8	61.40	61.4	61.4	44.70	44.7	44.7
Quadrula metanevra	8	84.28	65.2	100.7	63.44	48.1	71.5	46.72	35.5	51.8
Quadrula pustulosa	78	57.56	44.1	82.8	53.53	42.8	67.4	34.22	25.2	45.4
Tritogonia verrucosa	9	107.59	78.1	136.3	57.36	43.4	70.9	35.21	26.6	42.5

Appendix A-2. (Continued)

Three Bed Composite and Year 1992	N	Length Mean	Length Min	Length Max	Height Mean	Height Min	Height Max	Thickness Mean	Thickness Min	Thickness Max
Actinonaias ligamentina	1	94.80	94.8	94.8	65.40	65.4	65.4	49.60	49.6	49.6
Amblema plicata	13	105.46	89.9	124.7	77.27	65.5	88.8	45.11	24.9	54.8
Anodonta grandis	5	130.06	122.0	136.8	76.06	67.3	84.9	58.54	54.0	65.1
Cyclonaias tuberculata	68	80.10	63.2	97.1	67.49	53.4	87.1	38.73	29.5	44.7
Ellipsaria lineolata	14	90.49	69.6	99.6	67.96	49.7	77.2	39.56	31.3	44.8
Elliptio crassidens	137	112.26	88.4	136.6	69.83	55.6	83.3	44.75	27.2	53.3
Lampsilis abrupta	6	108.85	96.8	116.3	74.63	66.3	83.4	54.70	50.7	59.8
Ligumia recta	3	157.27	148.0	165.7	60.00	56.9	62.4	52.30	47.3	59.9
Megalonaias nervosa	4	173.35	155.9	183.2	120.88	112.2	128.2	60.93	53.1	69.3
Obliquaria reflexa	6	57.17	52.0	61.5	43.45	40.9	47.9	32.30	28.9	36.7
Plethobasus cyphyus	1	91.40	91.4	91.4	64.80	64.8	64.8	50.30	50.3	50.3
Pleurobema cordatum	82	98.53	64.7	127.9	76.15	60.9	94.2	46.29	37.5	59.8
Potamilus alatus	16	142.99	116.6	161.2	105.32	90.6	116.9	41.65	35.1	47.4
Quadrula metanevra	8	78.61	61.9	87.2	61.76	58.3	66.5	43.92	37.4	48.2
Quadrula pustulosa	48	56.37	45.3	66.9	52.70	40.2	62.7	33.52	25.2	44.8
Tritogonia verrucosa	9	106.24	77.0	127.3	59.00	43.1	66.7	36.29	21.7	48.3

Appendix A-2. (Continued)

Three Bed Composite and Year 1994	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	13	106.79	84.7	119.1	76.72	59.2	89.7	48.44	35.0	54.7
Anodonta grandis	7	135.29	121.4	142.7	79.13	66.7	85.1	57.84	47.6	64.6
Cyclonaias tuberculata	64	78.52	58.4	91.2	66.28	50.3	74.3	38.94	28.3	48.9
Ellipsaria lineolata	11	87.68	76.1	100.2	66.95	57.7	76.7	40.38	32.9	48.6
Elliptio crassidens	216	113.88	96.5	129.8	71.10	61.3	88.6	45.37	36.6	52.9
Lampsilis abrupta	2	105.05	101.2	108.9	84.20	82.3	86.1	65.65	65.4	65.9
Leptodea fragilis	3	117.67	112.2	122.1	72.87	70.5	76.9	39.60	39.4	40.0
Ligumia recta	1	161.40	161.4	161.4	73.30	73.3	73.3	61.20	61.2	61.2
Megalonaias nervosa	2	174.45	168.7	180.2	119.45	119.2	119.7	63.85	58.7	69.0
Obliquaria reflexa	11	57.30	52.8	69.5	45.68	41.4	51.7	35.04	29.6	42.7
Plethobasus cyphyus	1	88.60	88.6	88.6	59.40	59.4	59.4	46.20	46.2	46.2
Pleurobema cordatum	95	97.71	59.8	116.5	75.96	58.1	90.1	46.85	34.3	62.7
Pleurobema oviforme	1	71.90	71.9	71.9	59.80	59.8	59.8	41.70	41.7	41.7
Potamilus alatus	10	149.92	128.3	172.3	115.17	99.6	128.6	43.34	38.4	46.5
Quadrula metanevra	4	74.18	68.4	81.9	57.53	54.4	60.2	40.33	39.3	42.2
Quadrula pustulosa	65	58.02	46.2	66.6	54.08	43.8	64.8	35.28	27.1	49.9
Tritogonia verrucosa	7	115.60	95.8	140.3	58.90	52.4	69.6	36.64	30.7	42.0

Appendix A-2. (Continued)

Three Bed Composite and Year 1996	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	11	104.90	78.2	125.4	73.50	52.4	86.5	46.10	26.7	57.3
Anodonta grandis	7	141.10	118.1	160.0	81.80	67.7	102.4	56.90	47.4	64.2
Cyclonaias tuberculata	38	83.00	73.0	94.9	69.20	58.4	80.8	40.90	34.6	47.7
Ellipsaria lineolata	15	92.20	69.7	107.5	67.90	48.0	80.7	43.40	30.8	50.7
Elliptio crassidens	140	112.90	88.9	151.1	68.60	53.5	85.7	45.50	34.2	61.7
Elliptio dilatata	1	95.40	95.4	95.4	41.00	41.0	41.0	29.70	29.7	29.7
Lampsilis abrupta	4	110.20	99.4	122.4	79.30	73.1	85.5	60.40	55.3	66.9
Lasmigona costata	1	118.40	118.4	118.4	60.60	60.6	60.6	35.20	35.2	35.2
Leptodea fragilis	1	126.20	126.2	126.2	71.30	71.3	71.3	40.70	40.7	40.7
Ligumia recta	2	157.50	155.0	160.0	61.50	61.1	61.9	49.40	49.4	49.5
Megalonaias nervosa	1	180.00	180.0	180.0	123.60	123.6	123.6	66.00	66.0	66.0
Obliquaria reflexa	6	56.10	51.8	59.6	43.90	39.8	50.1	36.40	33.4	40.3
Pleurobema cordatum	93	99.40	77.1	120.9	77.20	65.2	91.2	48.70	38.3	59.6
Potamilus alatus	35	145.90	98.2	180.0	85.80	60.1	131.7	41.30	28.9	51.5
Quadrula metanevra	2	81.90	77.8	86.1	63.50	61.0	66.1	49.60	47.7	51.6
Quadrula pustulosa	29	60.80	50.6	77.3	55.80	48.9	62.5	38.10	31.1	49.5
Tritogonia verrucosa	4	109.70	88.5	134.1	56.00	49.4	61.3	34.50	29.6	40.3

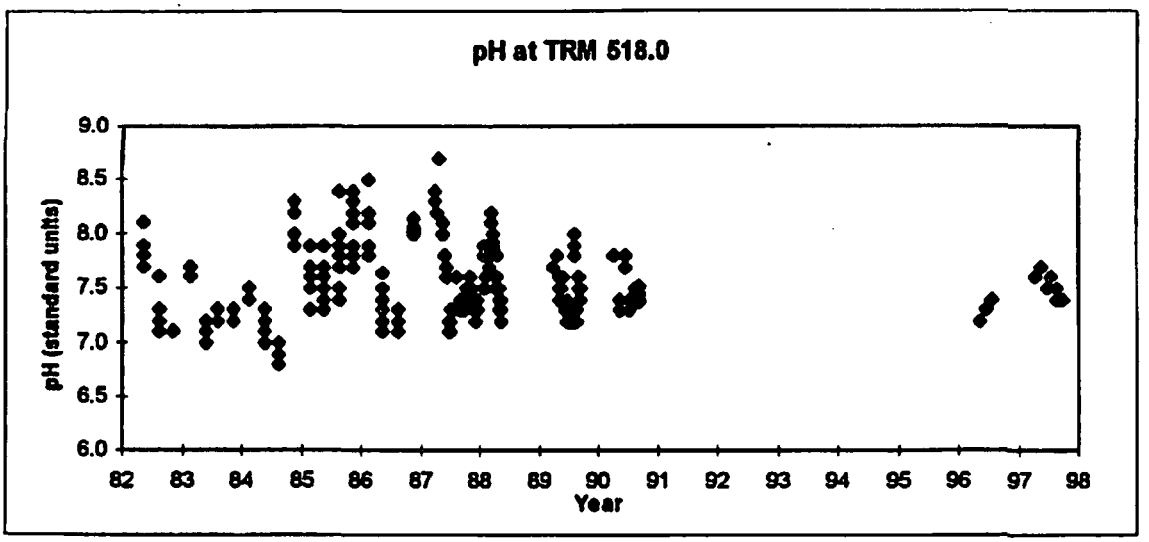
Three Bed Composite and Year 1997	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Amblema plicata	5	96.00	73.5	123.0	68.90	57.0	78.9	44.20	31.5	53.2
Anodonta grandis	1	147.00	147.0	147.0	81.00	81.0	81.0	63.40	63.4	63.4
Cyclonaias tuberculata	47	81.50	67.0	96.8	67.80	56.5	78.8	42.40	35.6	51.9
Ellipsaria lineolata	8	81.80	56.4	105.5	61.50	45.9	71.6	40.90	33.8	52.6
Elliptio crassidens	152	113.10	92.2	134.5	68.20	53.7	83.4	45.70	33.5	65.0
Lampsilis ovata	1	115.30	115.3	115.3	74.10	74.1	74.1	69.50	69.5	69.5
Leptodea fragilis	2	92.20	69.3	115.0	56.10	40.5	71.7	26.90	21.5	37.3
Ligumia recta	1	160.00	160.0	160.0	71.50	71.5	71.5	59.60	59.6	59.6
Obliquaria reflexa	3	54.10	50.6	57.4	42.00	34.7	46.7	34.50	33.0	36.6
Pleurobema cordatum	82	98.20	83.1	117.2	75.50	60.2	92.3	49.90	41.7	57.3
Potamilus alatus	12	146.40	105.7	168.8	83.50	63.3	95.8	42.60	33.3	48.9
Quadrula metanevra	2	88.00	85.0	91.0	64.60	63.5	65.7	45.90	45.4	46.4
Quadrula pustulosa	24	59.00	49.2	67.3	54.10	45.2	60.7	36.20	28.4	45.6
Tritogonia verrucosa	1	109.60	109.6	109.6	52.80	52.8	52.8	38.30	38.3	38.3

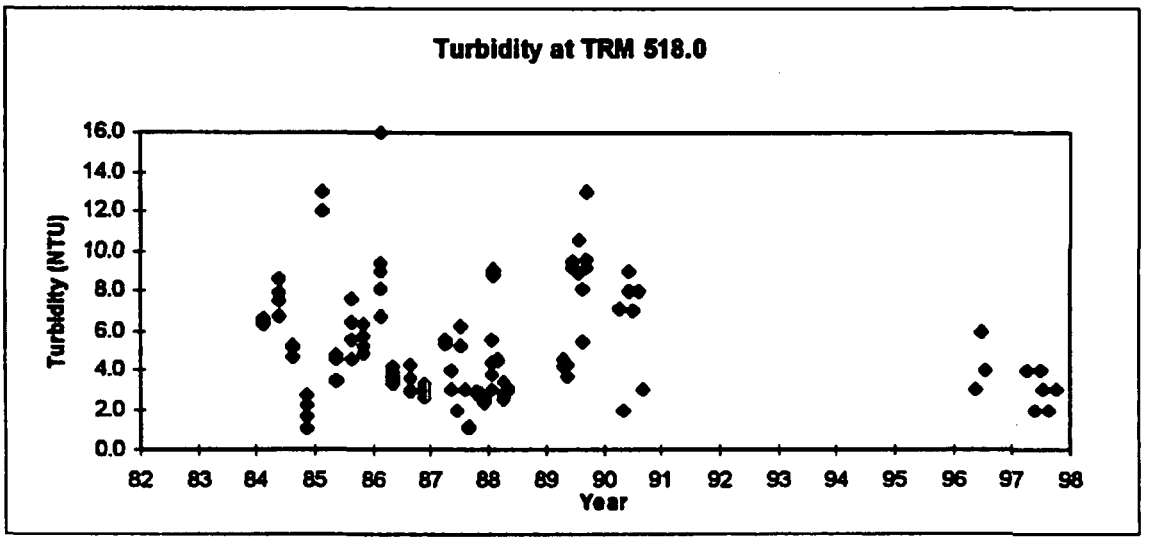
Appendix A-2. (Continued)

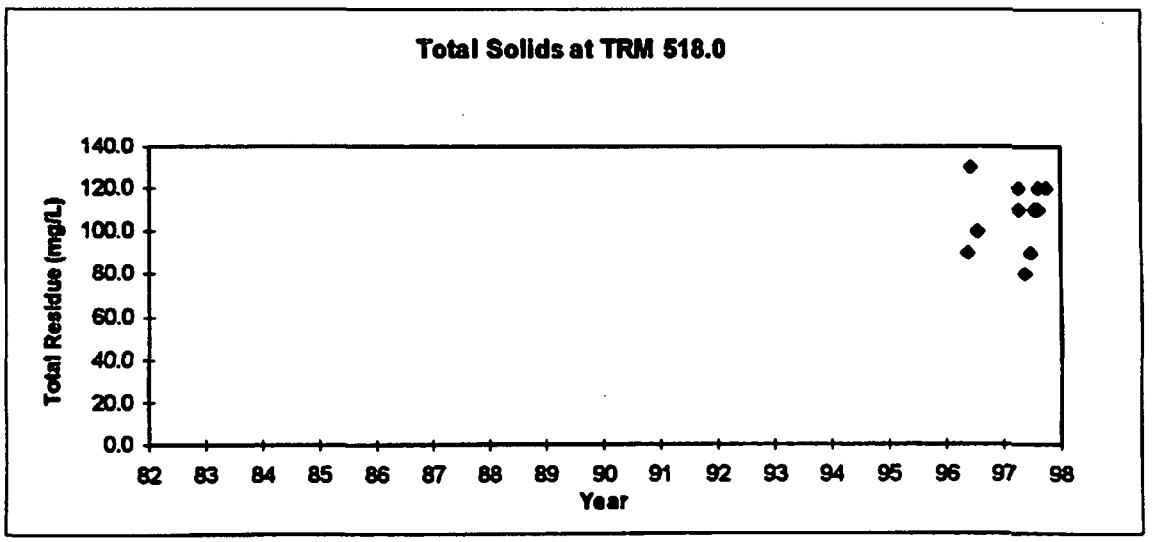
Three Bed Composite and Years 1983-1997	N	Length			Height			Thickness		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Actinonaias ligamentina	35	103.57	88.2	121.0	73.57	63.2	88.0	51.34	40.3	61.8
Amblema plicata	272	101.52	64.8	137.4	73.97	50.6	99.7	44.66	24.9	57.4
Anodonta grandis	132	127.57	80.9	160.0	71.34	46.1	102.4	53.12	34.5	71.2
Anodonta imbecillis	5	50.48	39.2	54.7	22.84	17.4	24.8	13.76	7.1	16.9
Anodonta suborbiculata	2	117.00	107.8	126.2	87.80	79.2	96.4	43.50	38.7	48.3
Cyclonaias tuberculata	897	79.30	56.9	111.0	67.36	47.6	97.7	39.04	23.7	51.9
Cyprogenia stegaria	5	55.02	51.6	60.0	51.80	49.7	55.6	38.78	36.0	44.1
Dromus dromas	1	60.10	60.1	60.1	58.30	58.3	58.3	32.80	32.8	32.8
Ellipsaria lineolata	265	85.90	51.8	112.3	64.99	39.2	86.0	39.27	22.6	53.3
Elliptio crassidens	2182	111.08	86.8	151.8	68.76	20.1	89.9	43.88	21.0	65.0
Elliptio dilatata	17	101.64	92.6	113.3	45.54	40.8	52.6	31.59	21.5	42.2
Fusconaia subrotunda	1	66.09	66.1	66.1	53.56	53.6	53.6	36.58	36.6	36.6
Lampsilis abrupta	62	101.18	70.5	122.4	73.62	59.4	86.1	55.83	39.8	67.7
Lampsilis ovata	26	128.39	102.1	152.2	85.52	70.0	103.4	65.83	55.9	77.3
Lasmigona complanata	1	180.20	180.2	180.2	114.30	114.3	114.3	40.30	40.3	40.3
Lasmigona costata	2	120.25	118.4	122.1	65.25	60.6	69.9	30.35	25.5	35.2
Leptodea fragilis	50	102.46	59.6	130.1	61.45	34.6	89.5	33.30	20.1	40.8
Ligumia recta	67	156.70	107.7	185.2	60.84	45.0	73.5	49.99	33.1	61.2
Megalonaias nervosa	34	166.23	124.6	190.8	115.10	87.2	130.2	60.06	52.4	71.4
Obliquaria reflexa	99	55.12	36.5	69.5	43.32	24.1	52.4	33.63	21.6	45.1
Plethobasus cyphyus	4	90.90	88.6	94.3	63.33	59.4	66.3	46.63	43.6	50.3
Pleurobema cordatum	1628	96.06	54.9	160.2	75.48	44.7	134.9	46.52	25.2	79.9
Pleurobema oviforme	9	71.04	63.5	76.1	55.01	48.6	60.8	39.66	33.0	41.7
Pleurobema plenum	4	65.73	51.3	84.6	59.63	49.4	70.2	43.75	36.4	50.6
Pleurobema rubrum	4	88.05	80.7	92.8	70.05	64.3	74.8	48.10	44.5	51.4
Potamilus alatus	407	141.46	46.9	187.7	98.42	56.7	134.5	40.60	21.5	139.8
Ptychobranchus fasciolaris	2	105.60	94.4	116.8	59.05	56.7	61.4	39.75	34.8	44.7
Quadrula metanevra	122	78.24	46.9	100.7	61.48	42.2	84.2	43.73	26.2	55.3
Quadrula pustulosa	827	57.18	36.1	82.8	53.87	32.1	98.4	34.39	20.2	49.9
Tritogonia verrucosa	116	112.77	76.7	148.8	58.92	40.6	76.3	36.59	19.7	60.4

Appendix B

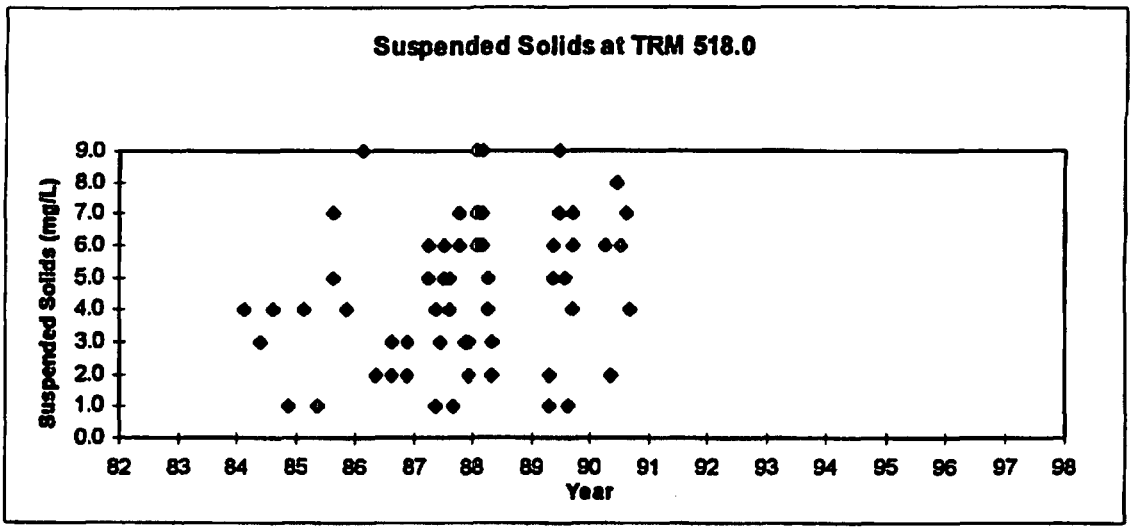
Appendix B-1. Selected water quality values measured during preoperational (1982-1991) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 518.0

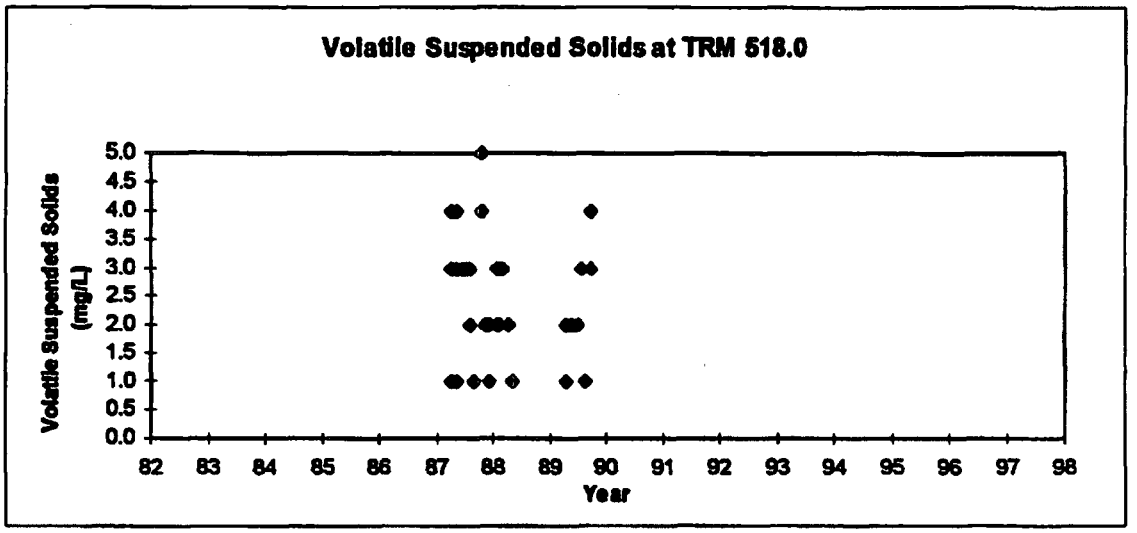


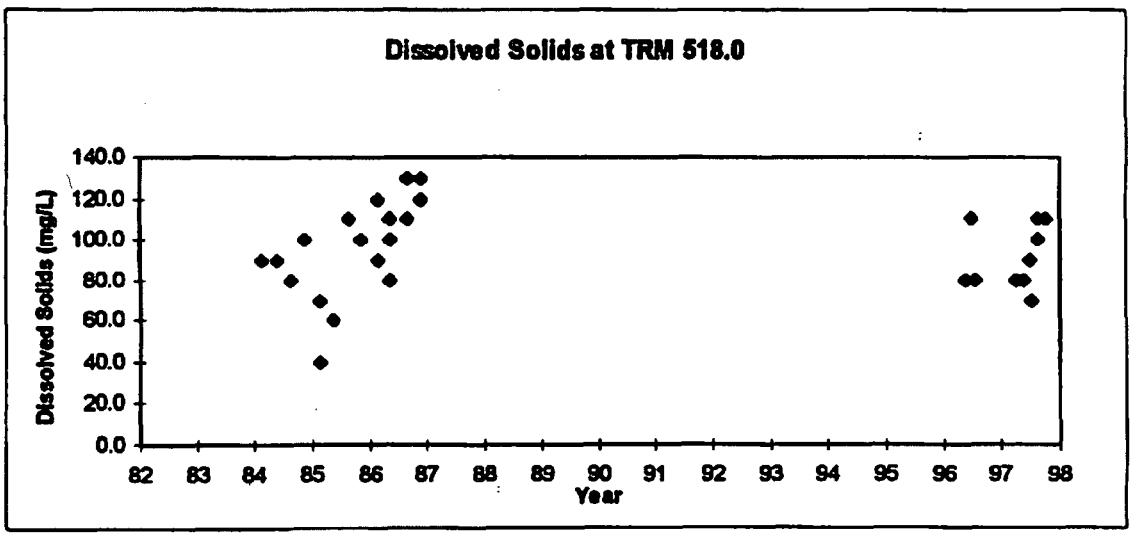




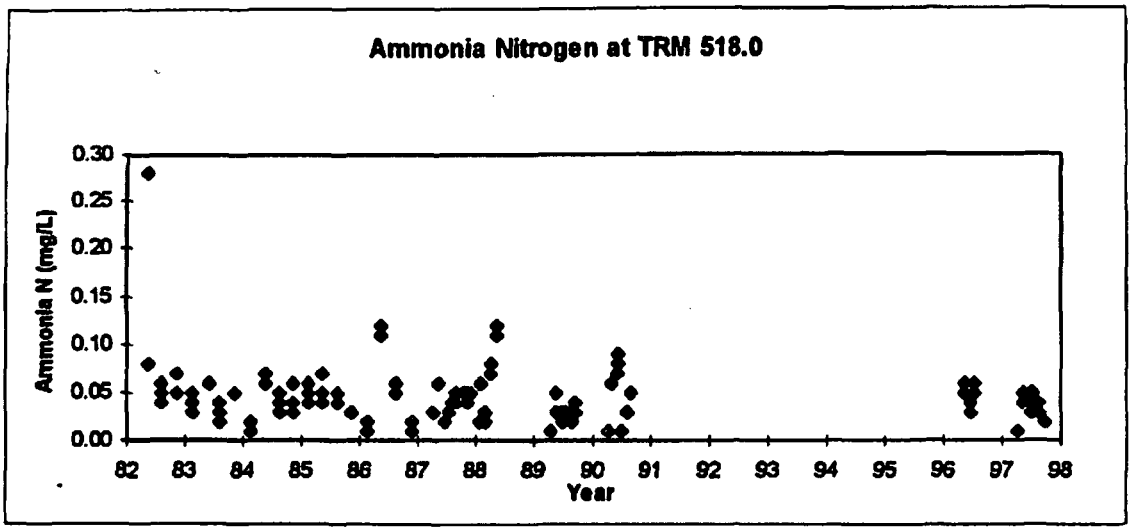
Appendix B-1 (Continued)

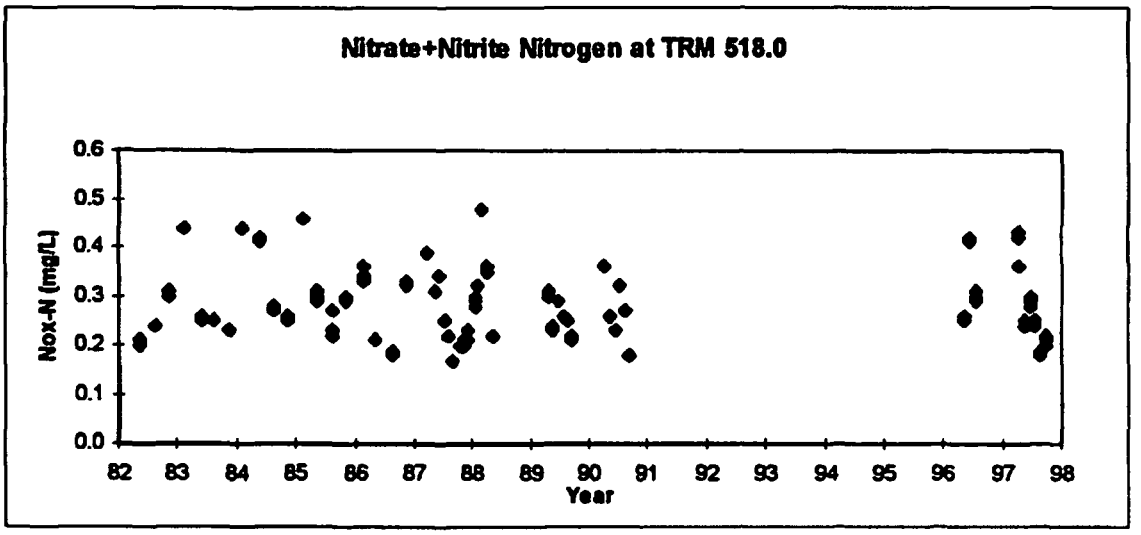


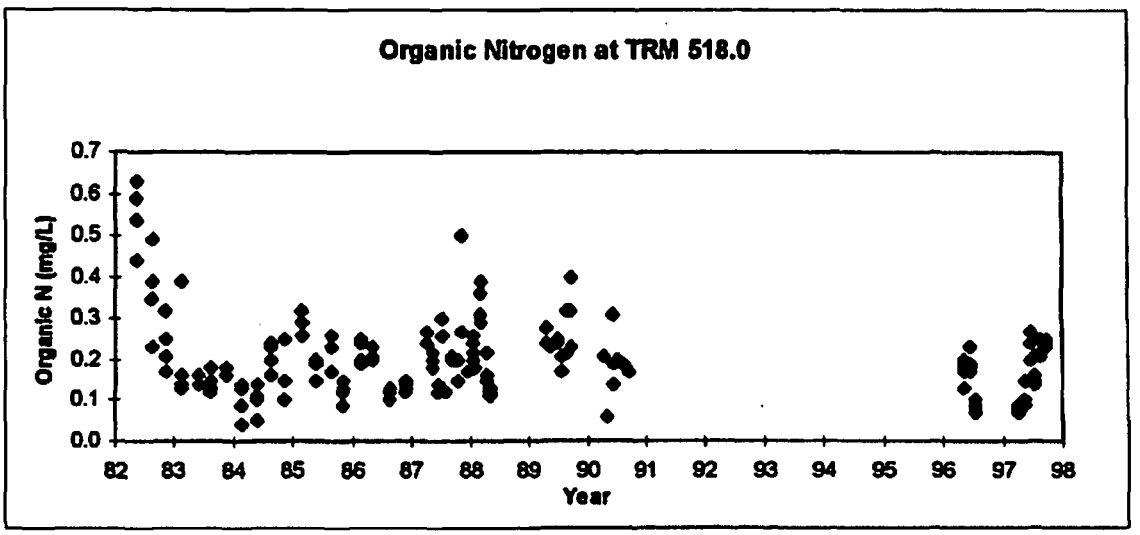




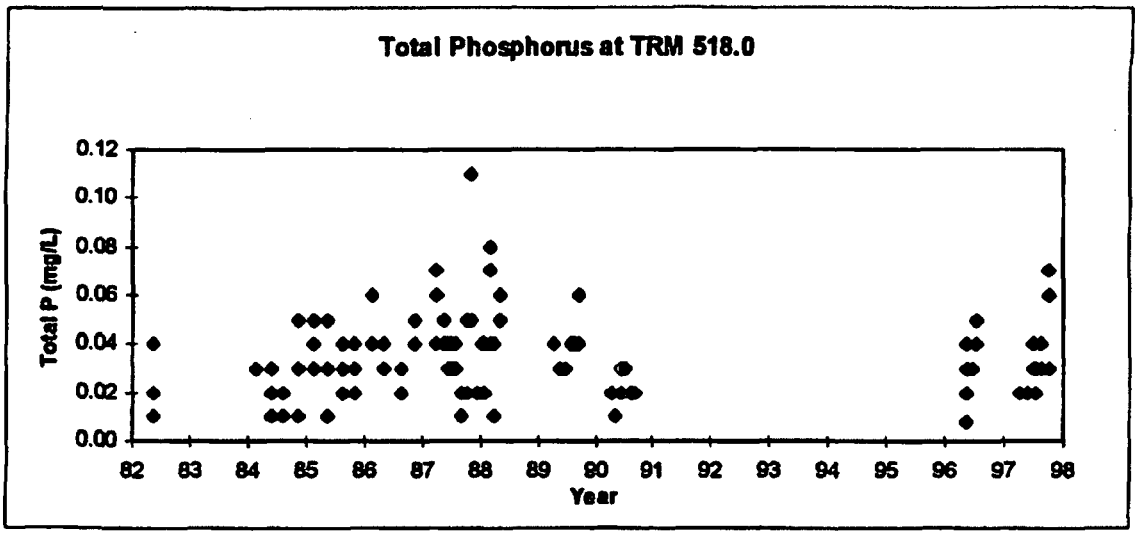
Appendix B-1 (Continued)

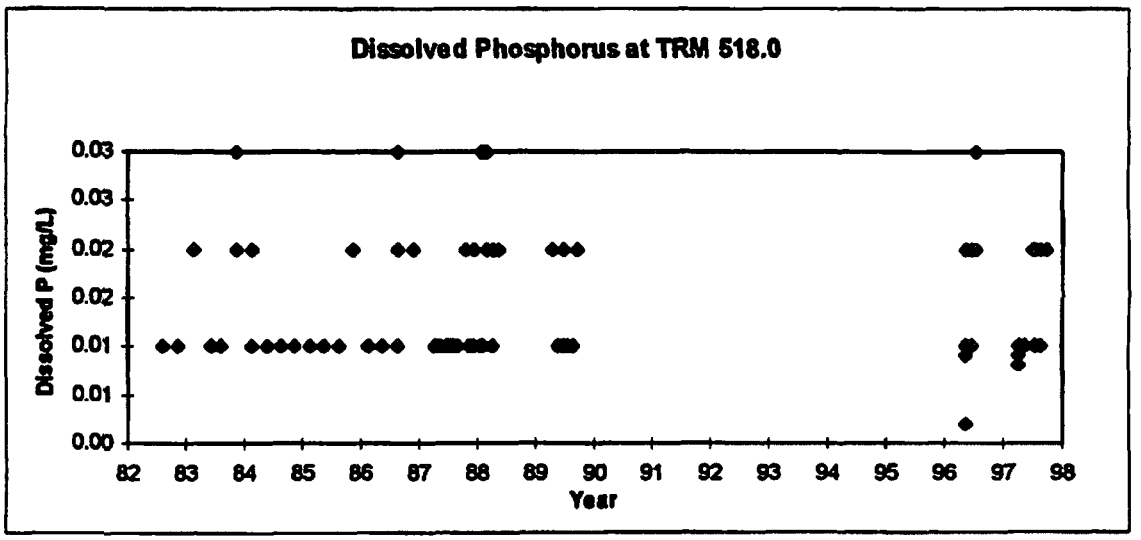


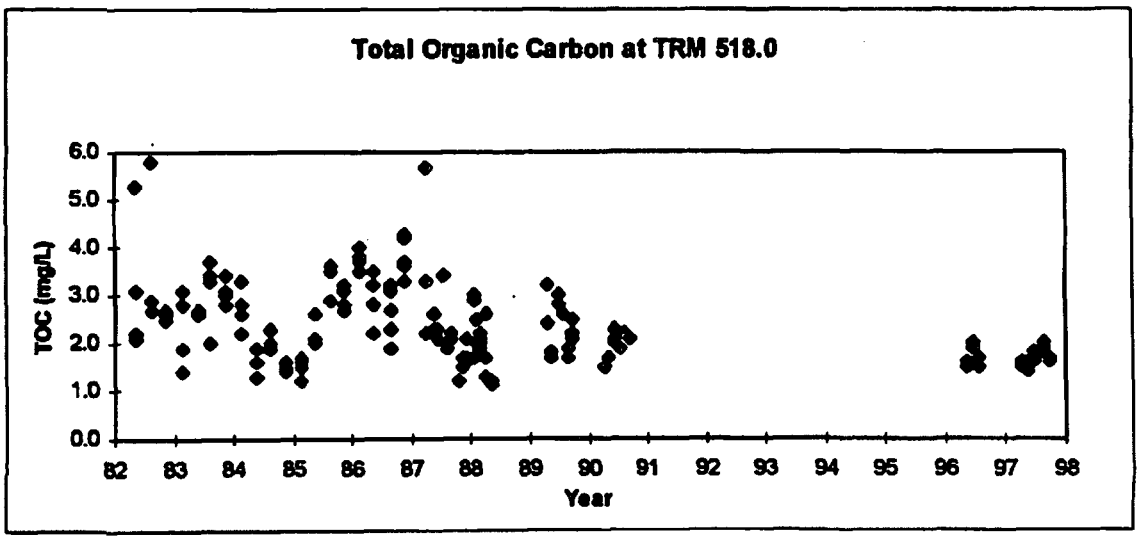




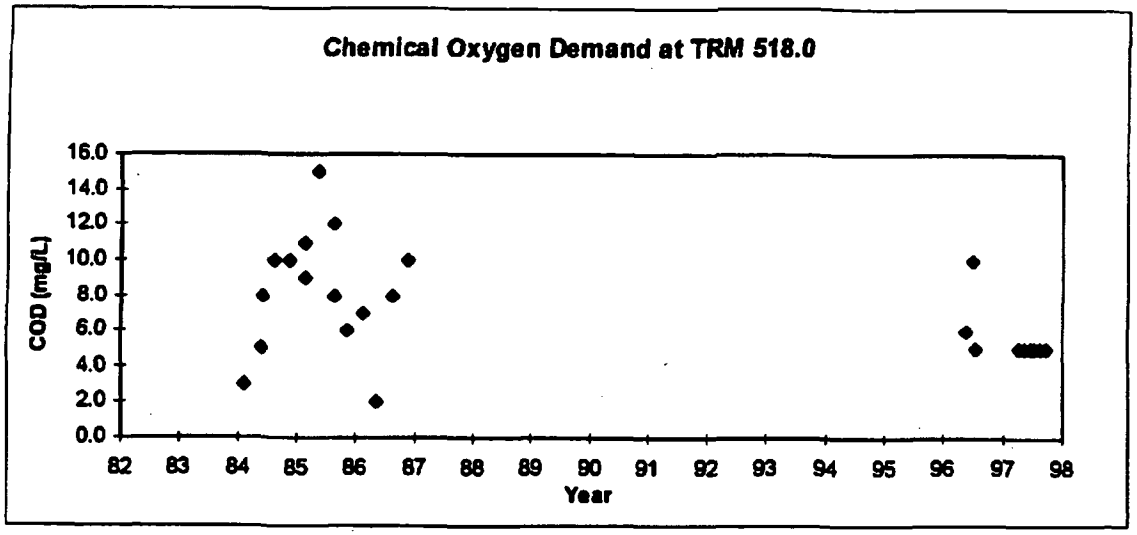
Appendix B-1 (Continued)

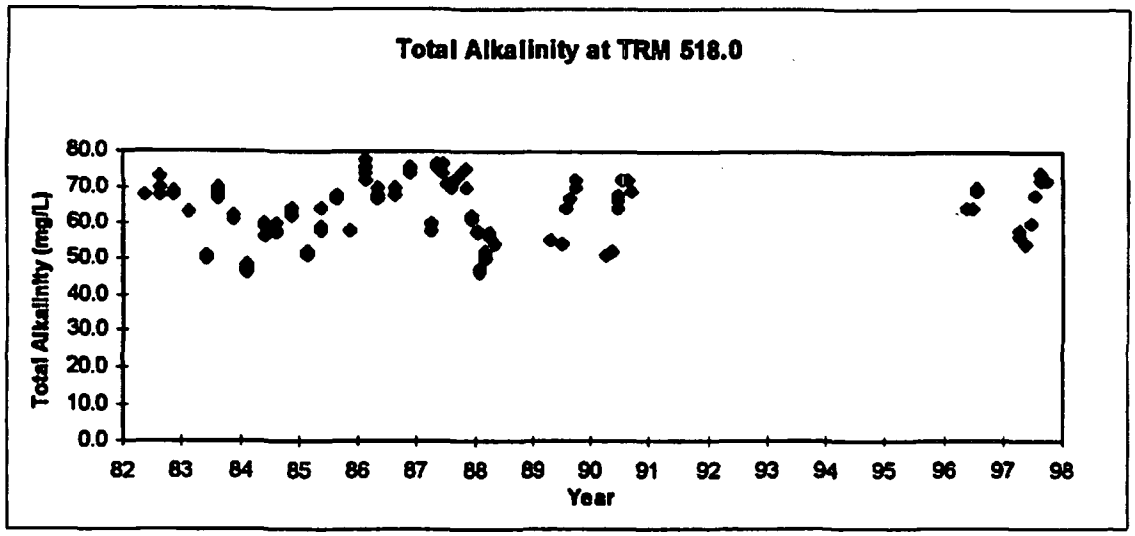


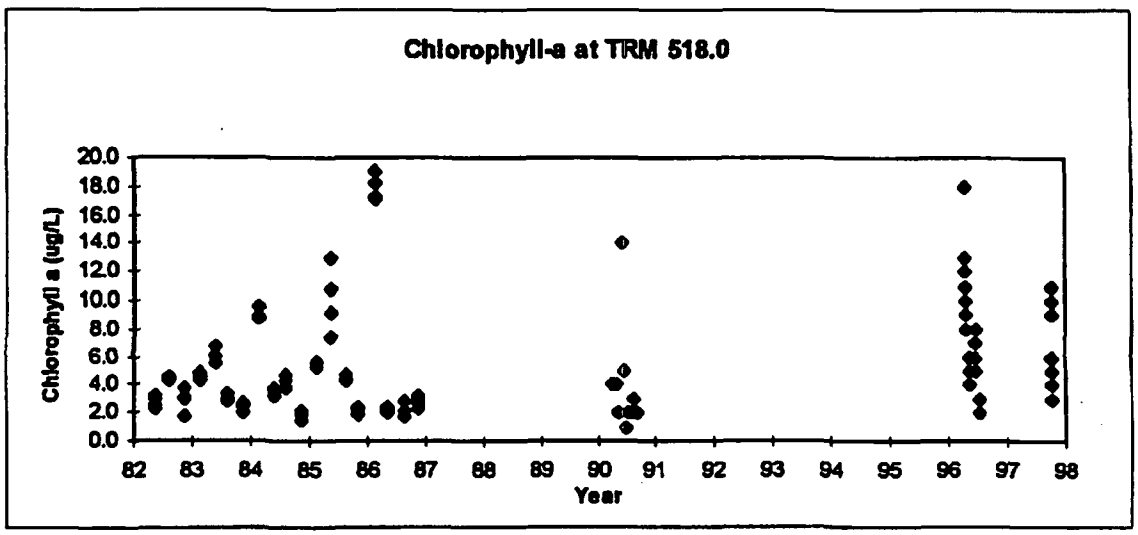




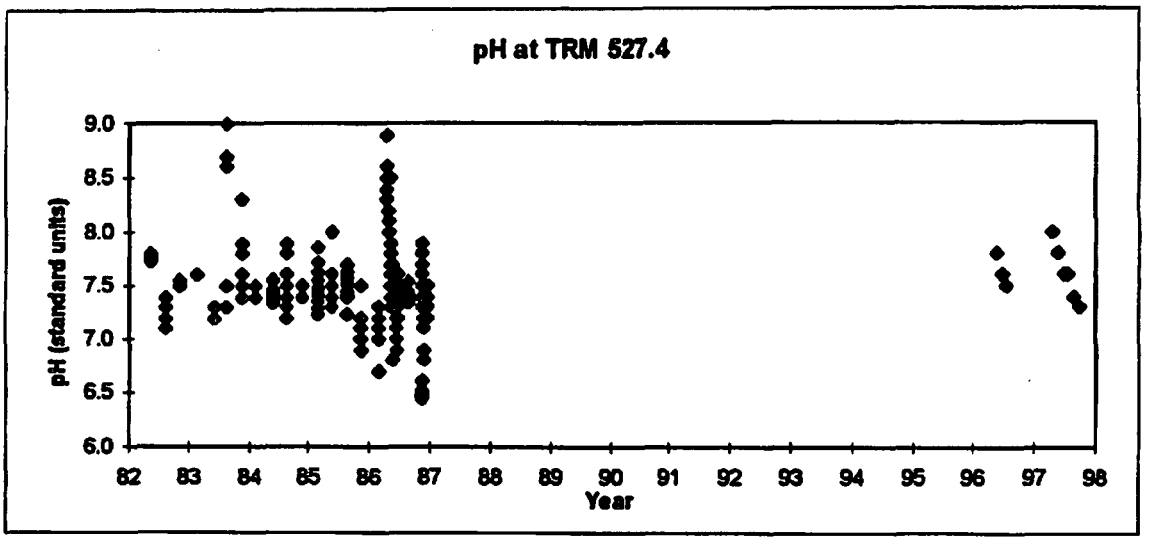
Appendix B-1 (Continued)

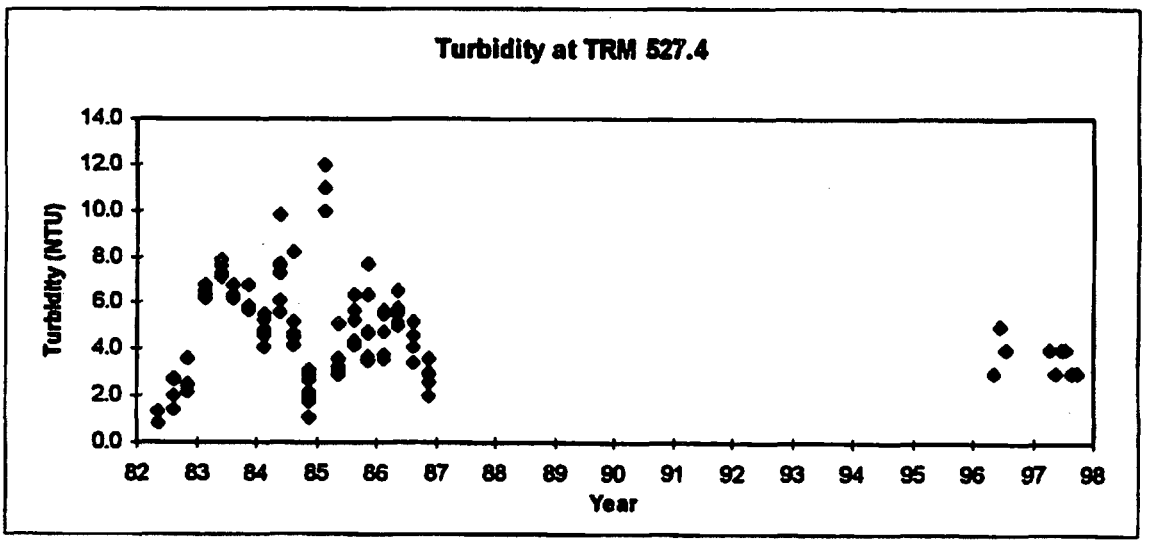


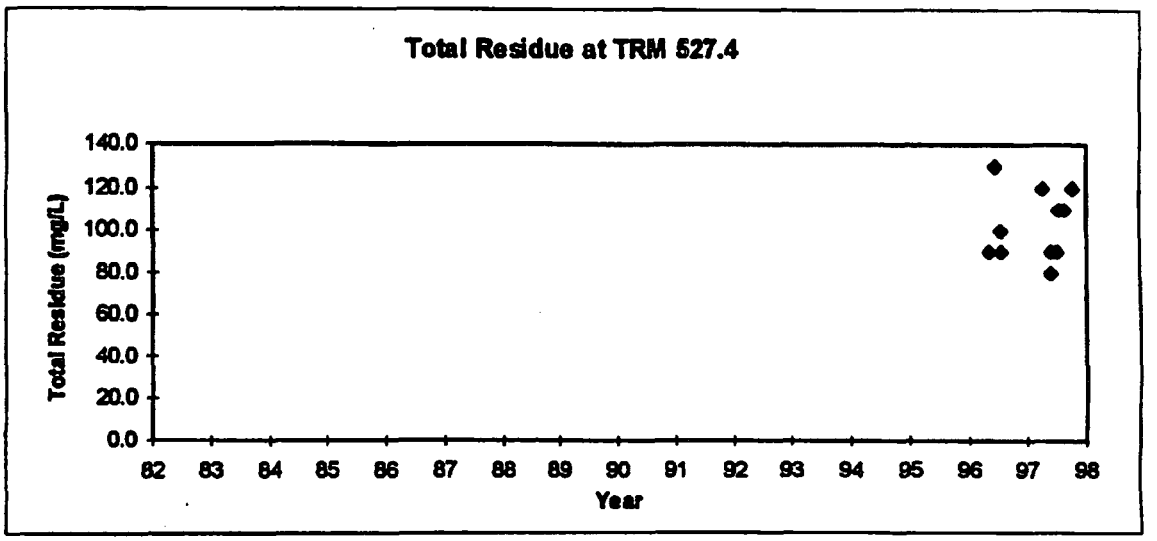




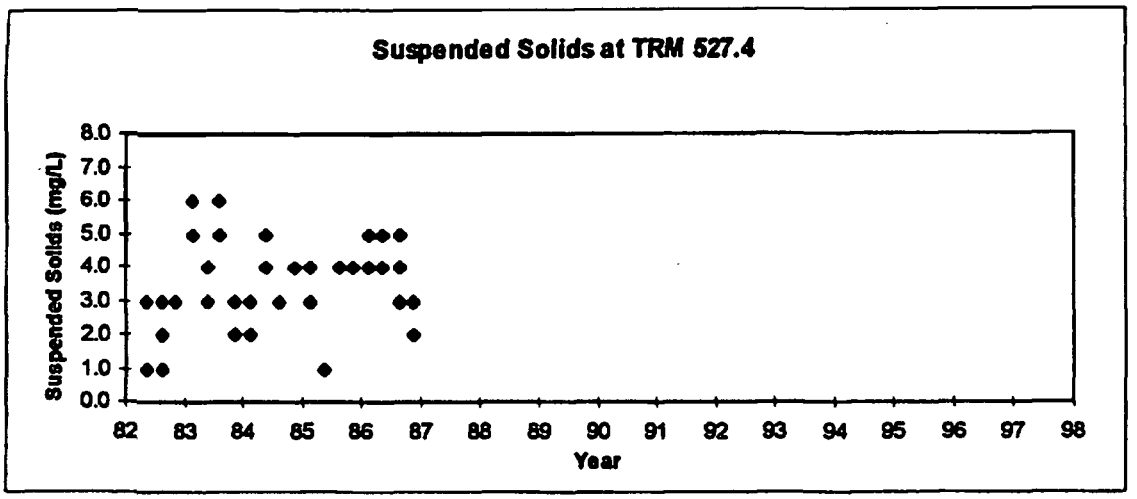
Appendix B-2. Selected water quality values measured during preoperational (1982-1987) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 527.4

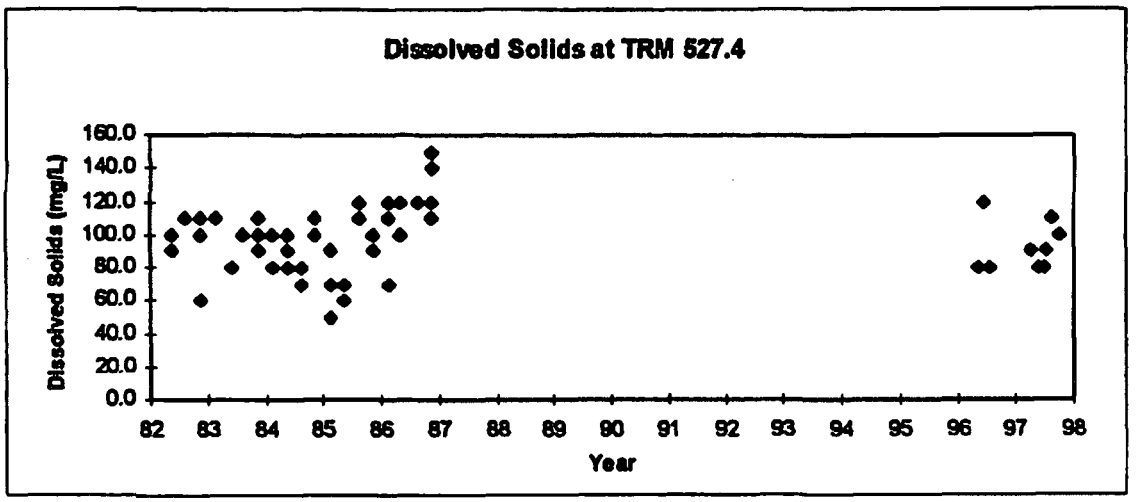




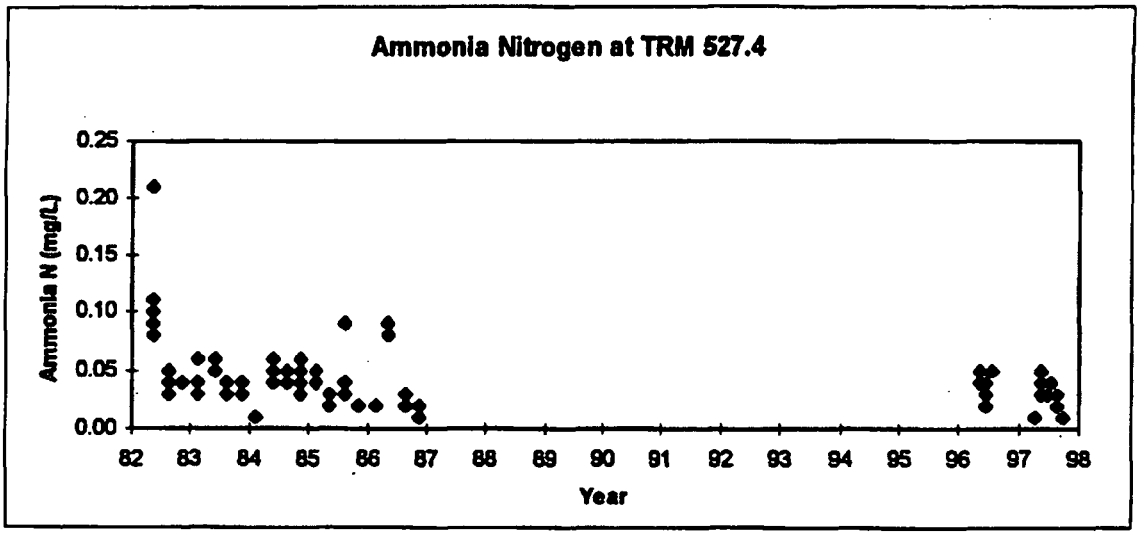


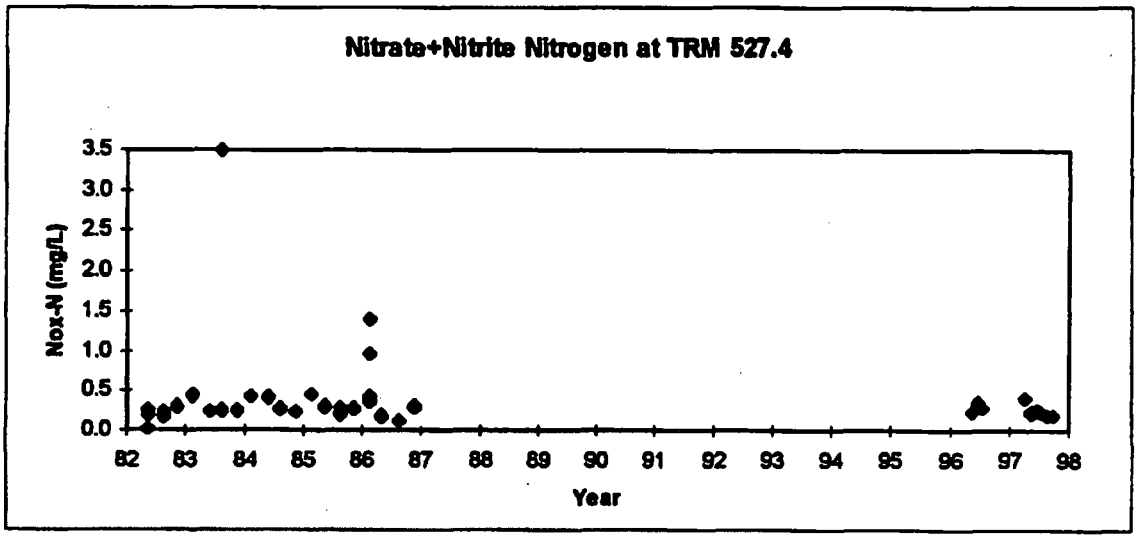
Appendix B-2 (Continued)

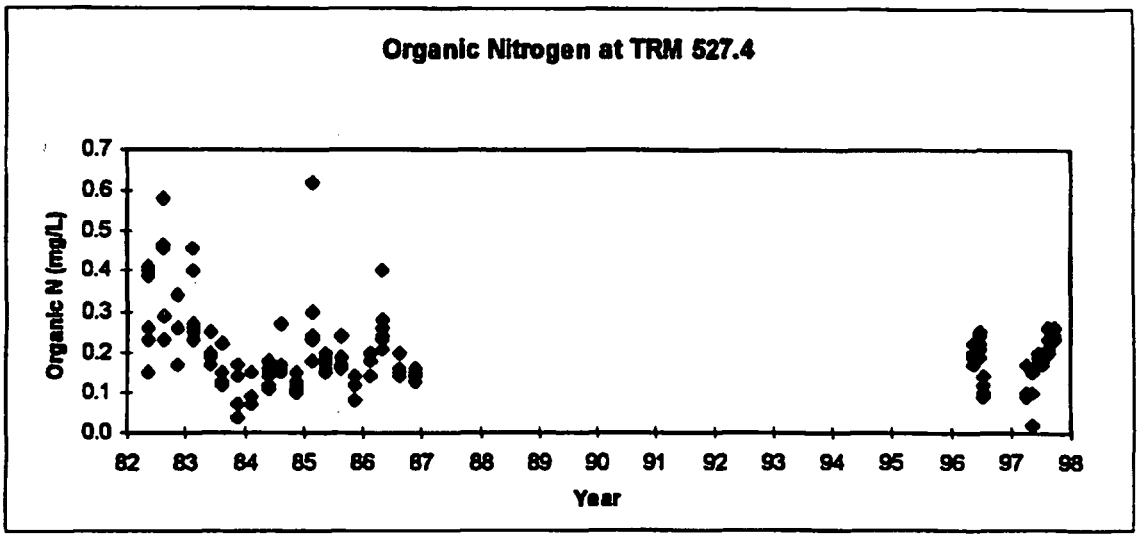




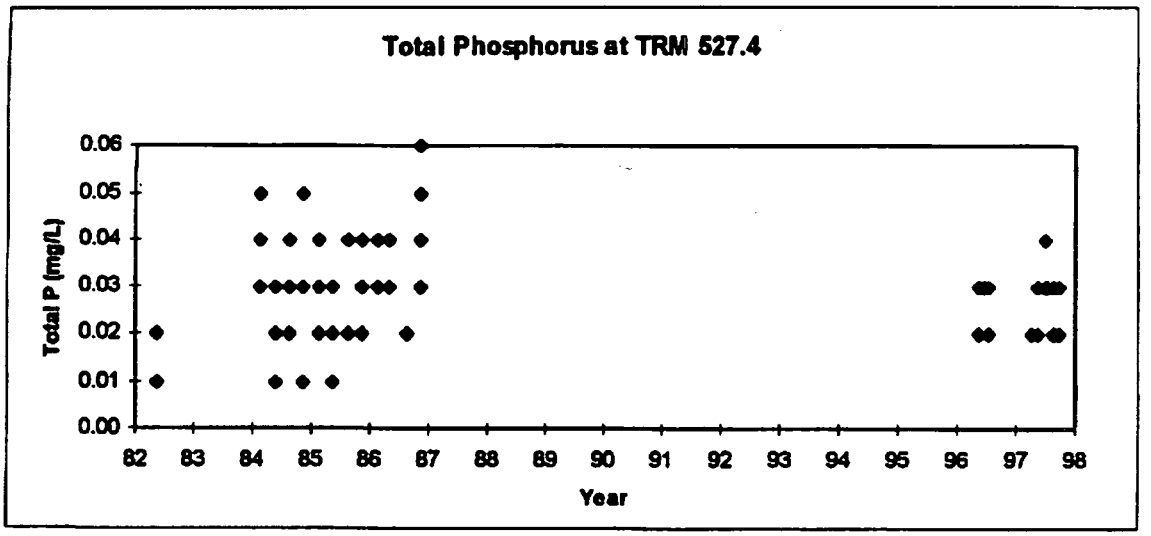
Appendix B-2 (Continued)

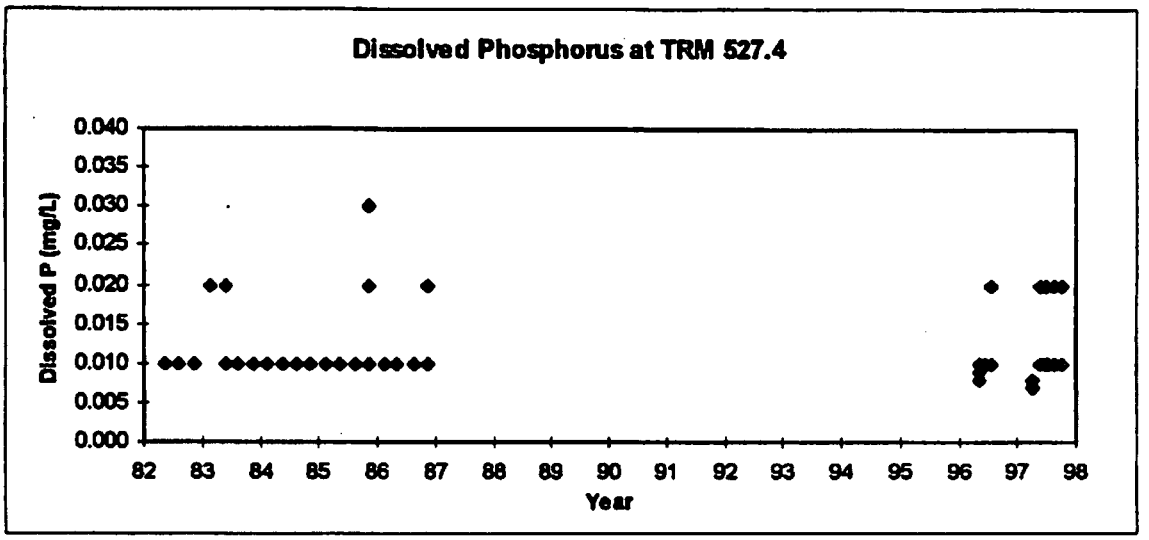


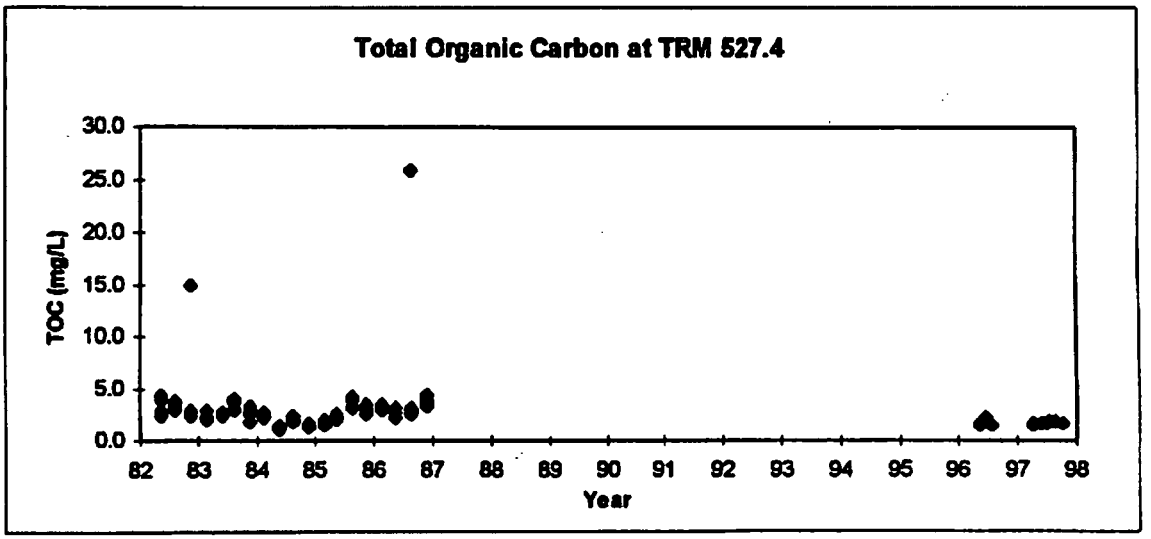




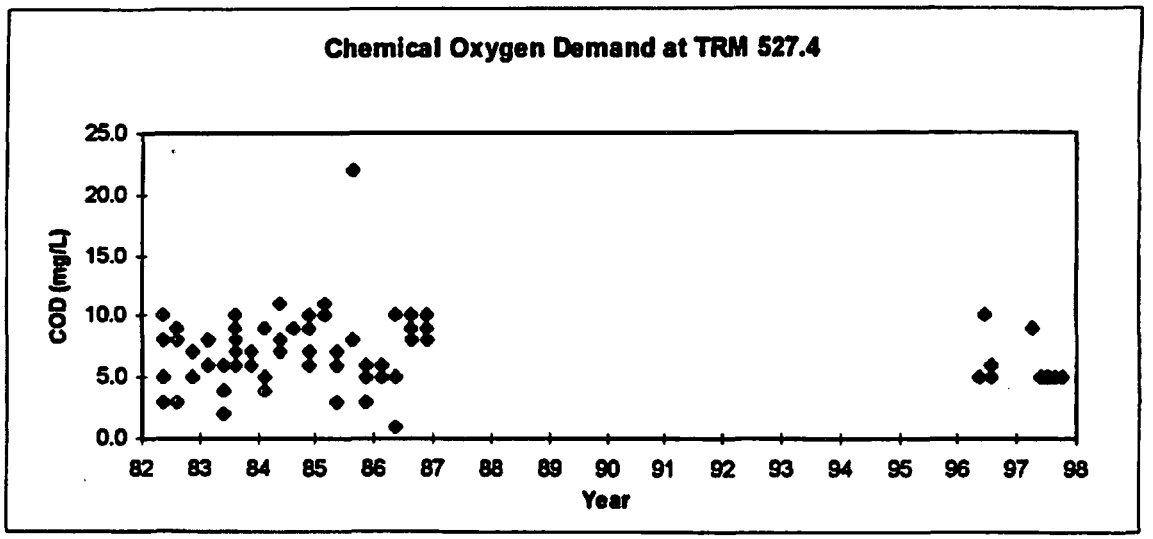
Appendix B-2 (Continued)

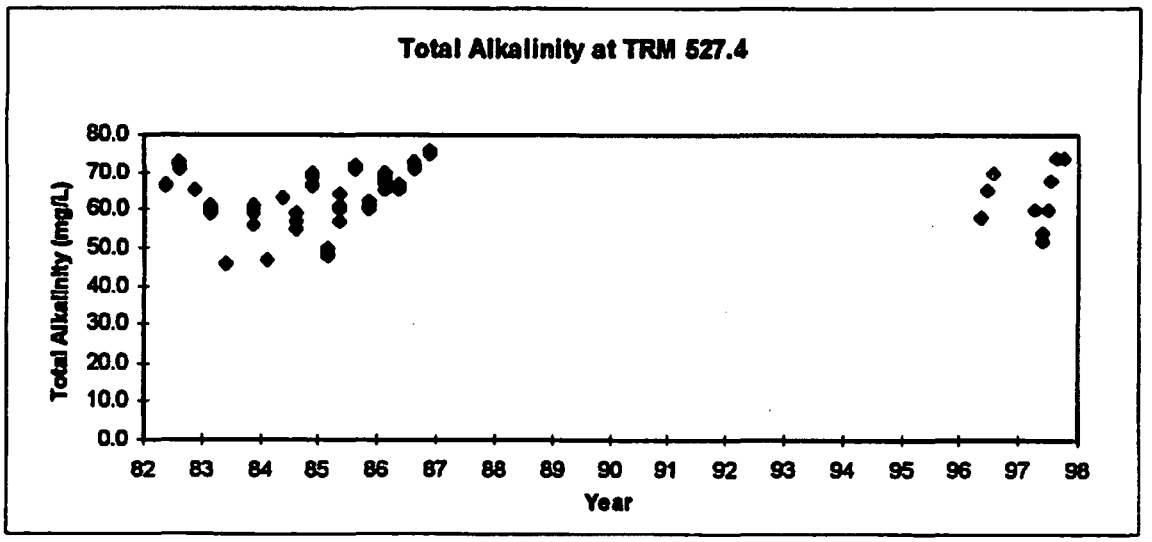


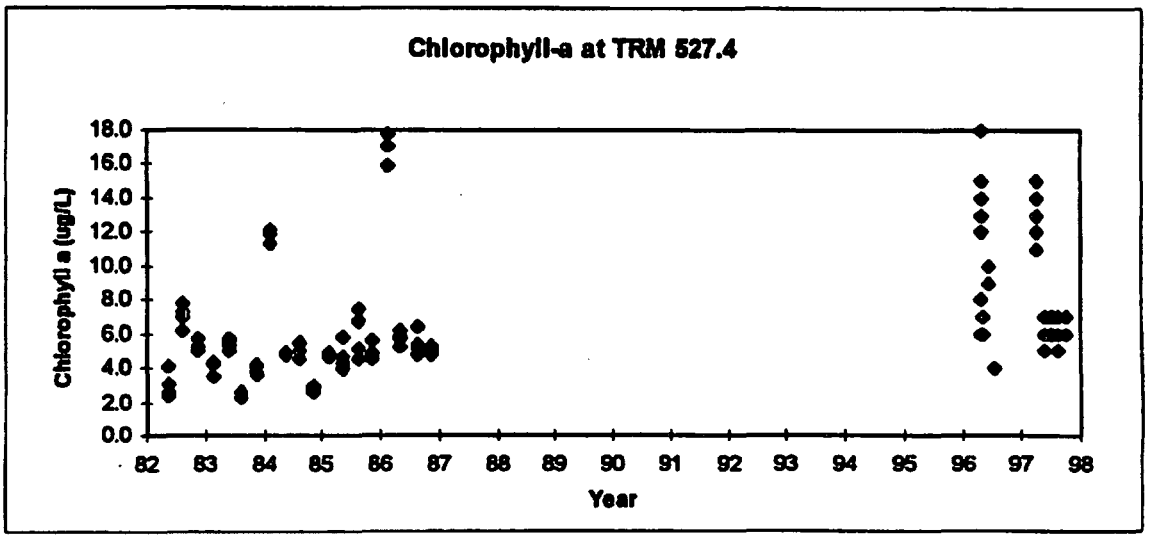




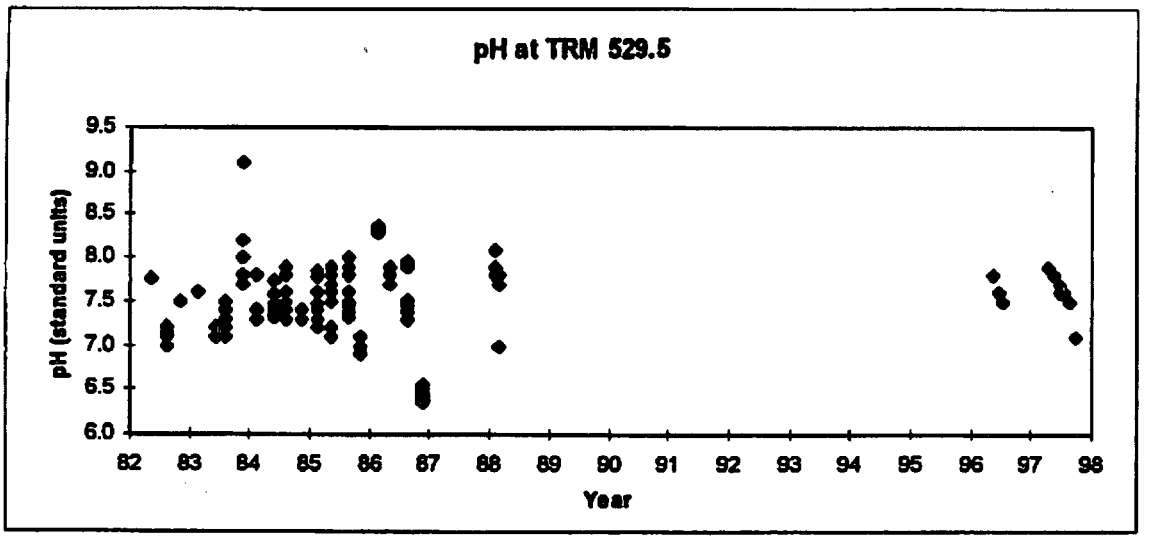
Appendix B-2 (Continued)

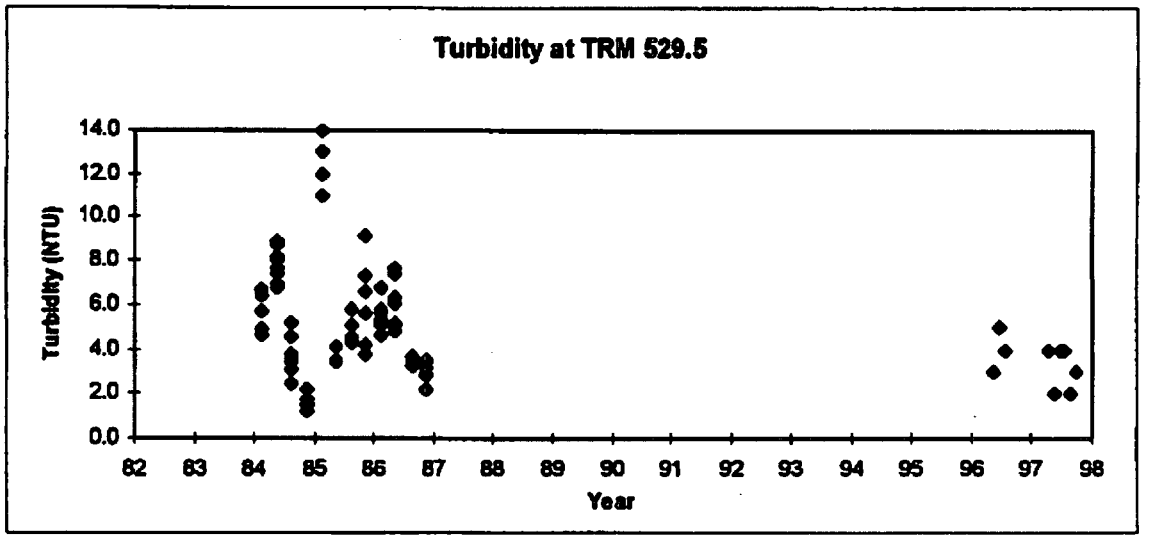


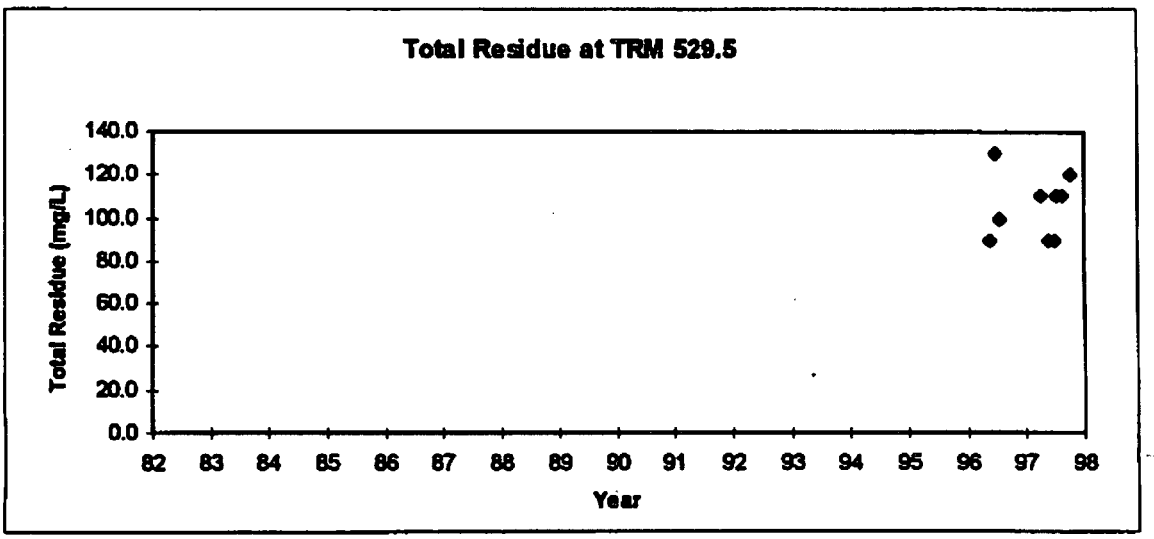




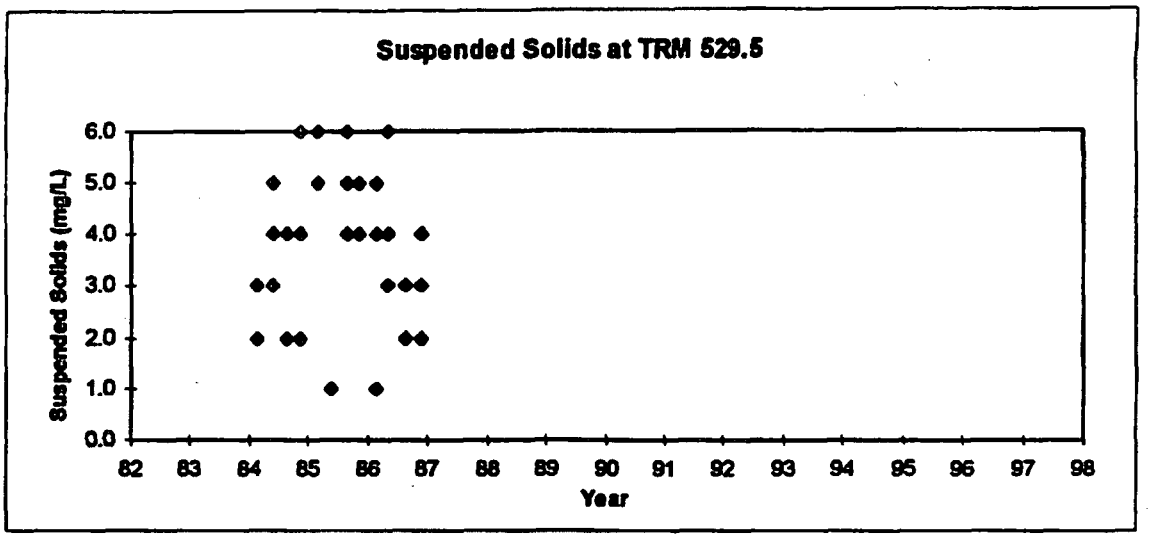
Appendix B-3. Selected water quality values measured during preoperational (1982-1987) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 529.5

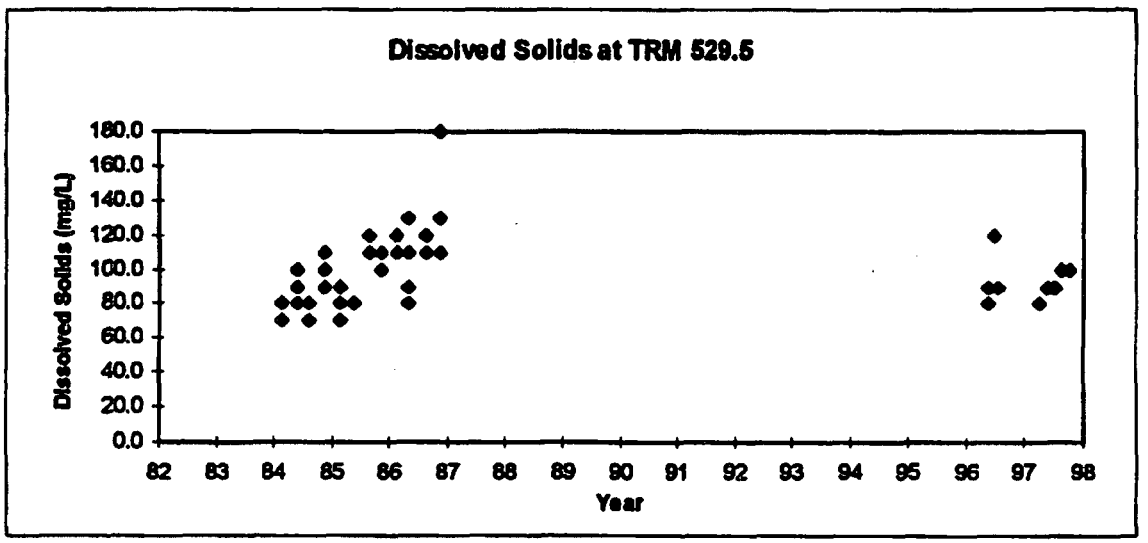




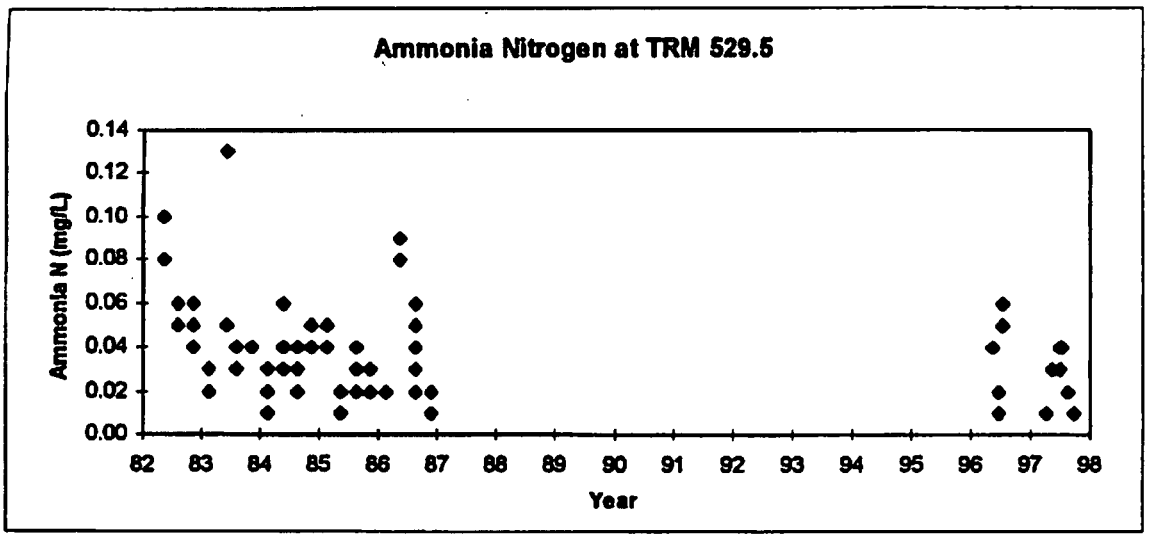


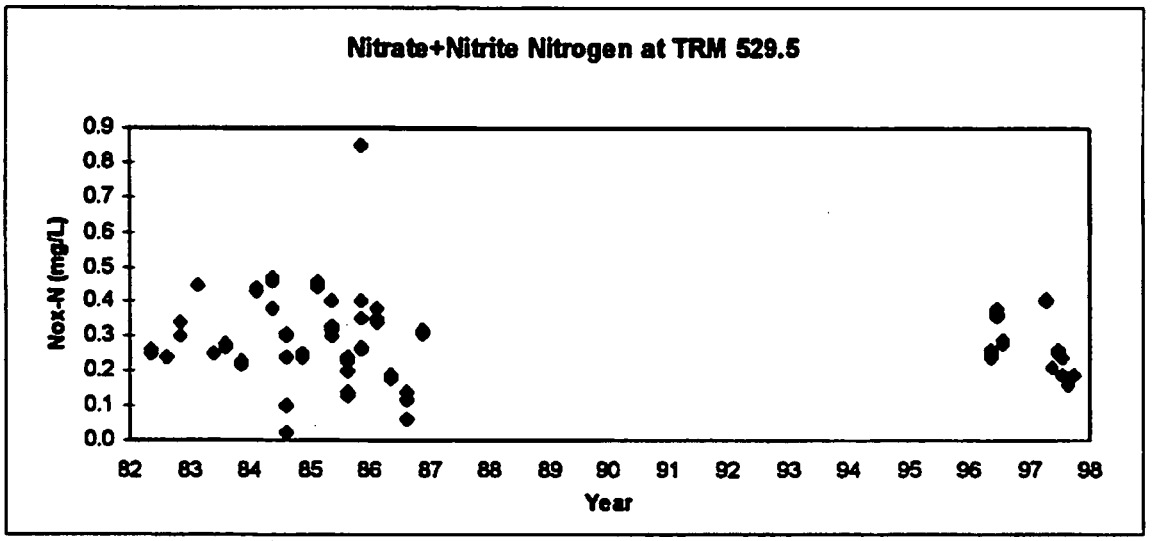
Appendix B-3 (Continued)

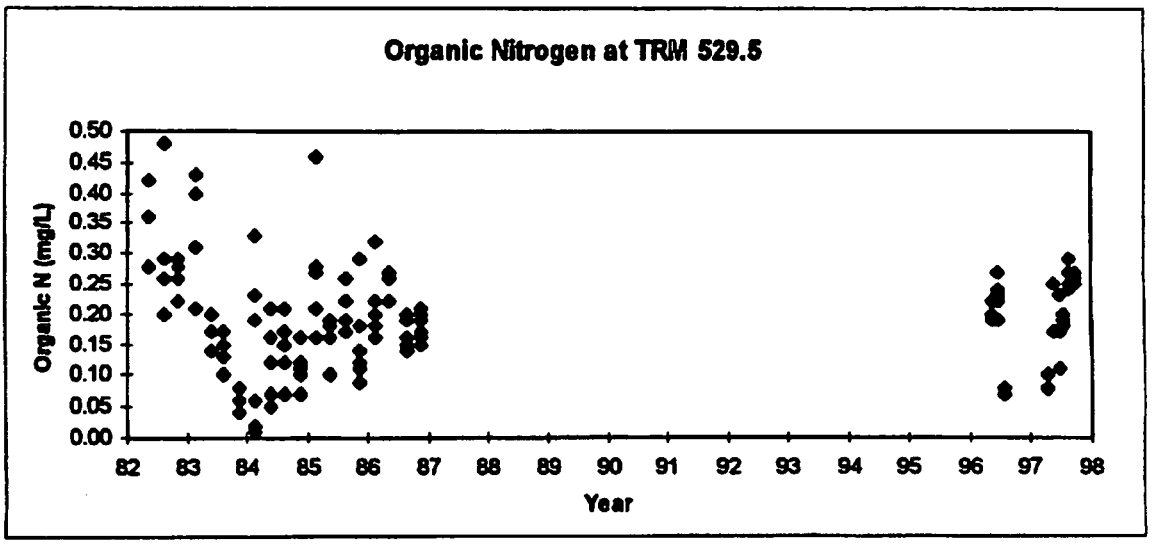




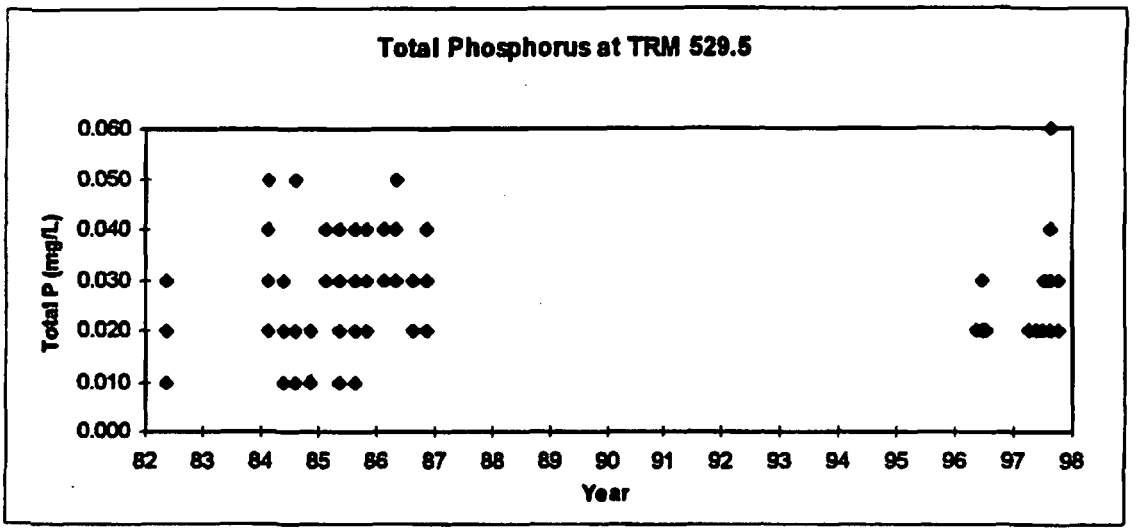
Appendix B-3 (Continued)

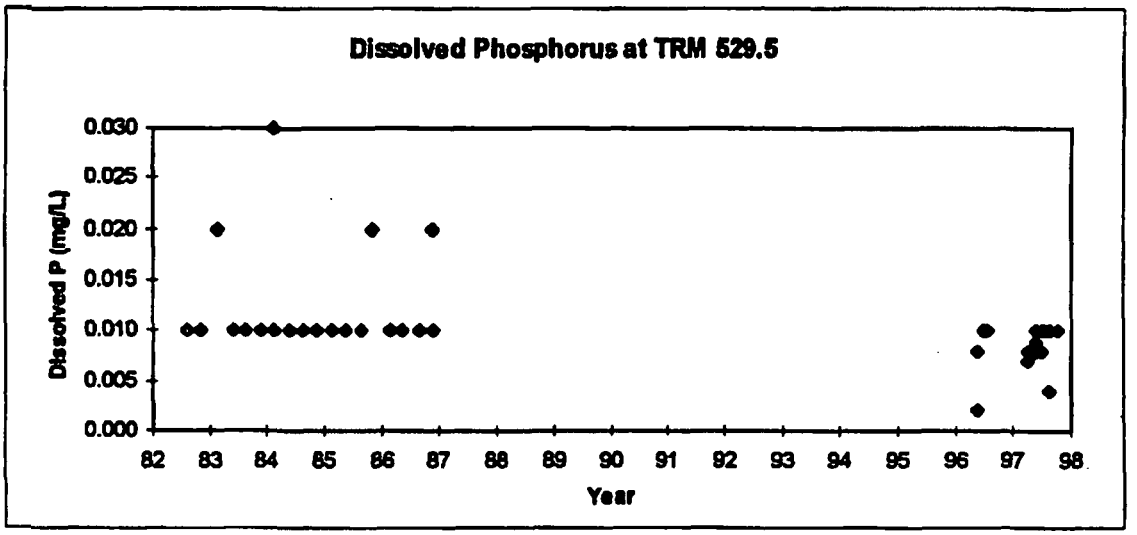


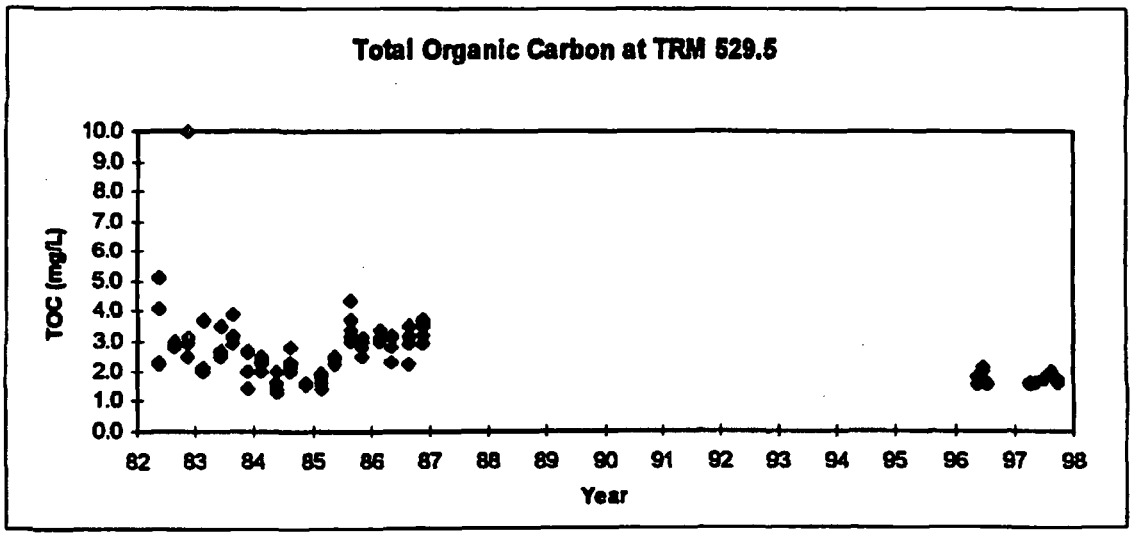




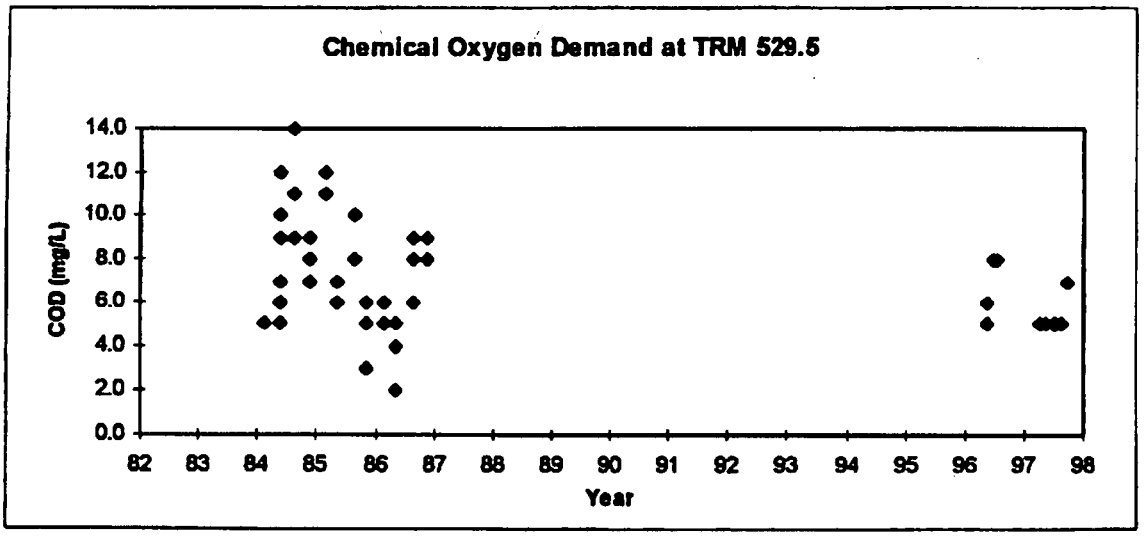
Appendix B-3 (Continued)

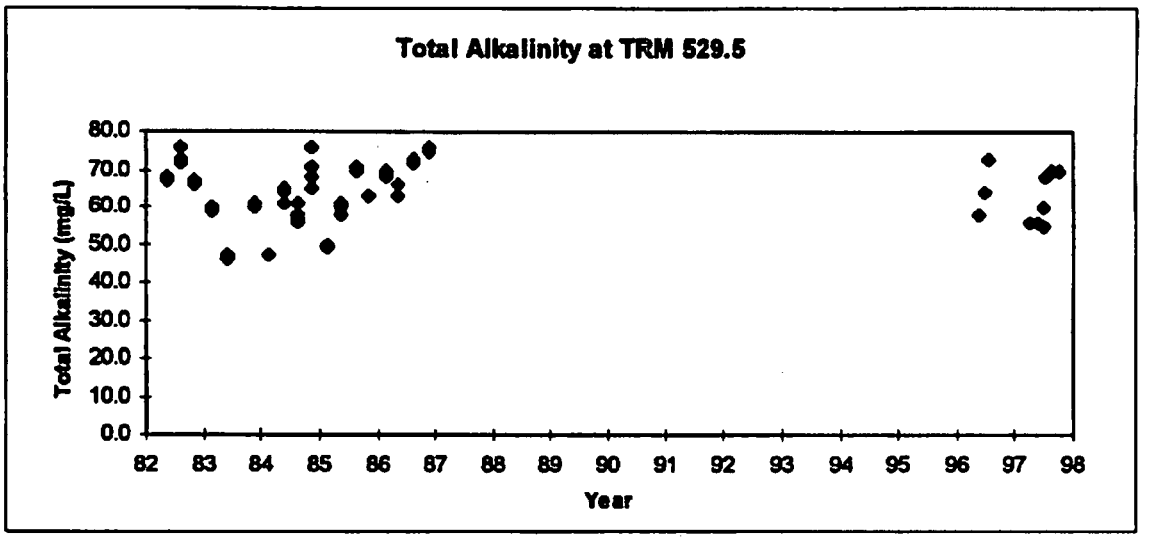


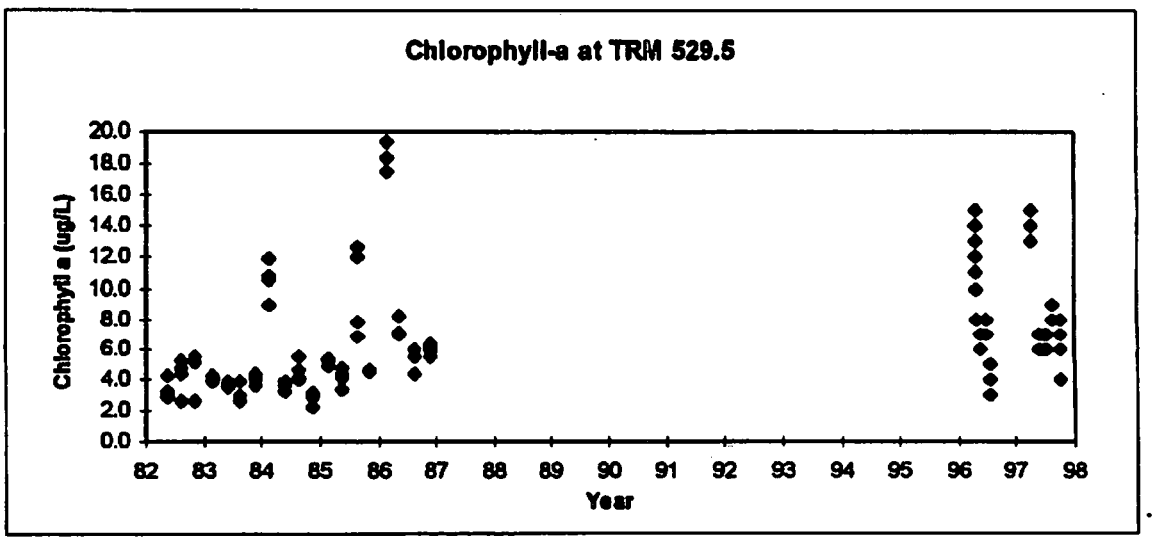




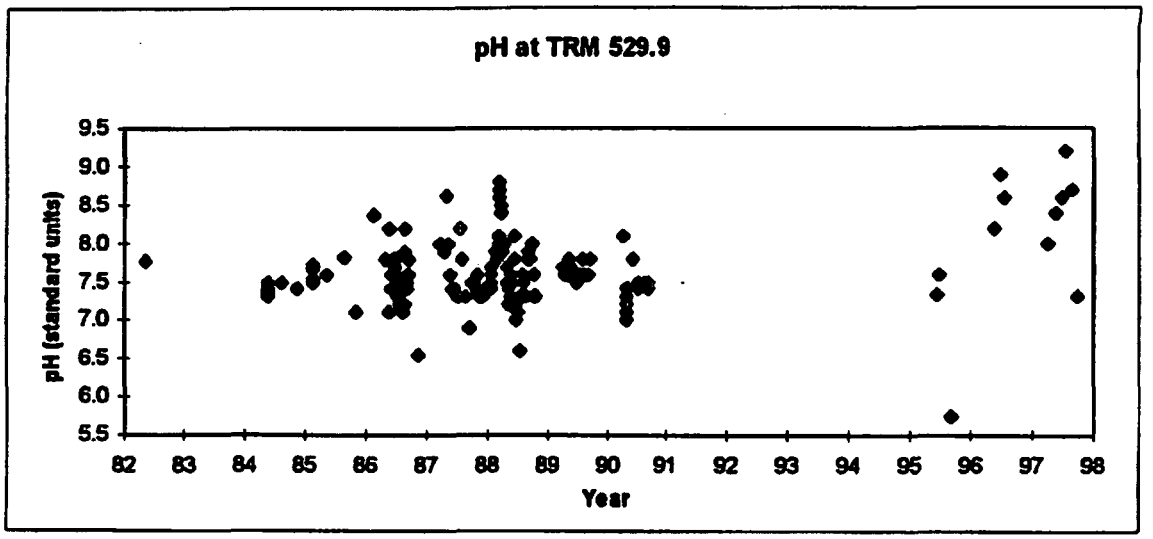
Appendix B-3 (Continued)

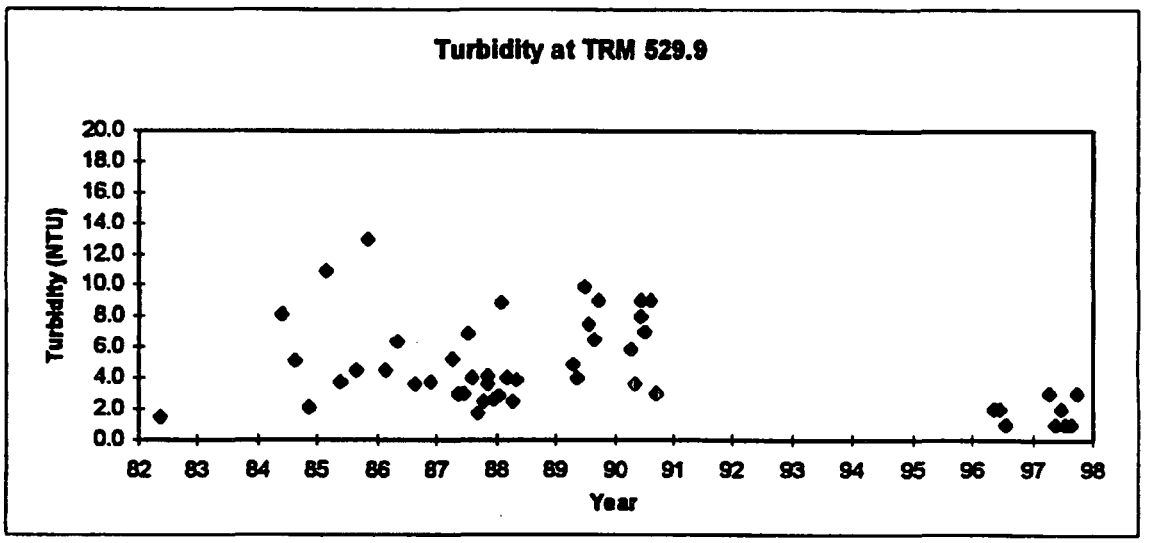


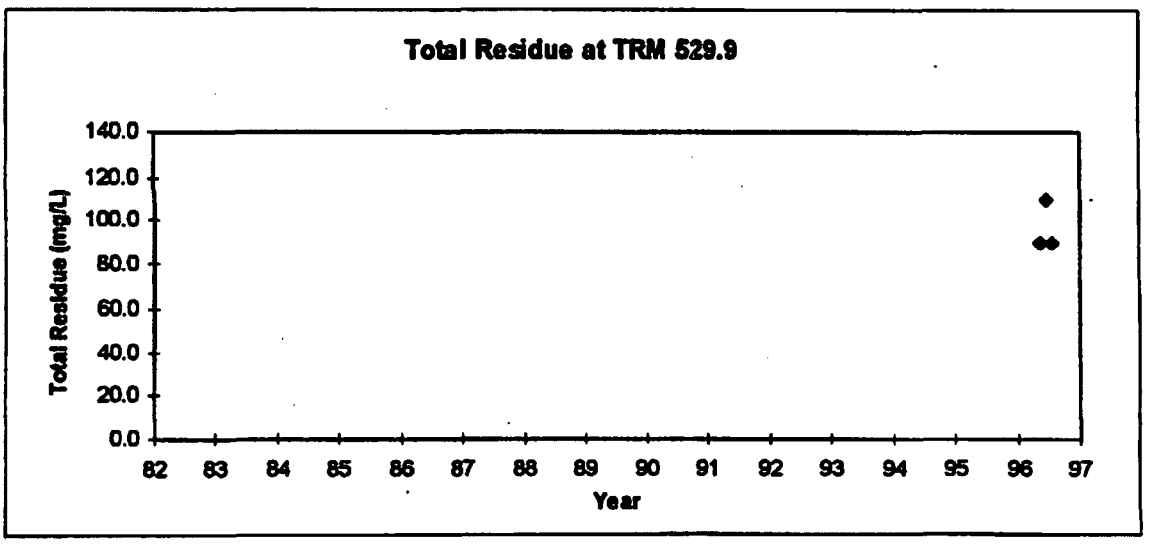




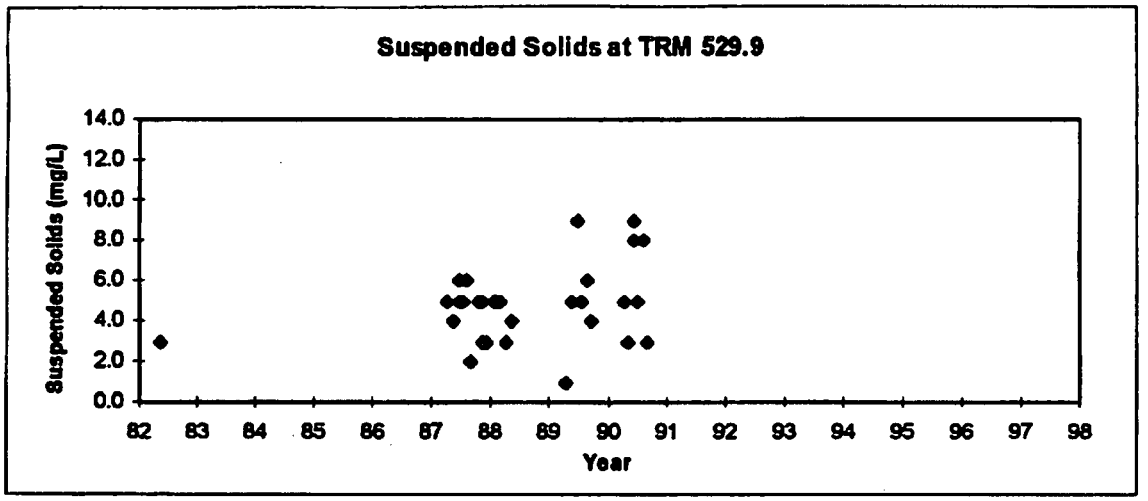
Appendix B-4. Selected water quality values measured during preoperational (1982-1991) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 529.9

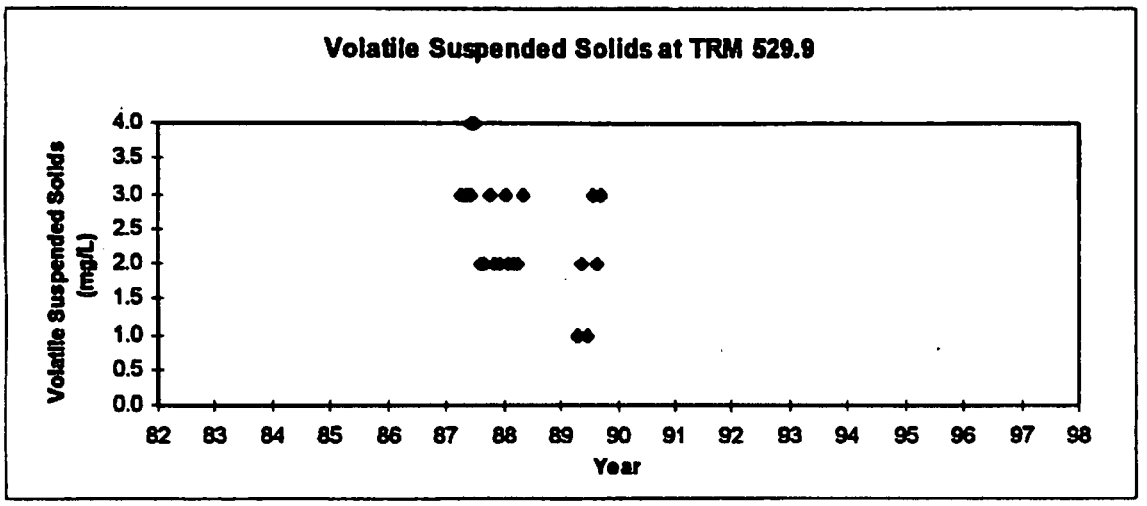


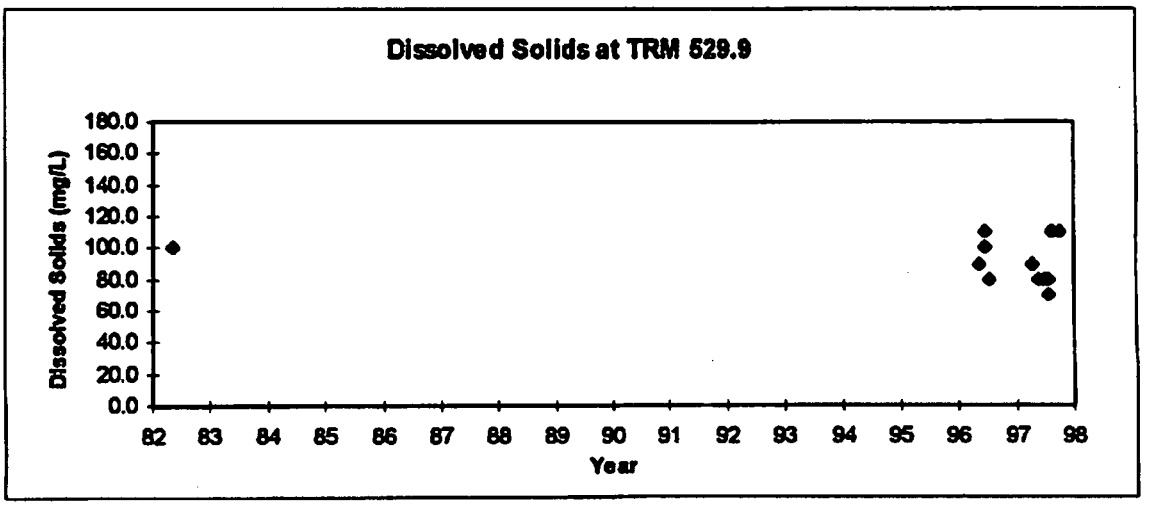




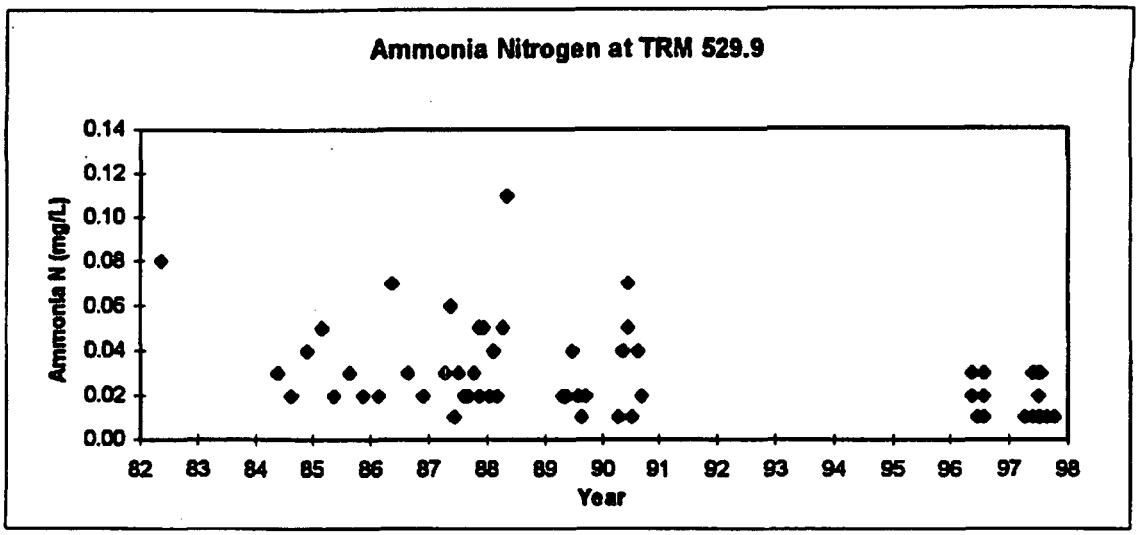
Appendix B-4 (Continued)

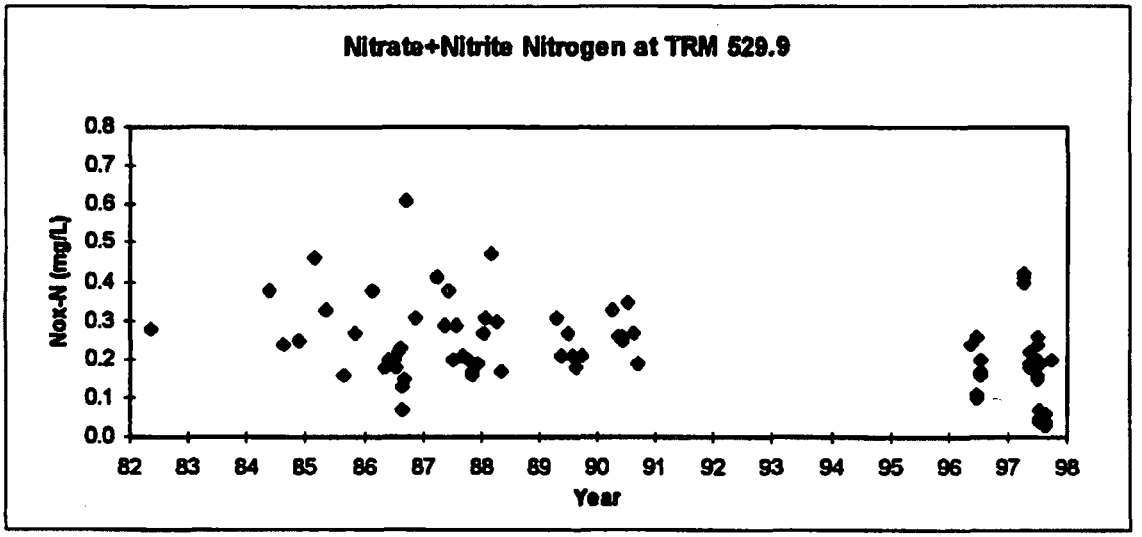


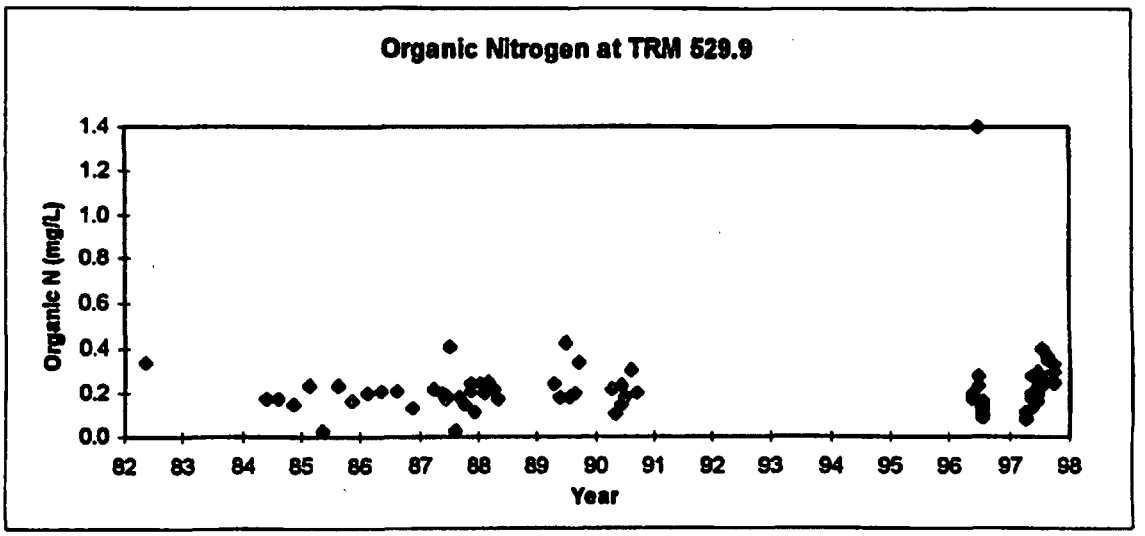




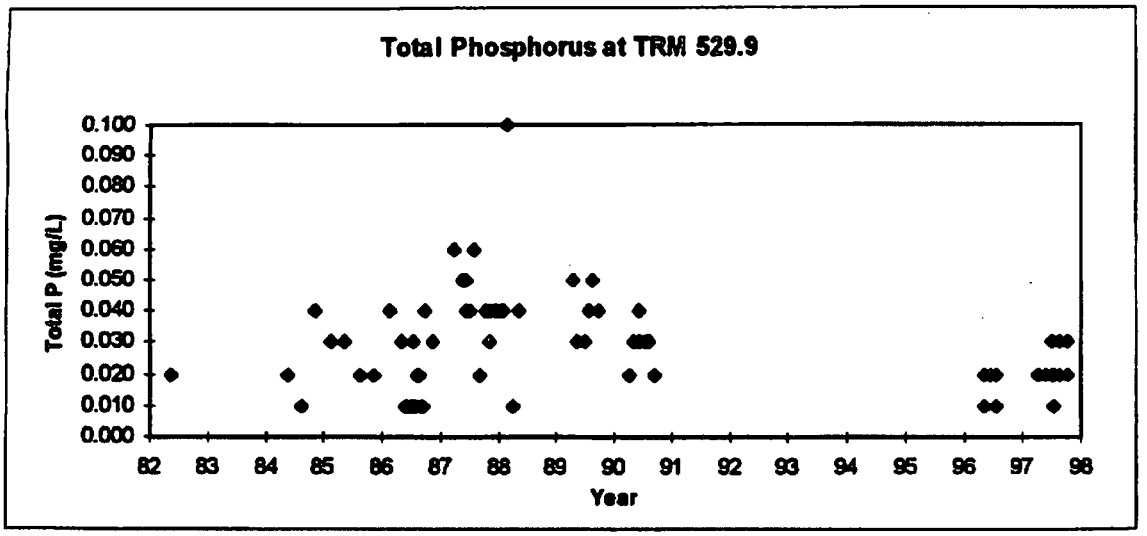
Appendix B-4 (Continued)

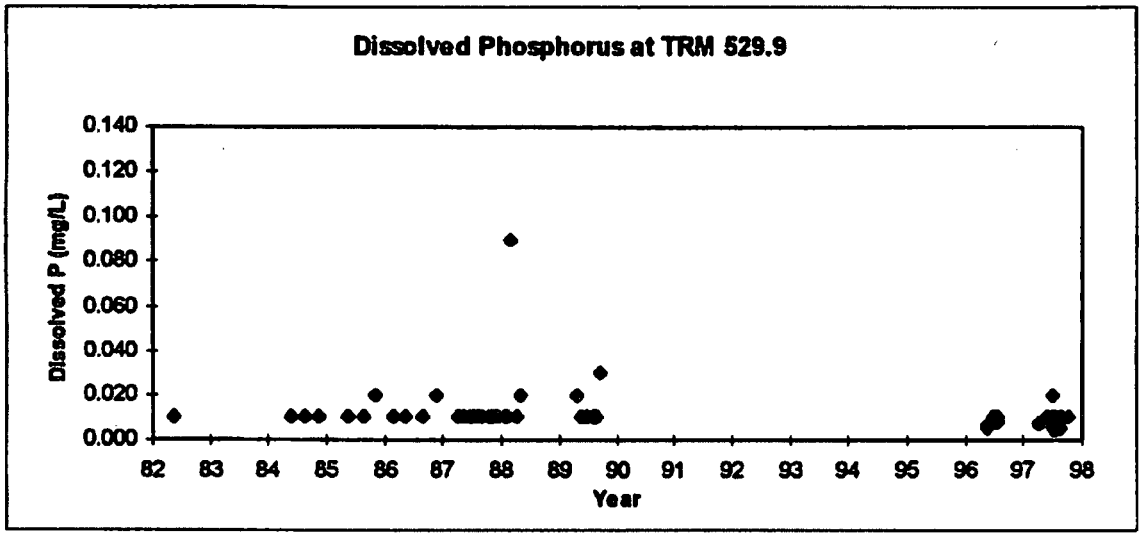


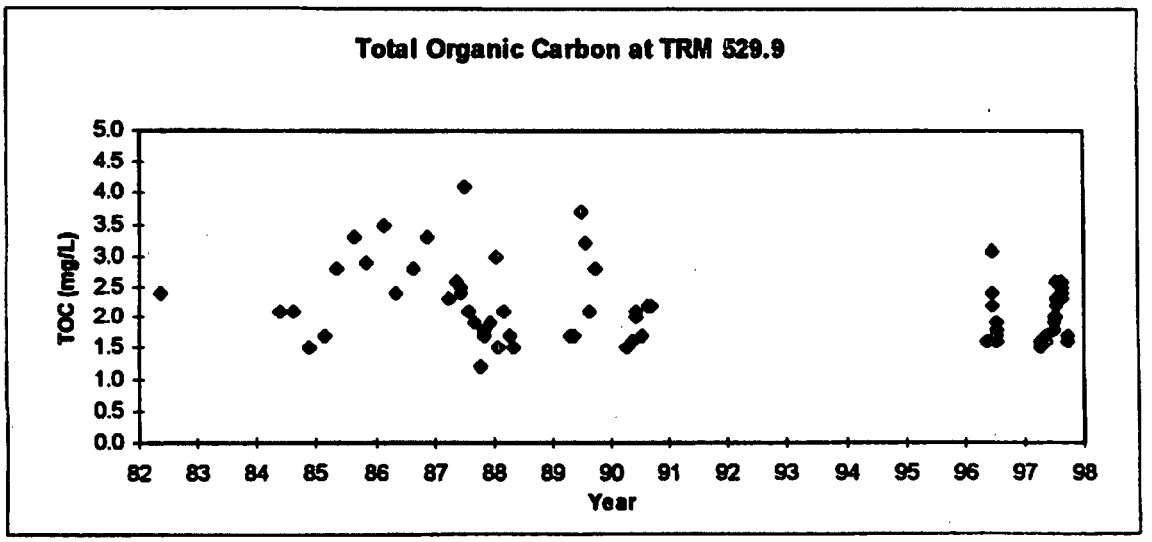




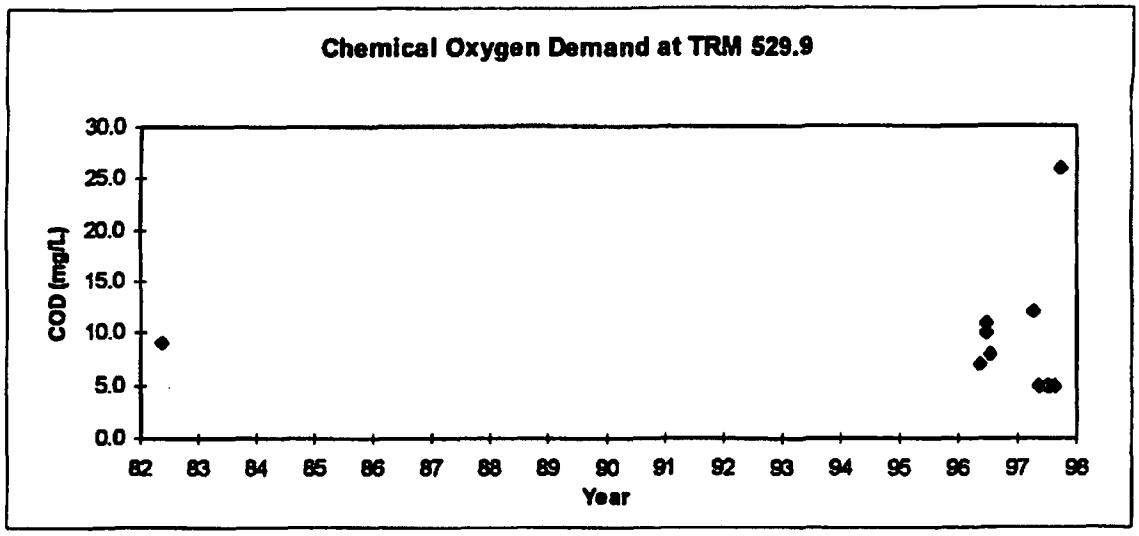
Appendix B-4 (Continued)

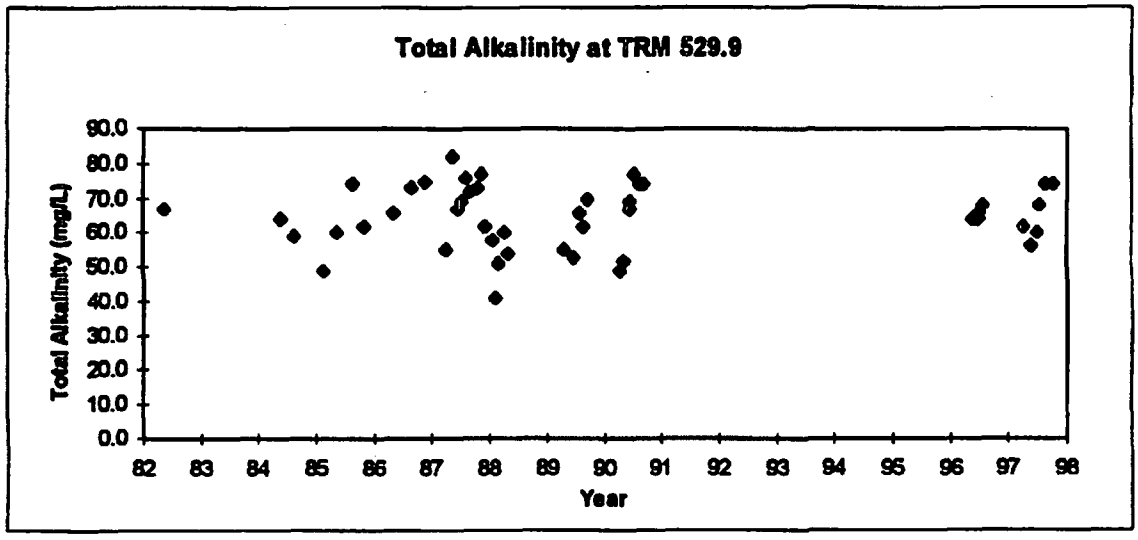


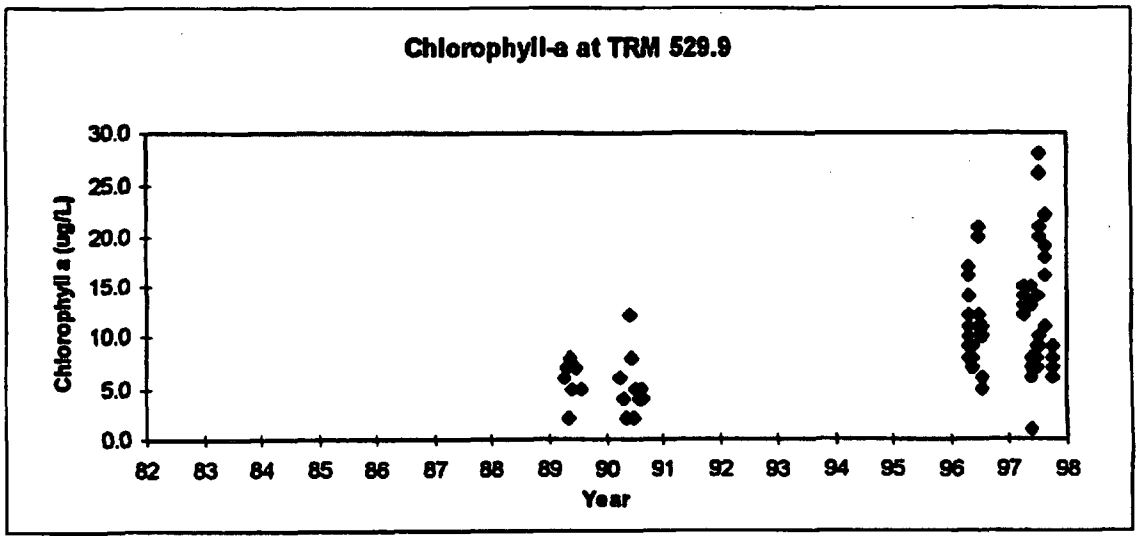




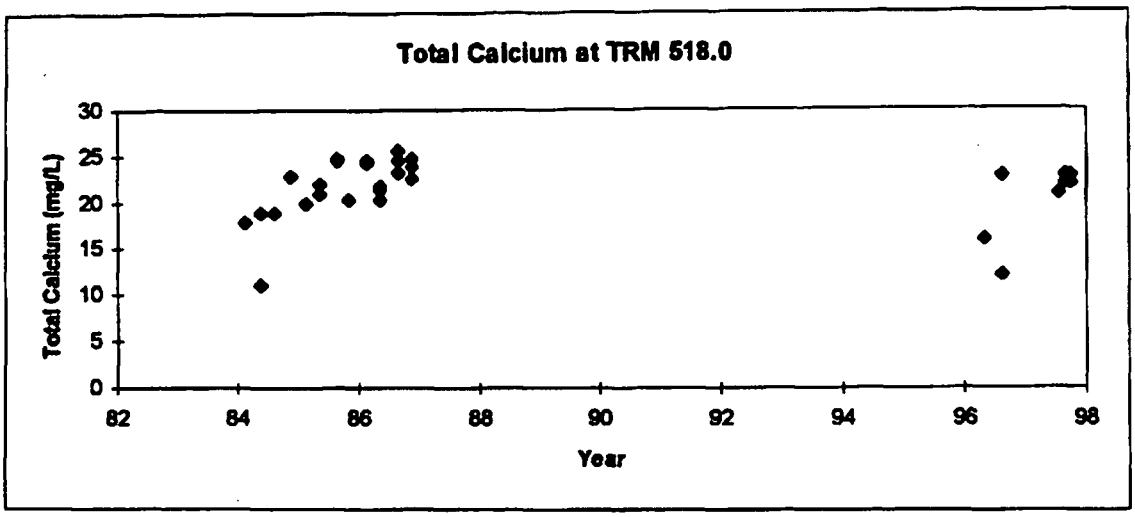
Appendix B-4 (Continued)

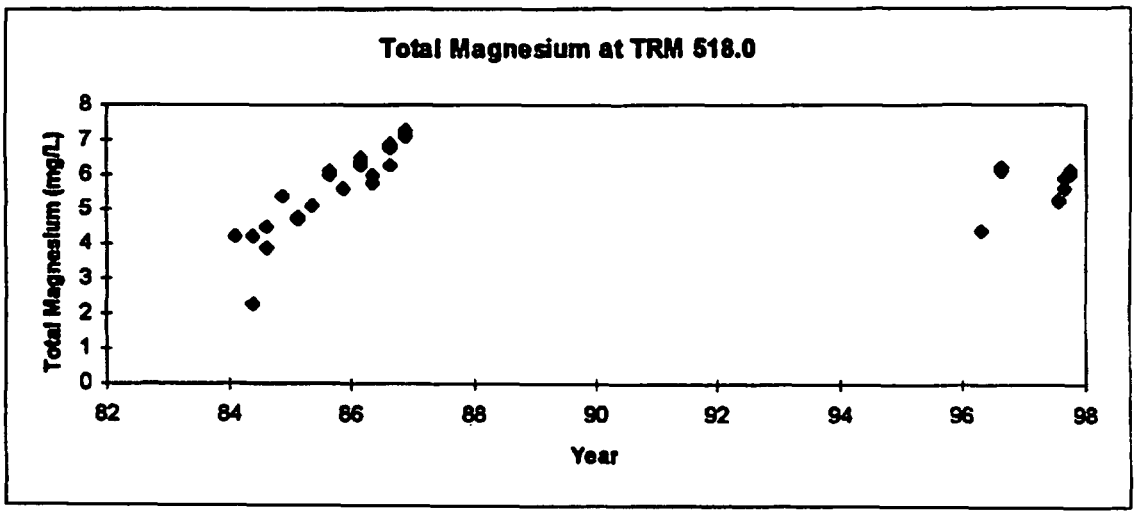


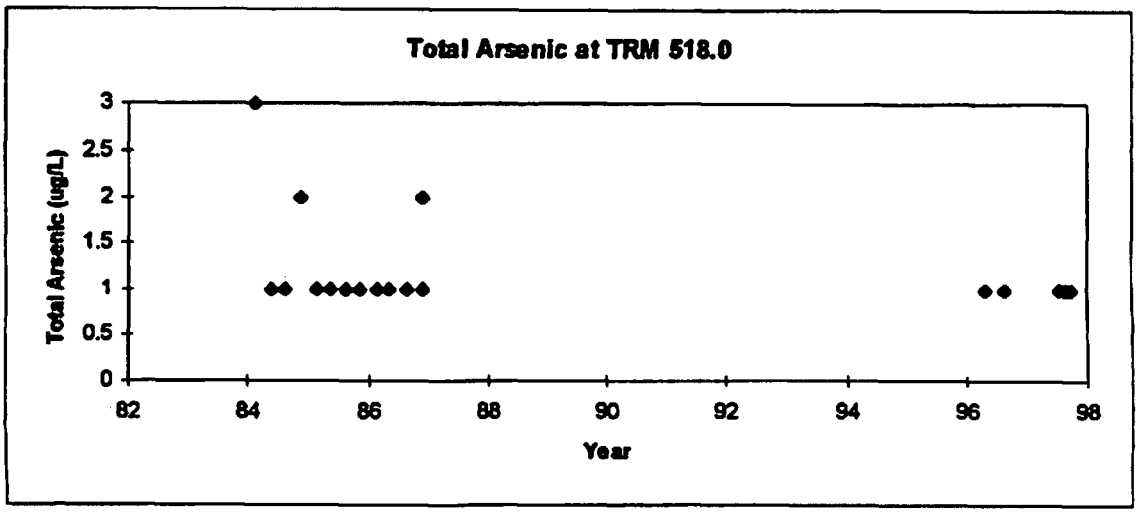




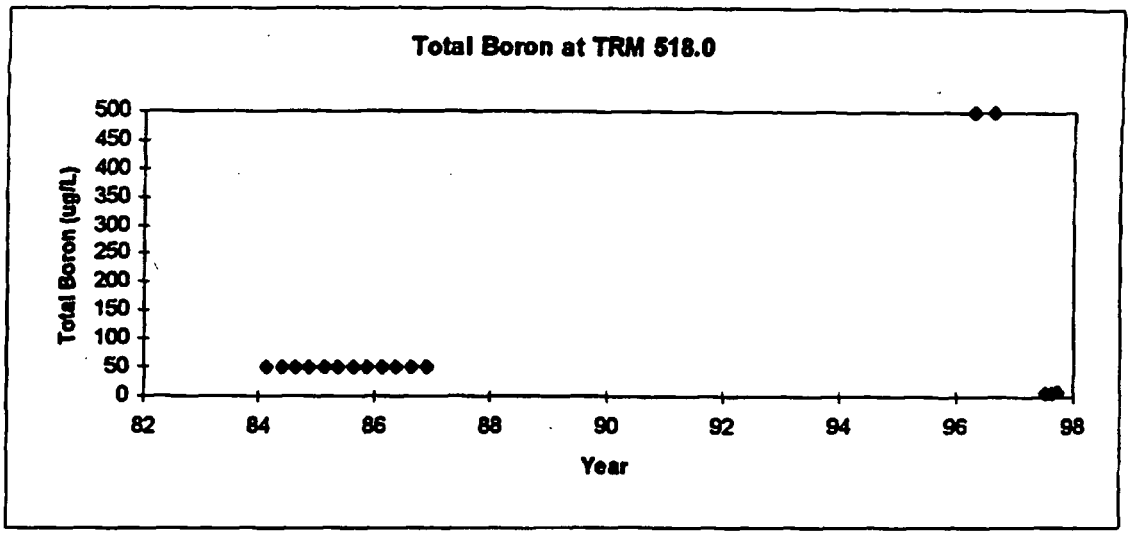
Appendix B-5. **Concentrations of selected metals during preoperational (1982-1987) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 518.0**

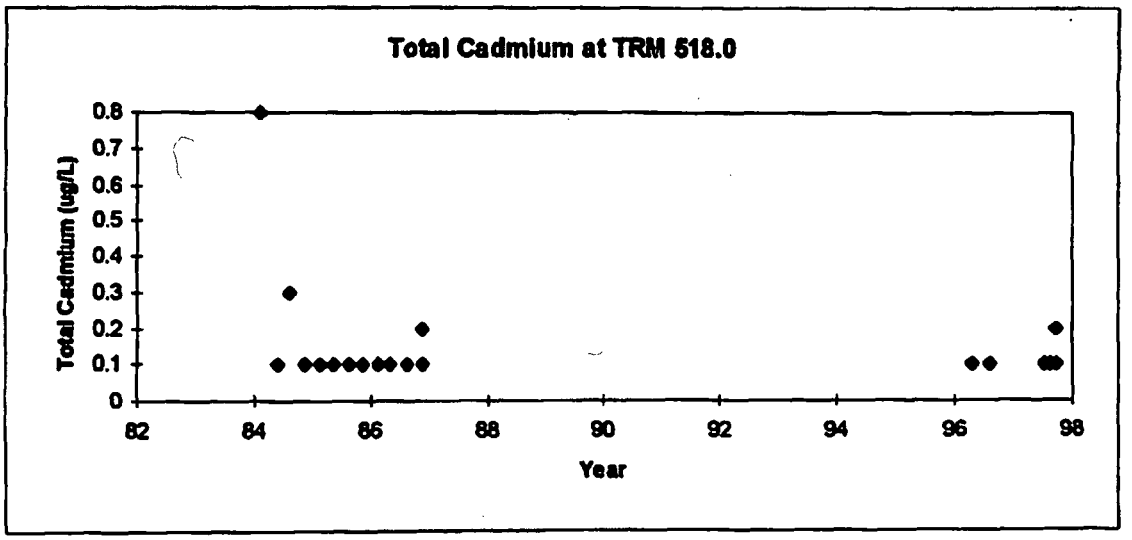


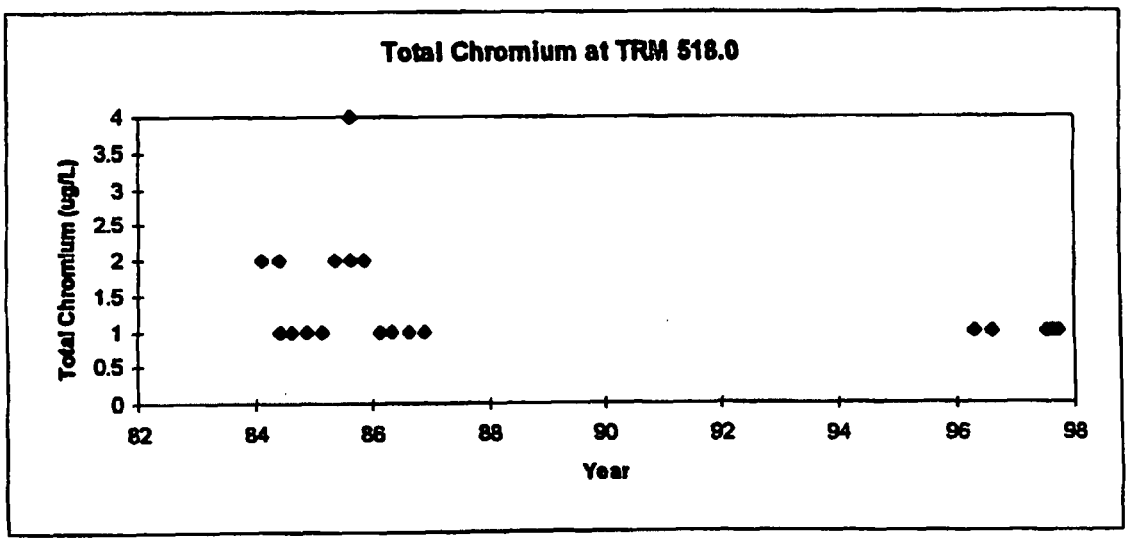




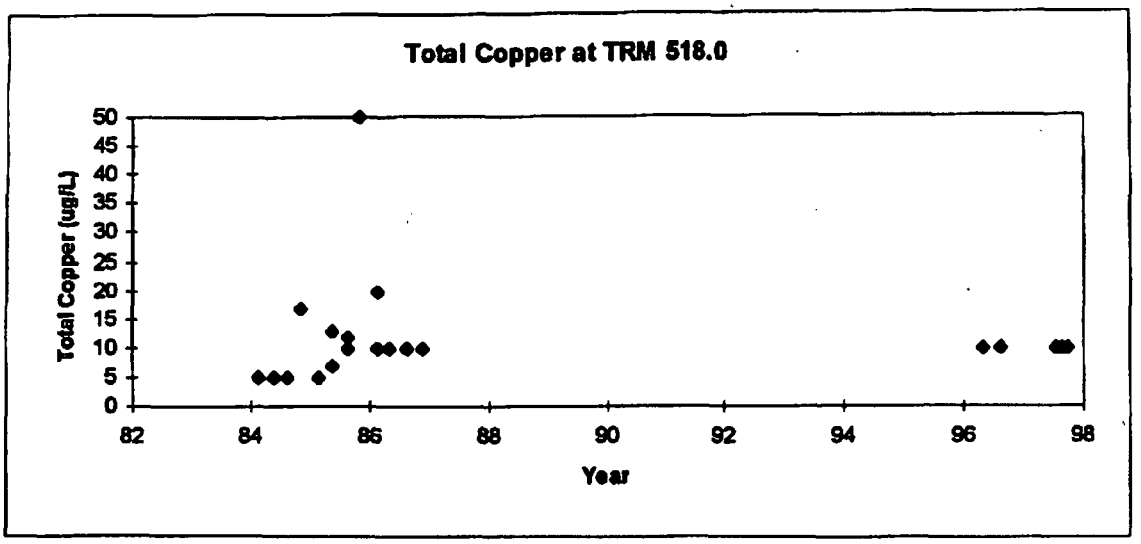
Appendix B-5 (Continued)

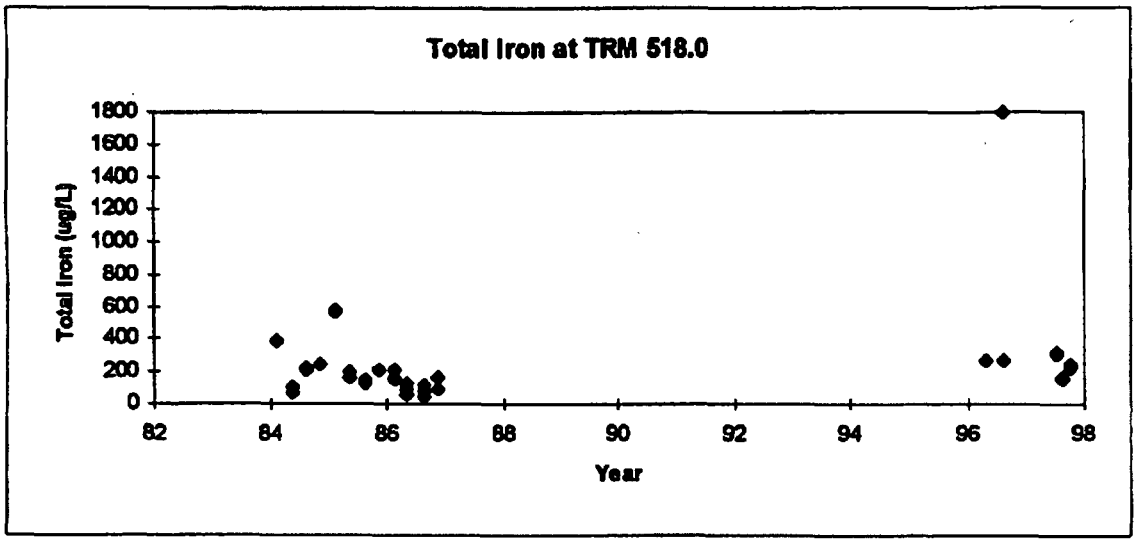


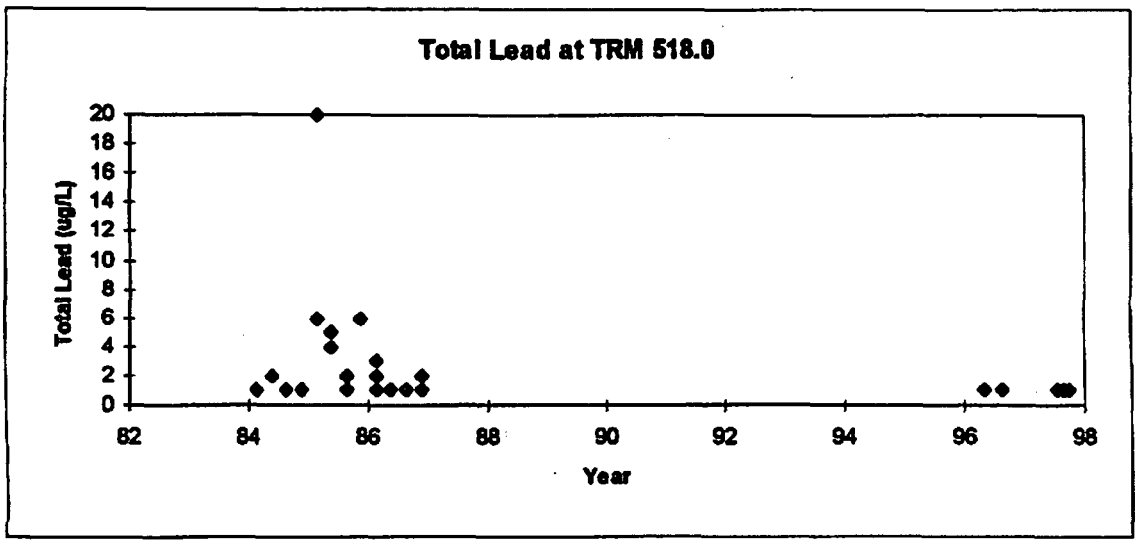




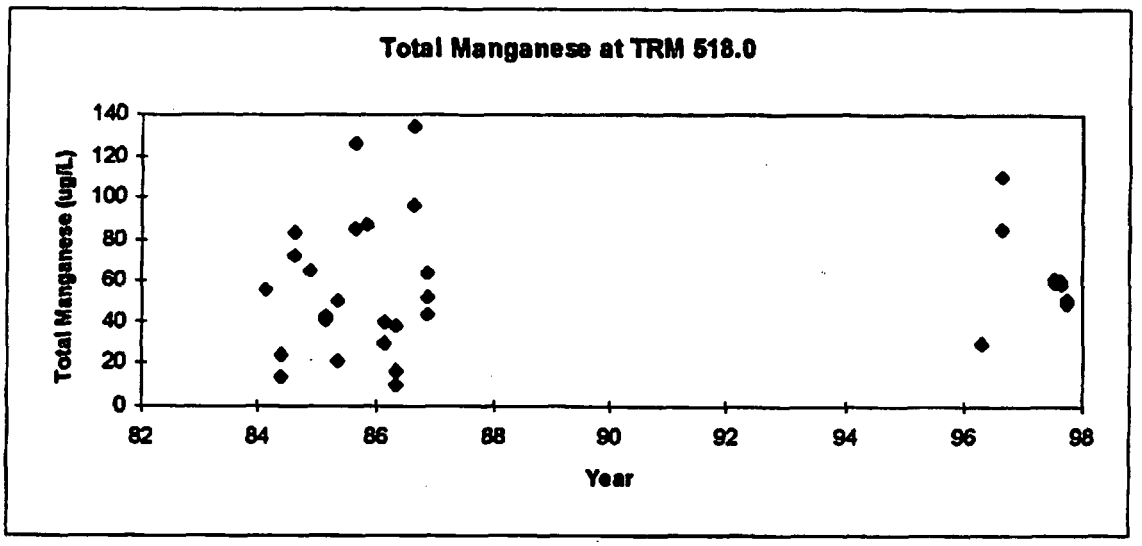
Appendix B-5 (Continued)

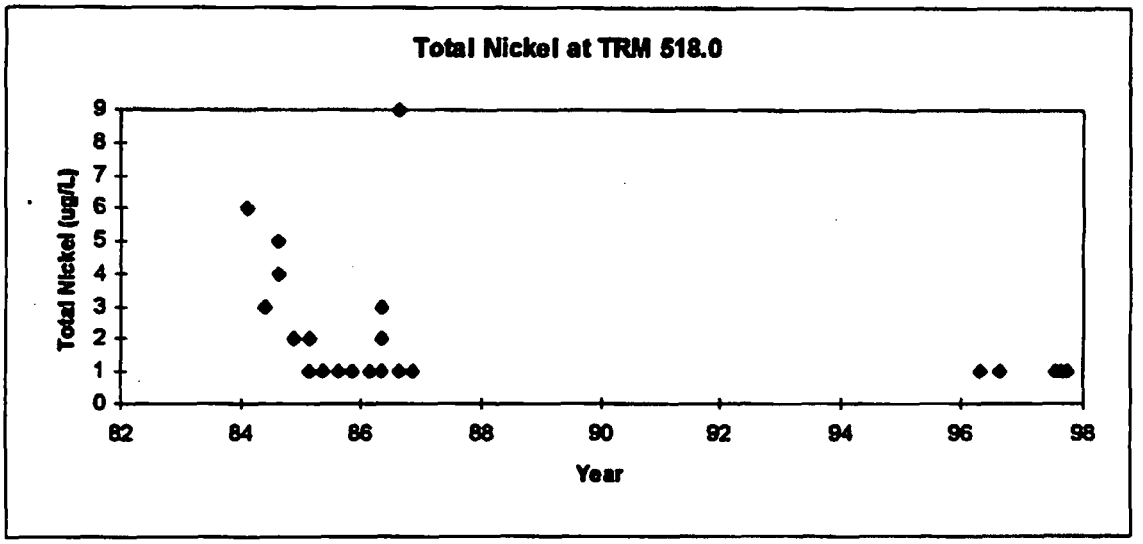


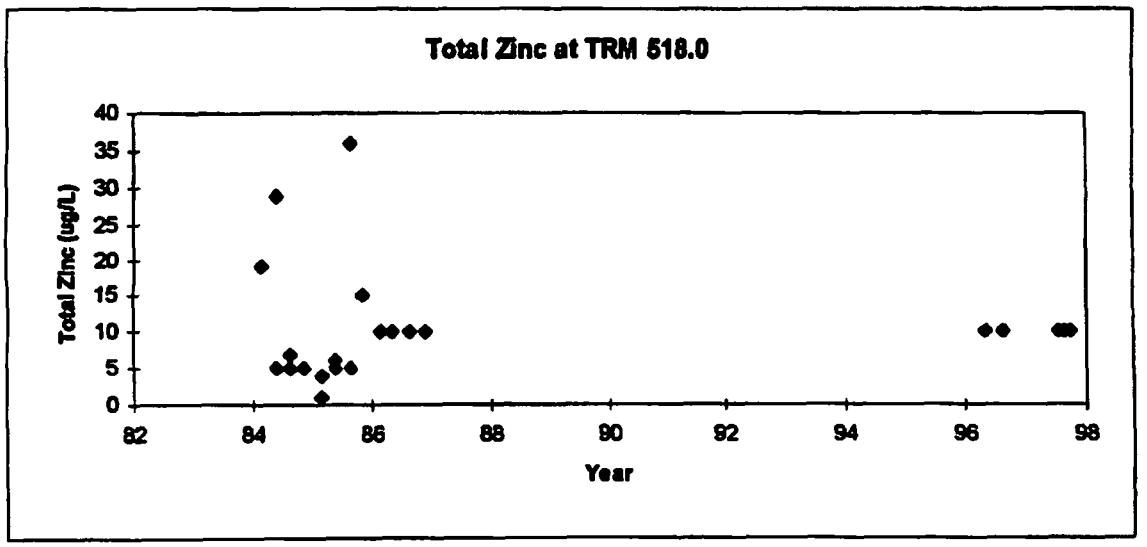




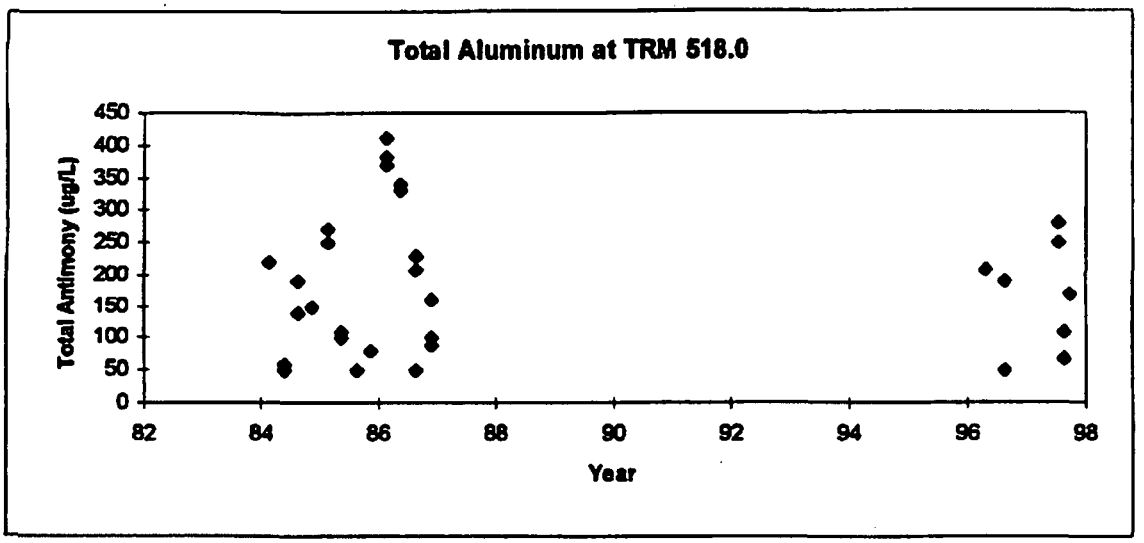
Appendix B-5 (Continued)

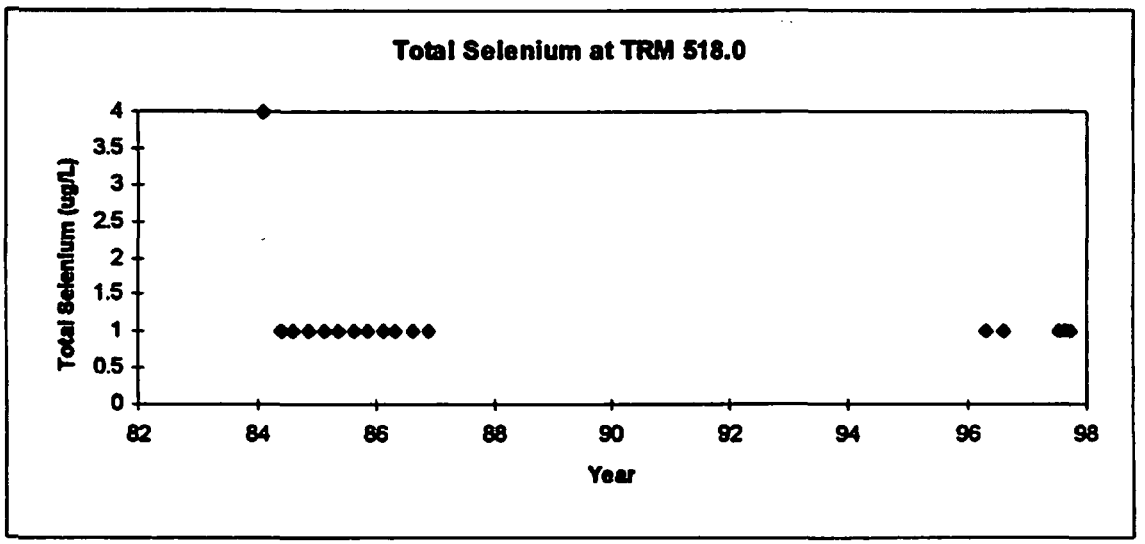


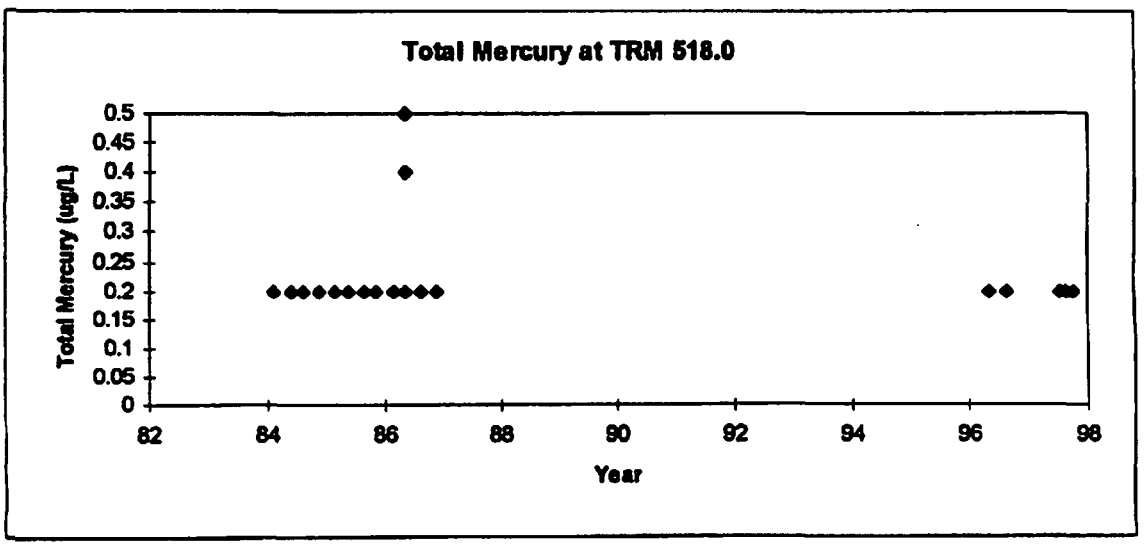




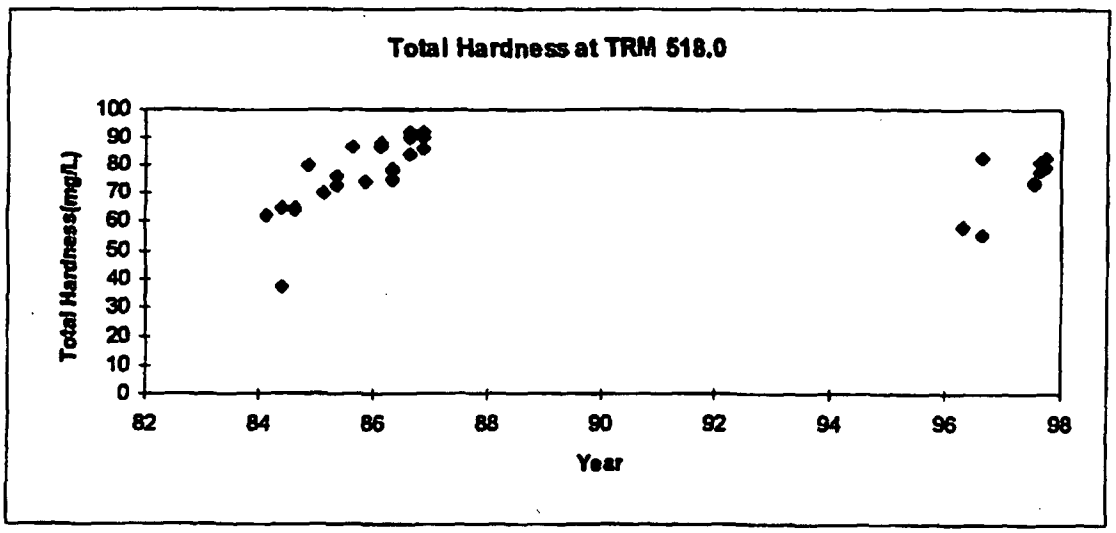
Appendix B-5 (Continued)



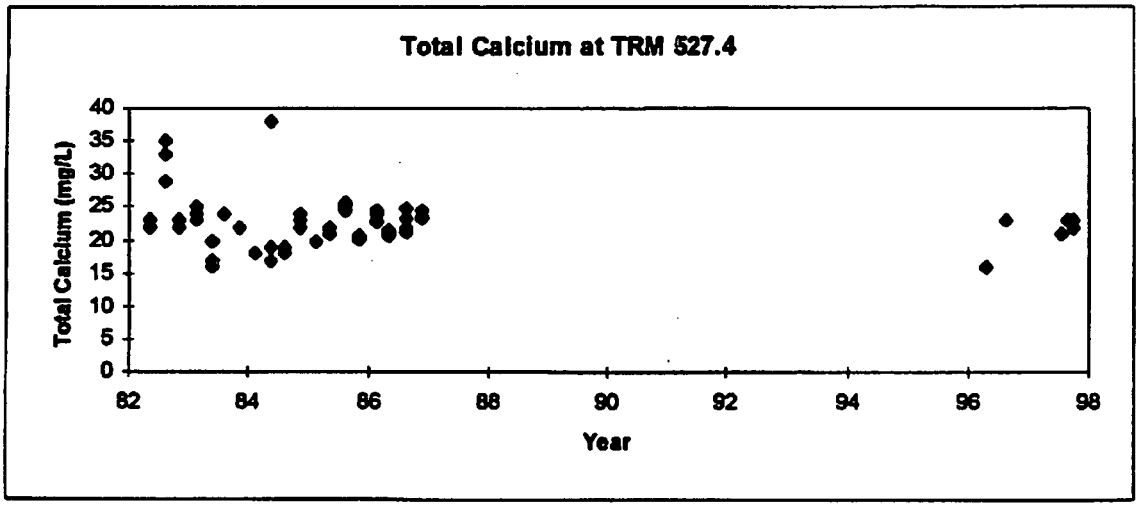


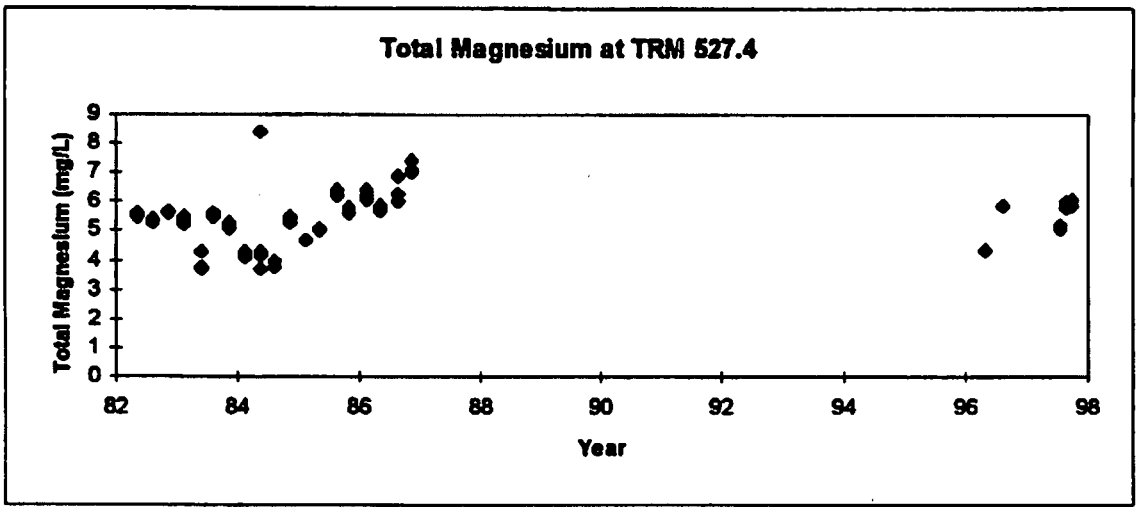


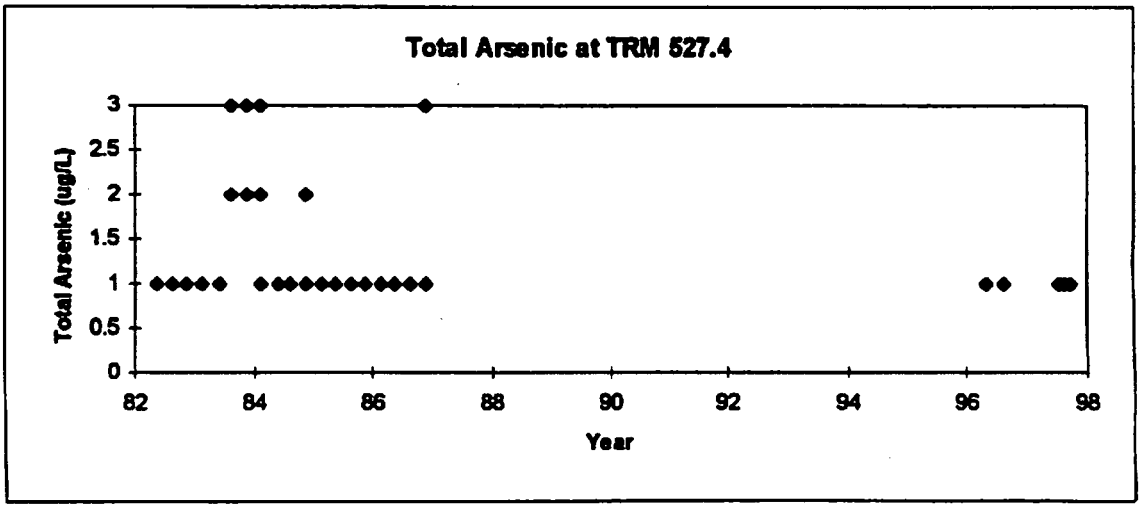
Appendix B-5 (Continued)



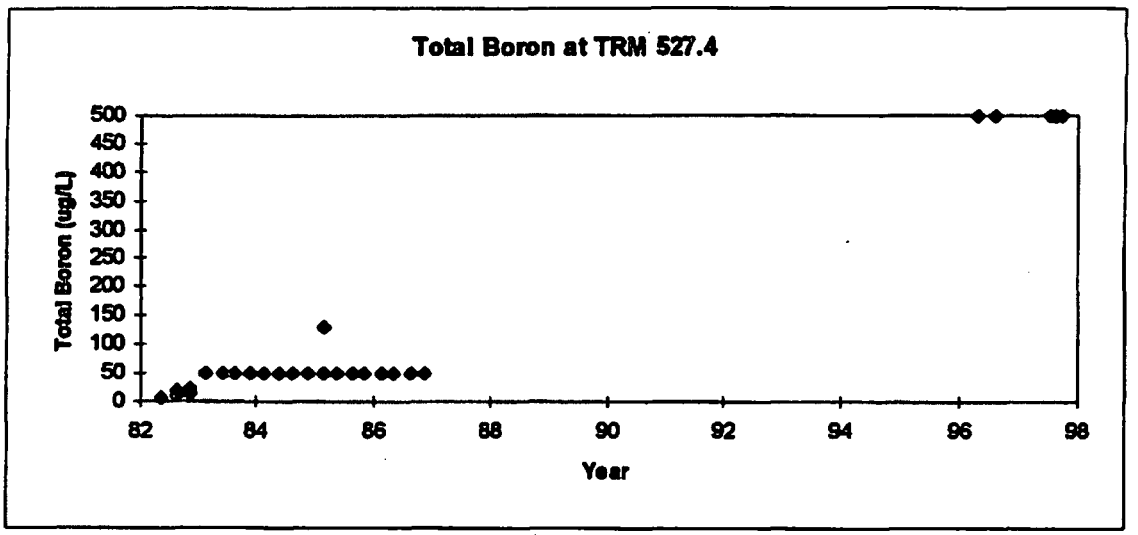
Appendix B-6. **Concentrations of selected metals during preoperational (1982-1987) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 527.4**

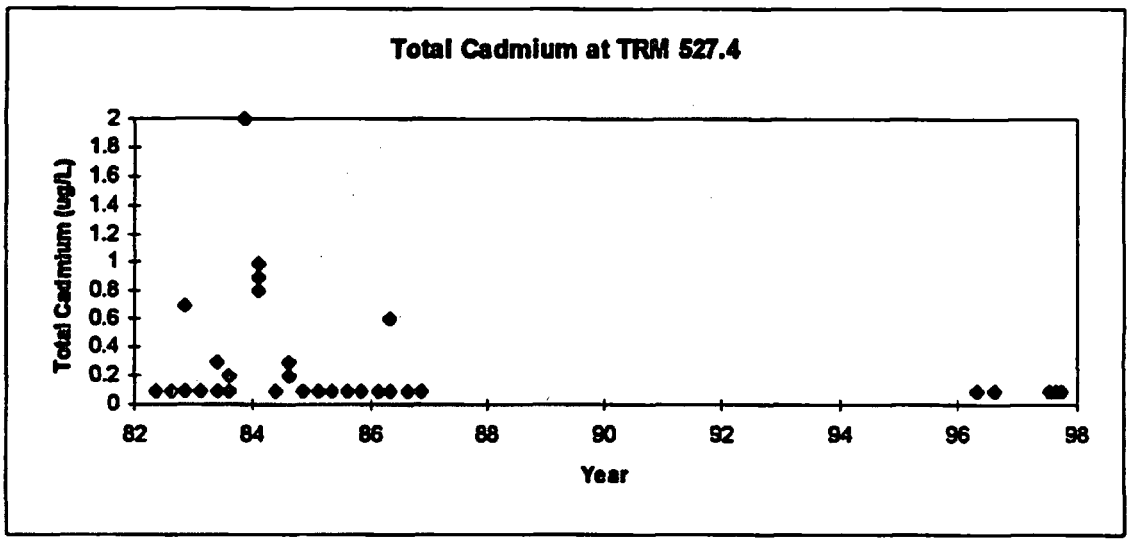


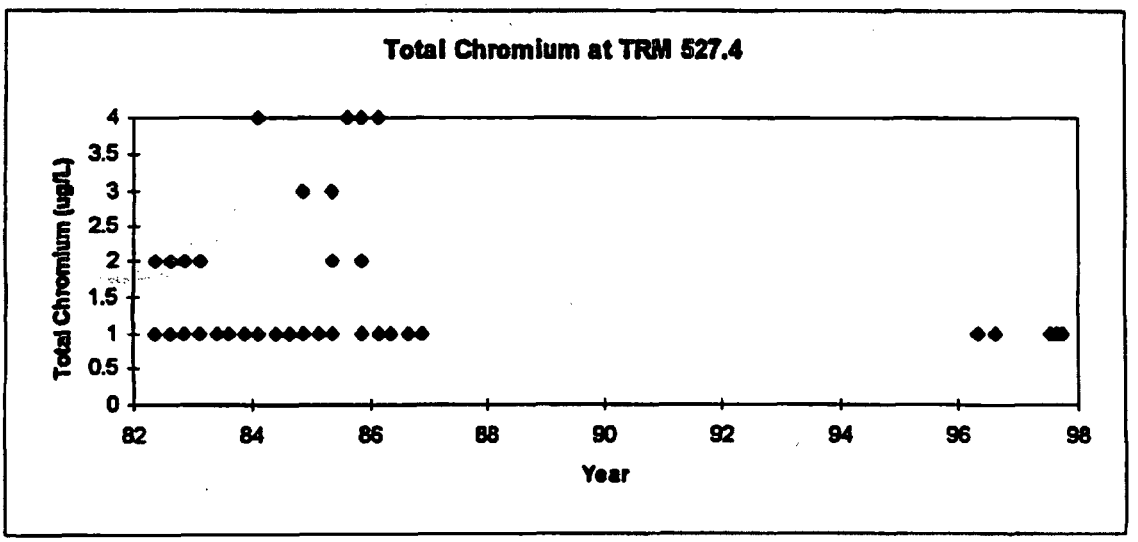




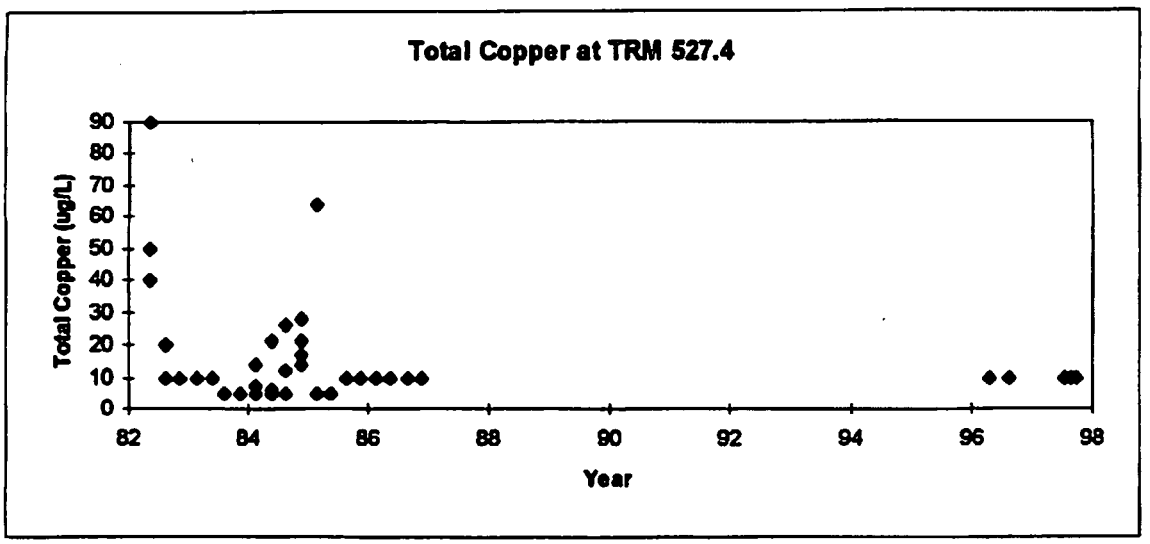
Appendix B-6 (Continued)

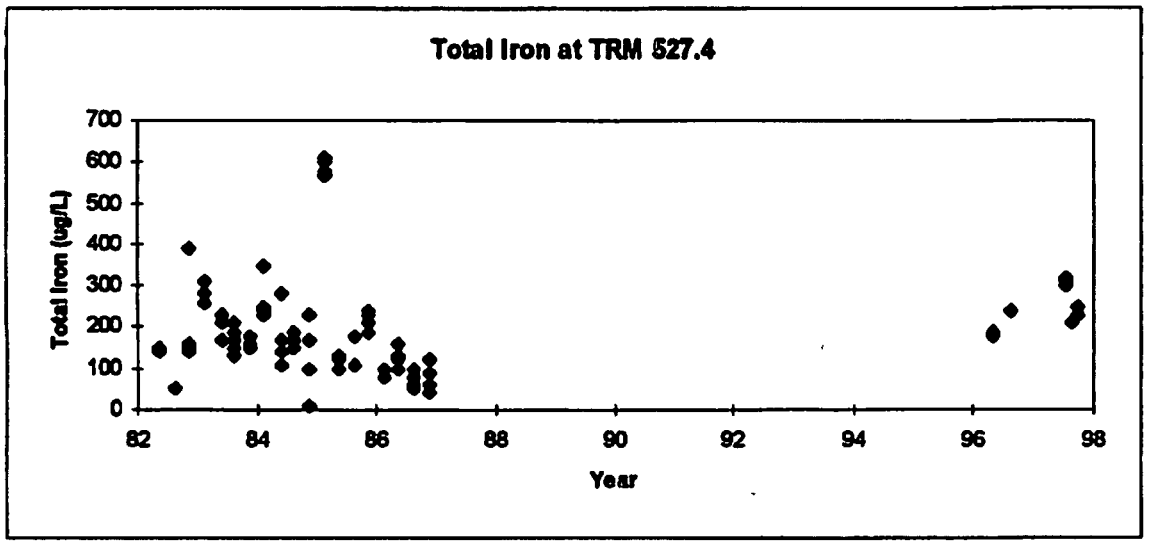


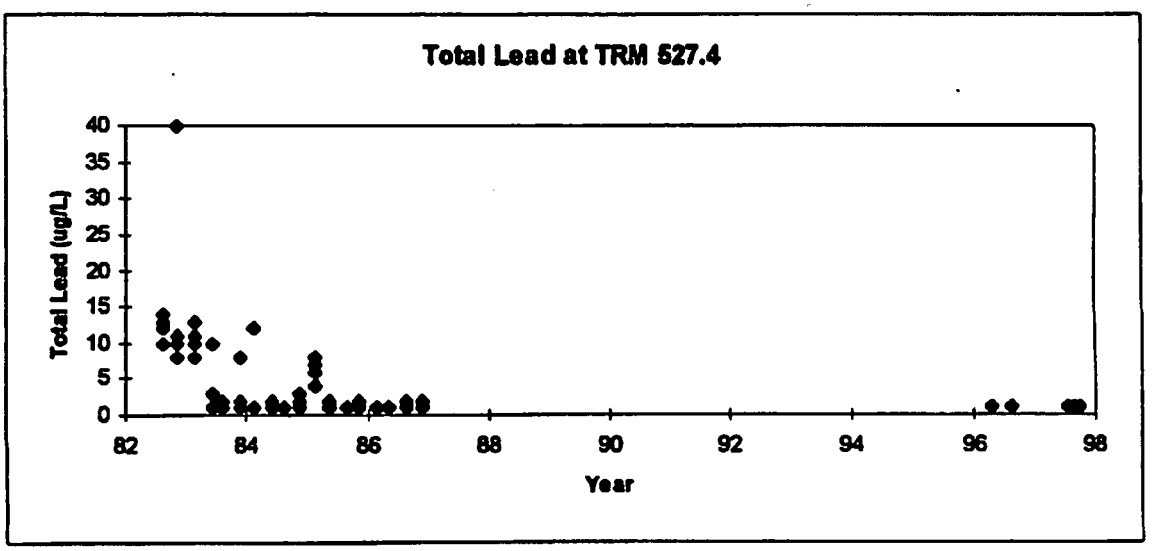




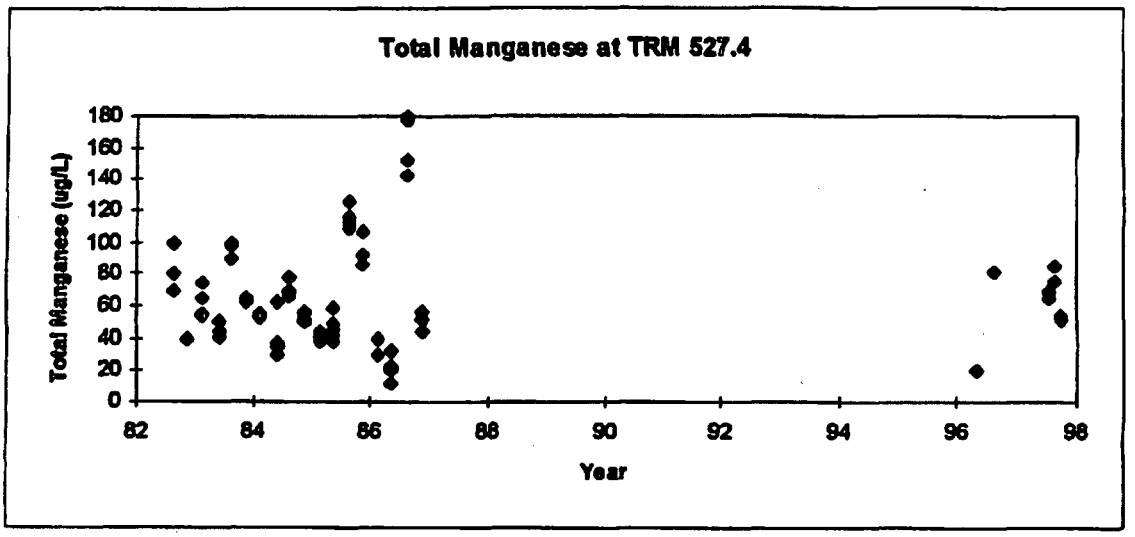
Appendix B-6 (Continued)

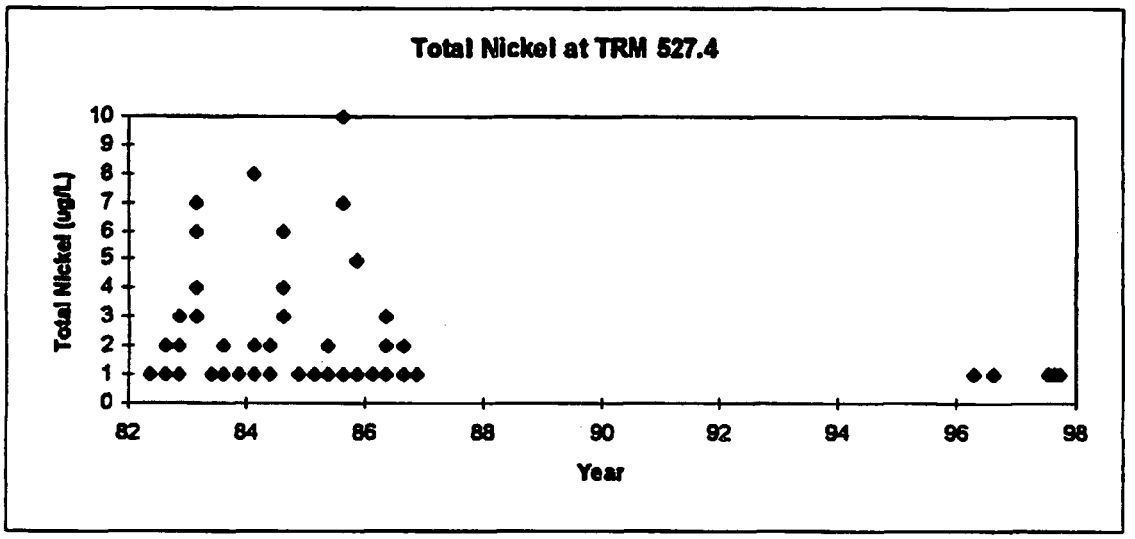


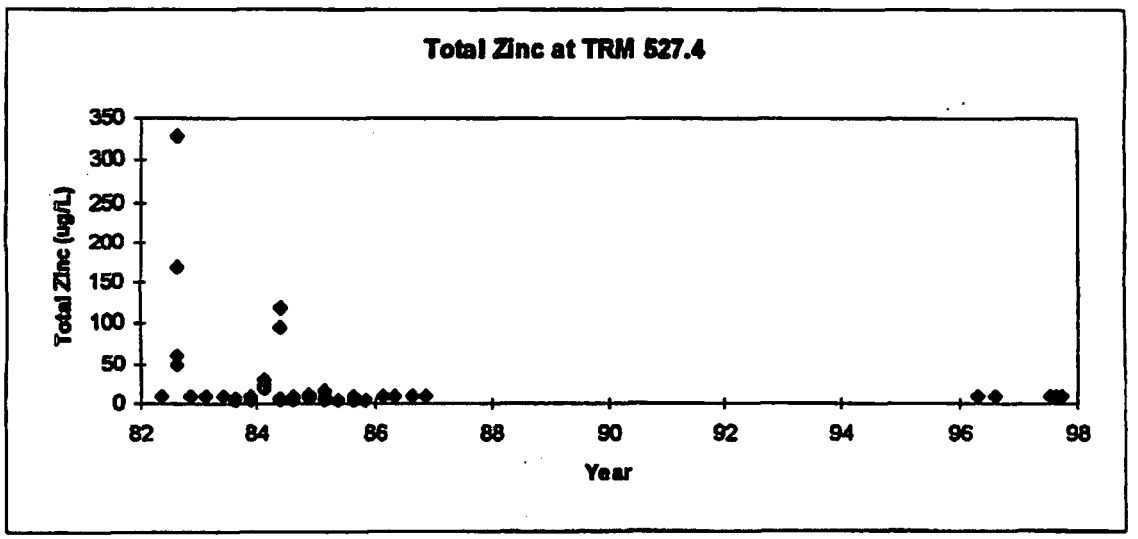




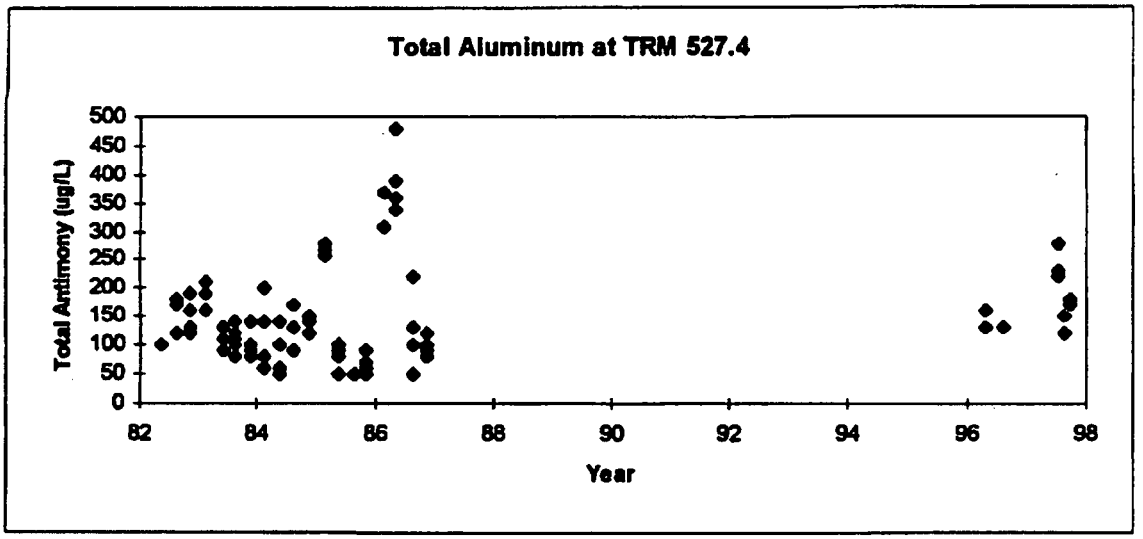
Appendix B-6 (Continued)

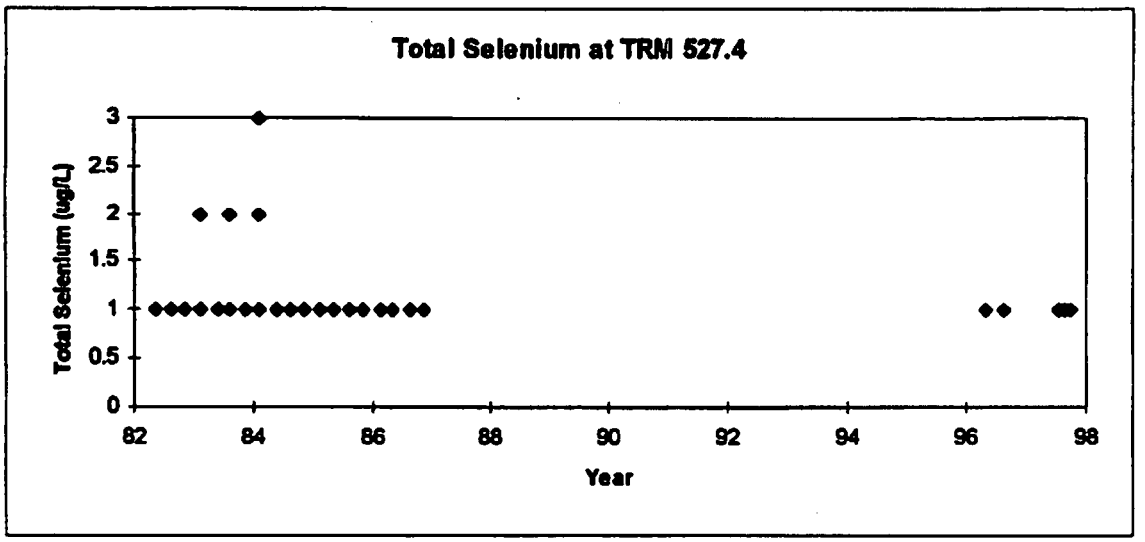


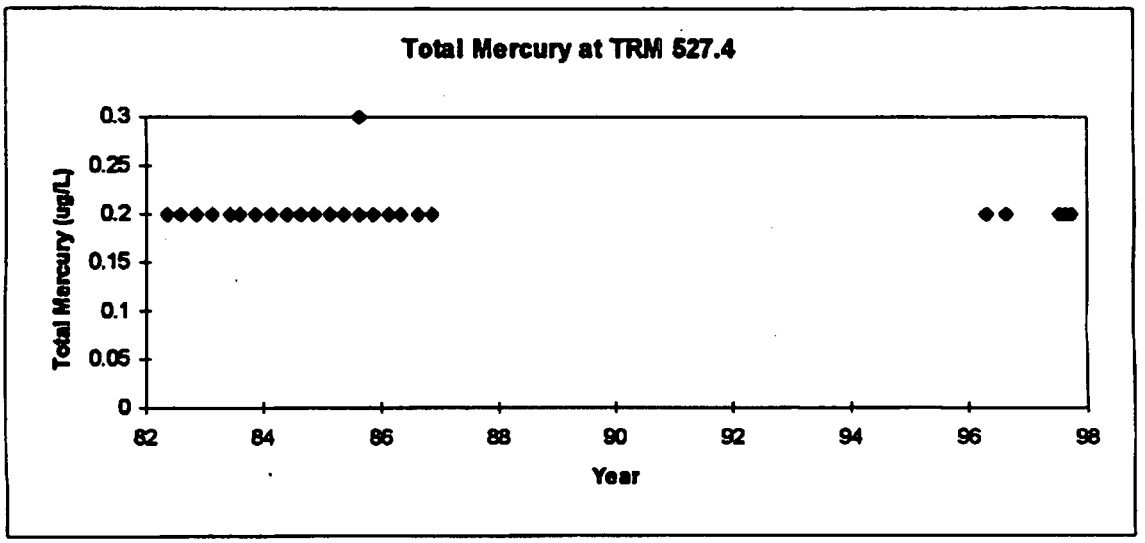




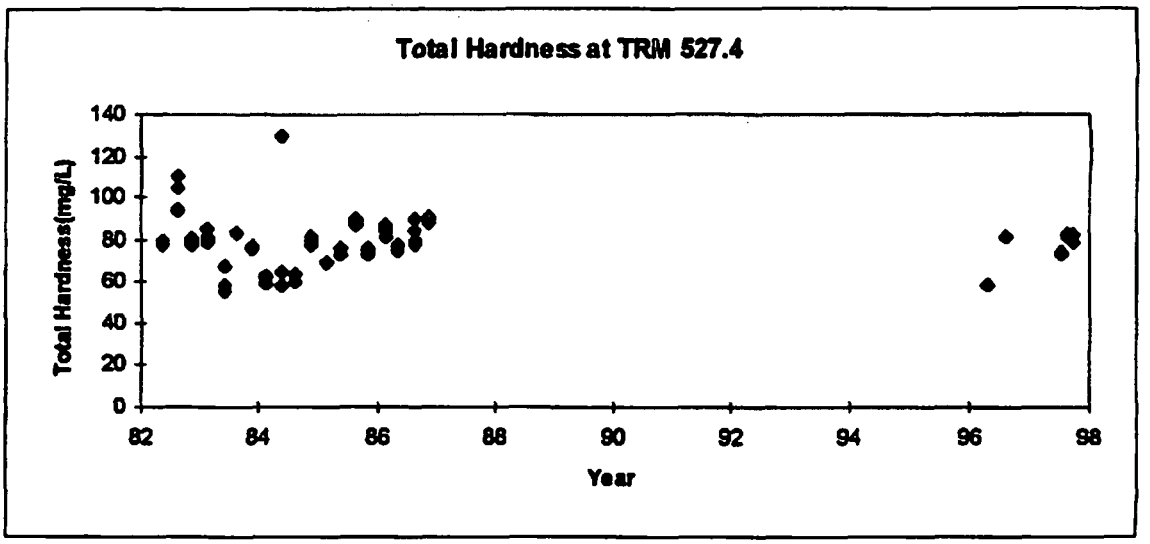
Appendix B-6 (Continued)



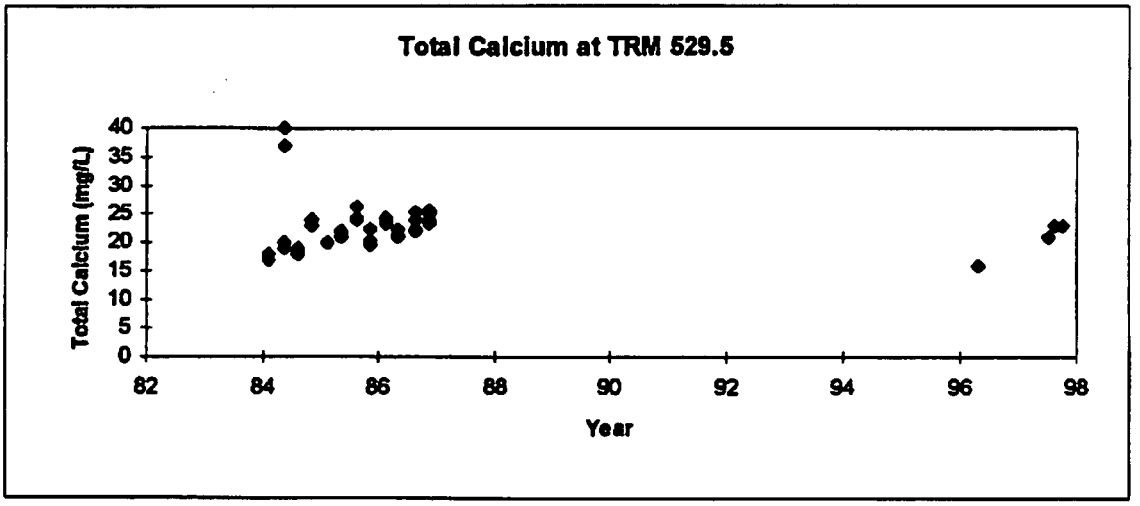


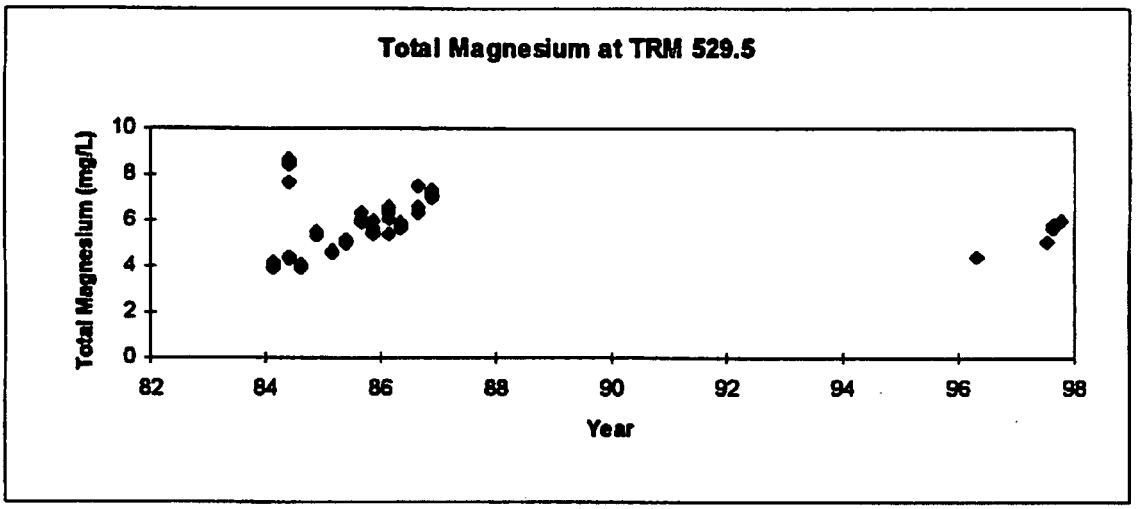


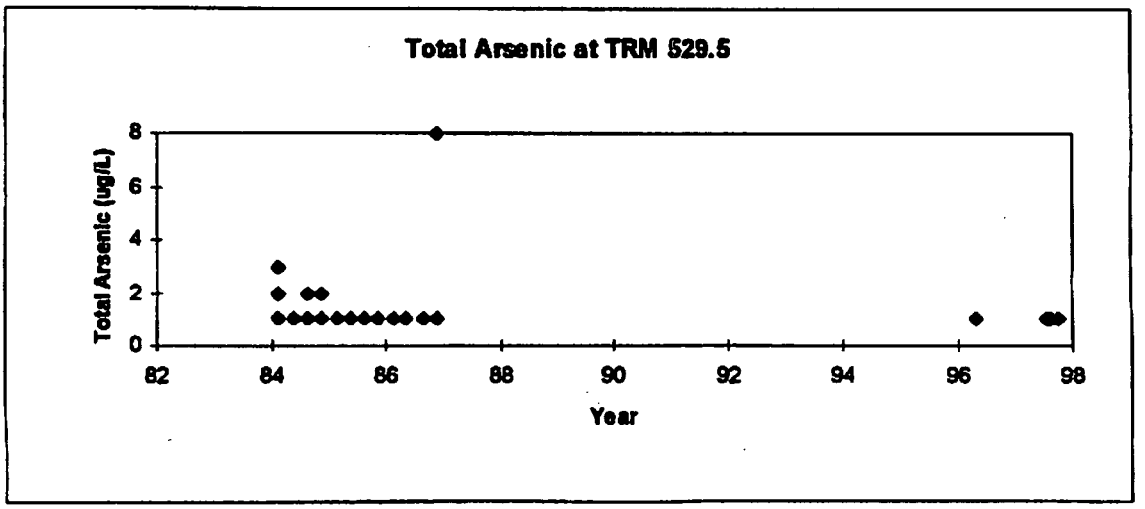
Appendix B-6 (Continued)



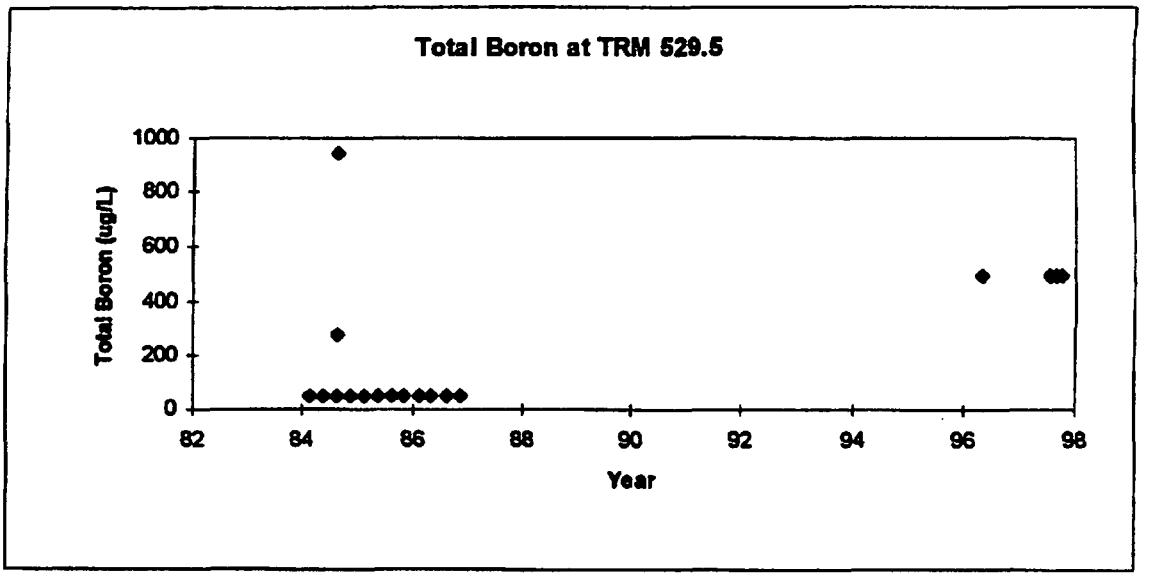
Appendix B-7. Concentrations of selected metals during preoperational (1984-1987) and operational (1996-1997) monitoring near Watts Bar Nuclear Plant at Tennessee River Mile 529.5

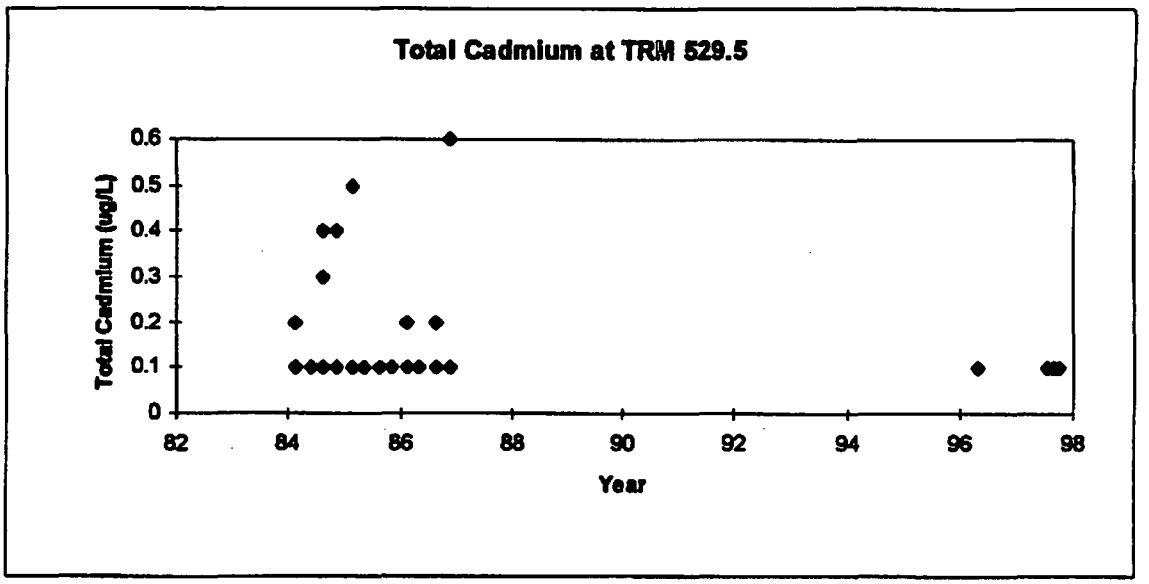


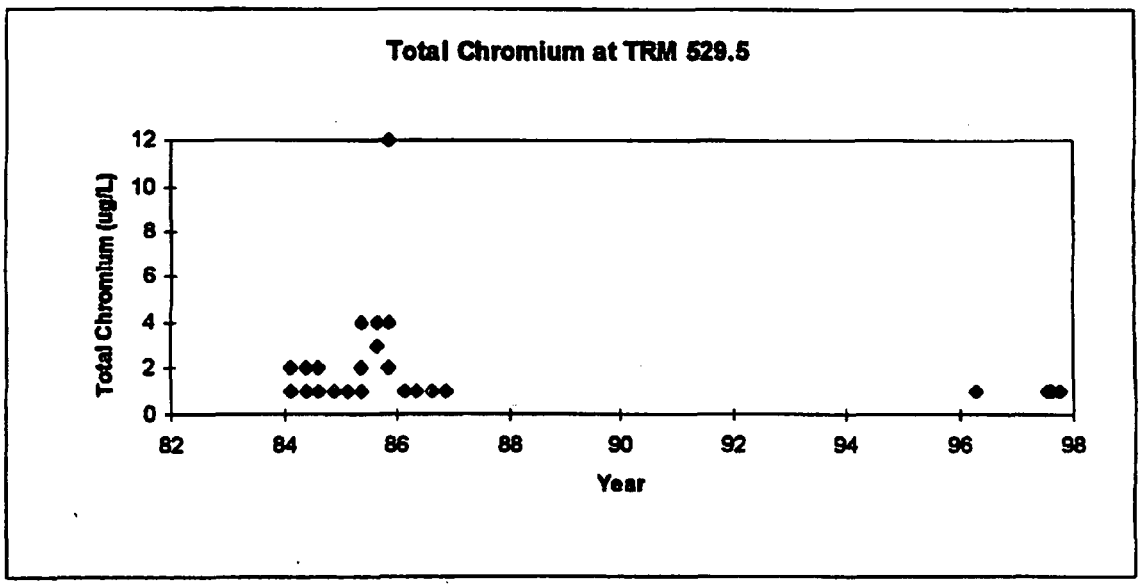




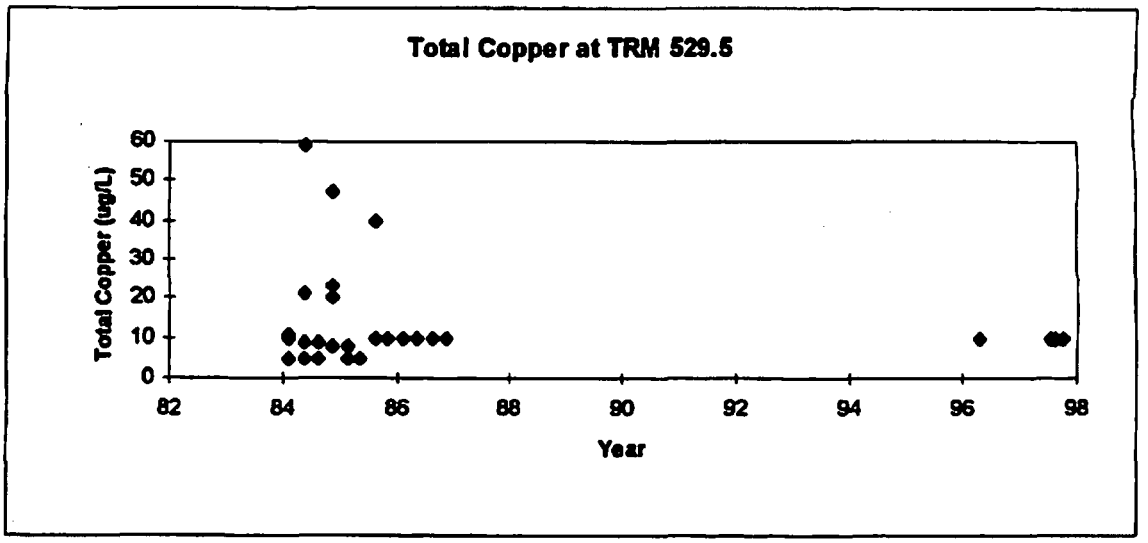
Appendix B-7 (Continued)

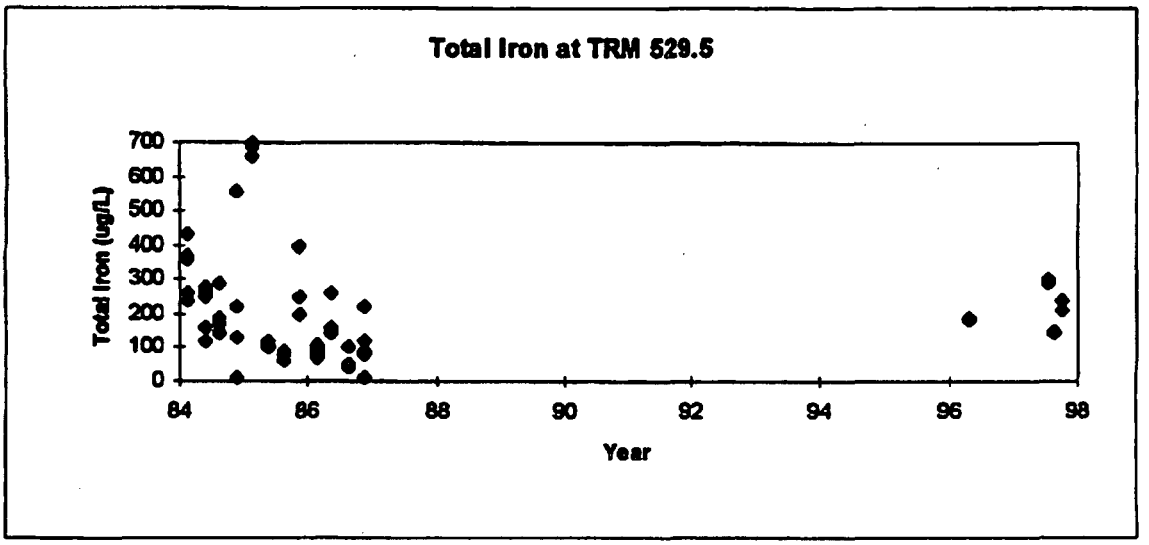


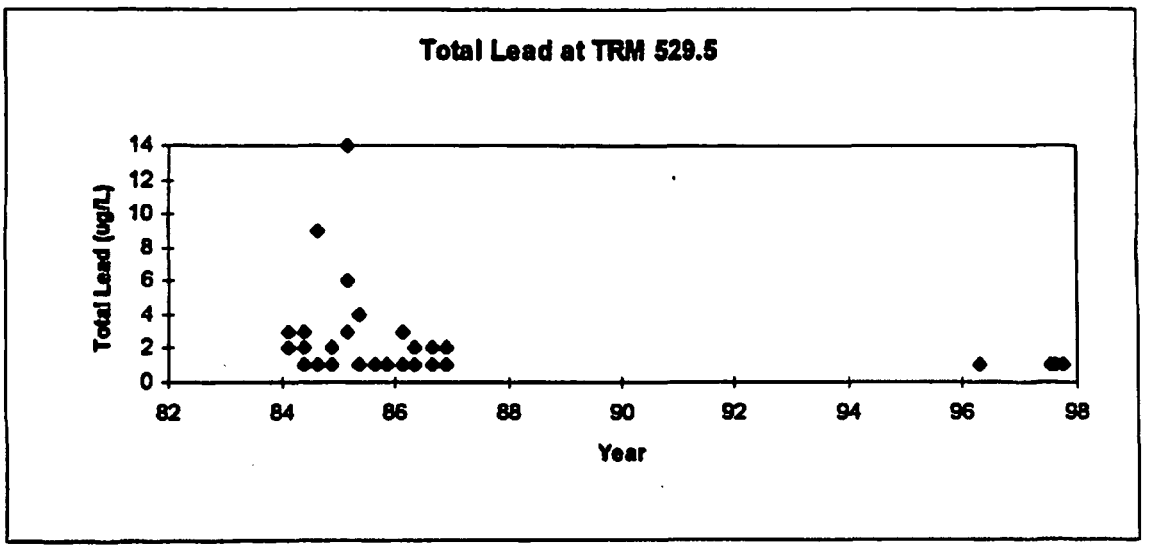




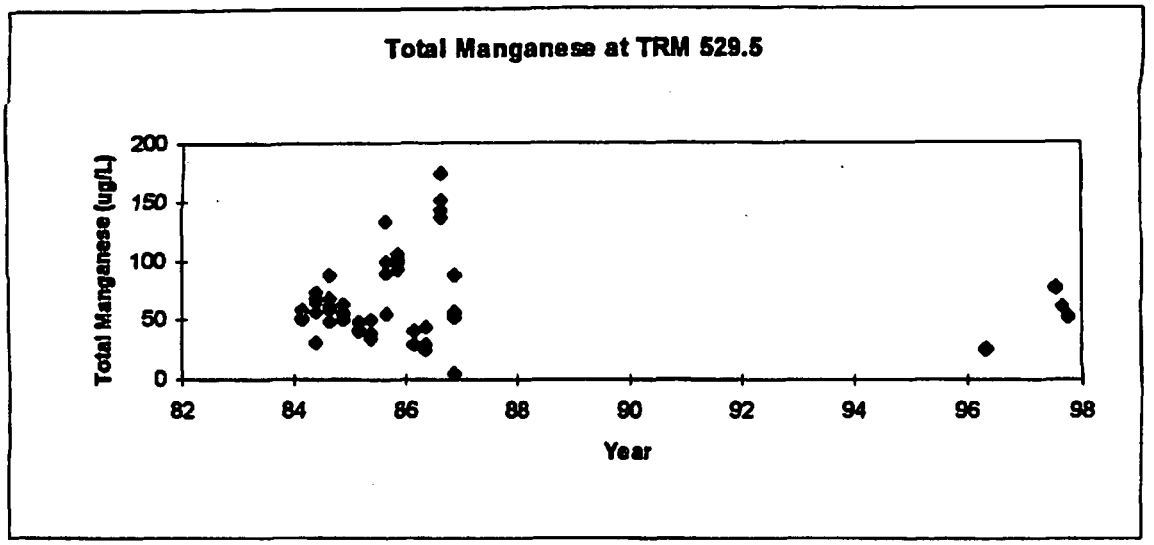
Appendix B-7 (Continued)

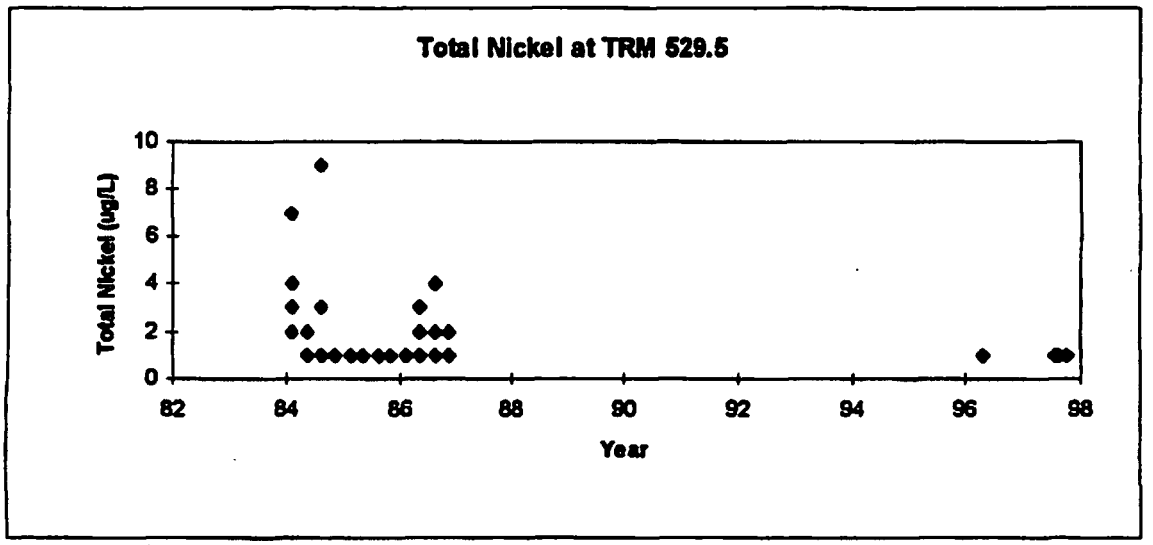


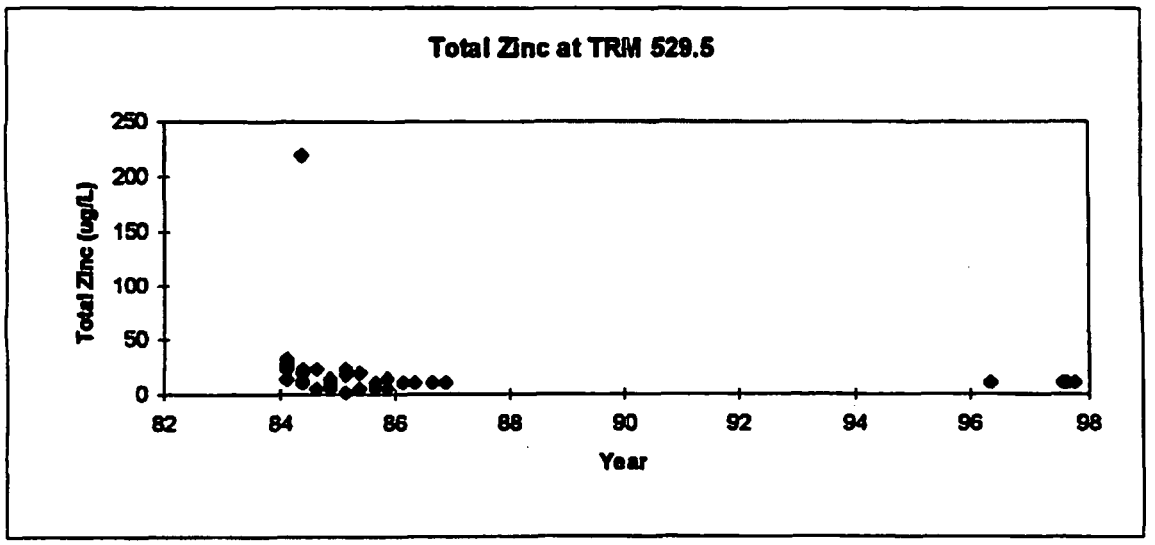




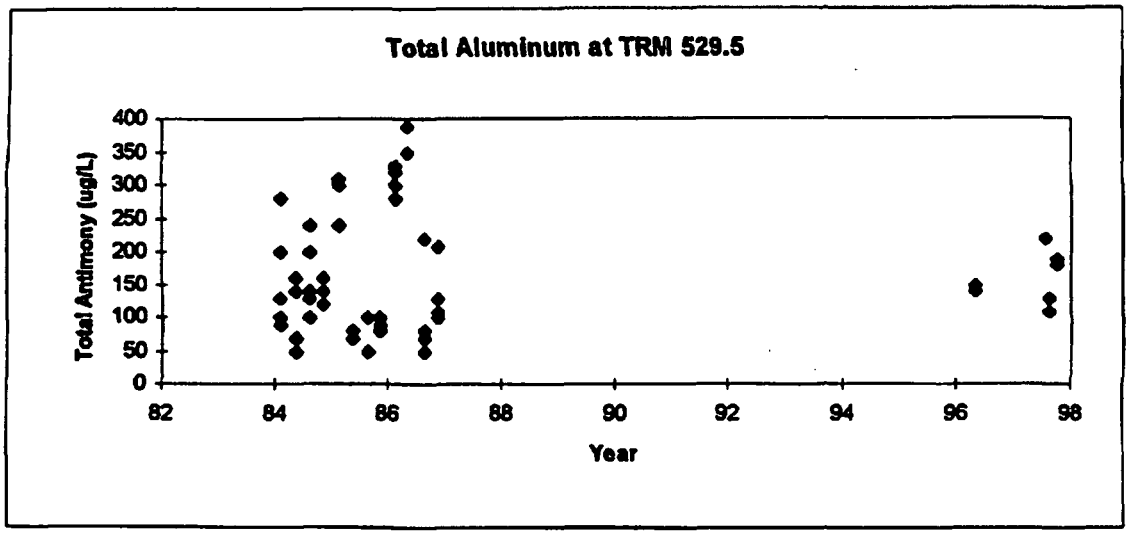
Appendix B-7 (Continued)

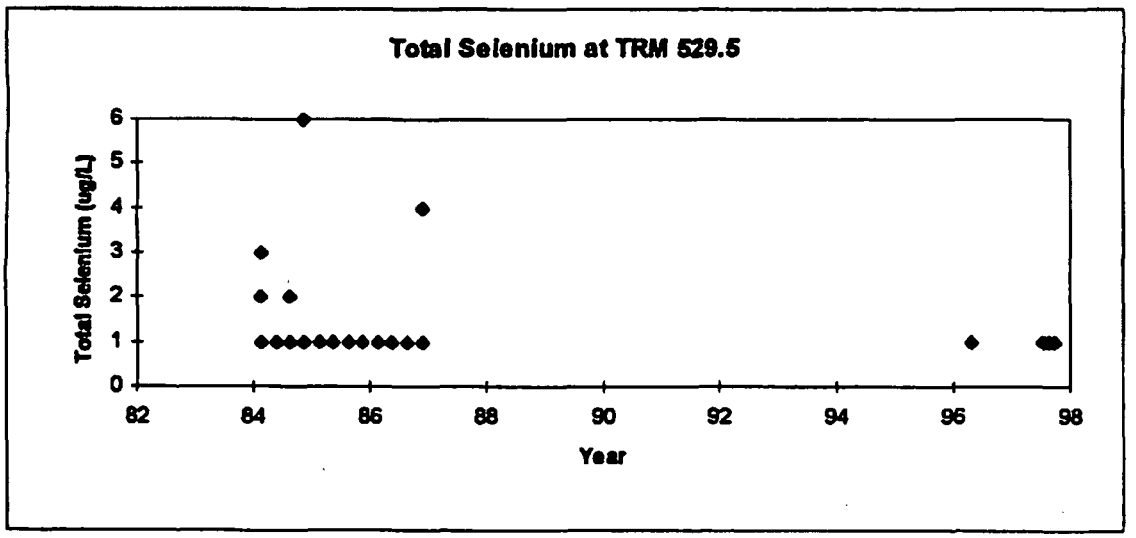


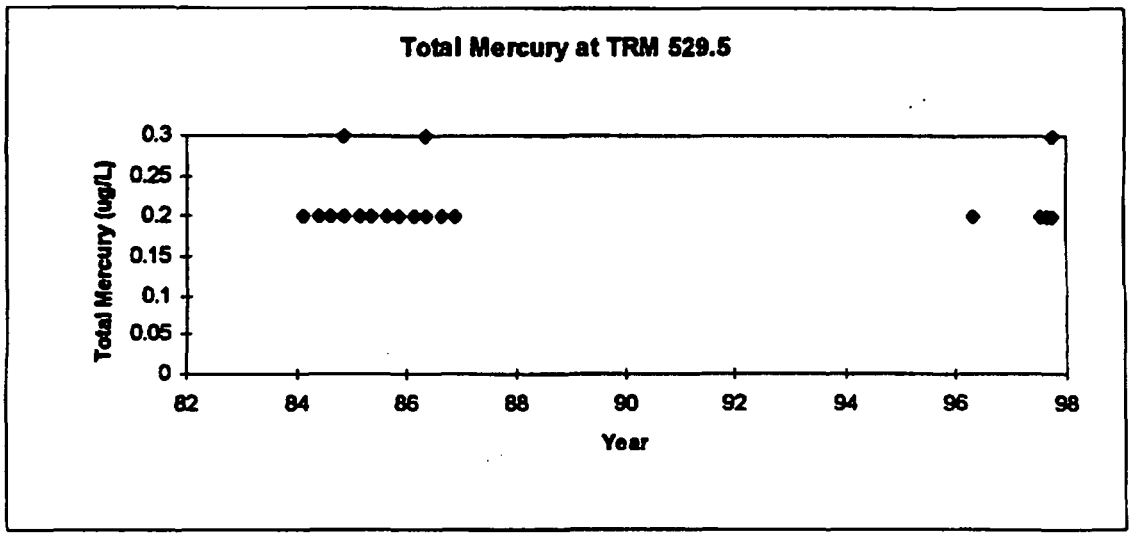




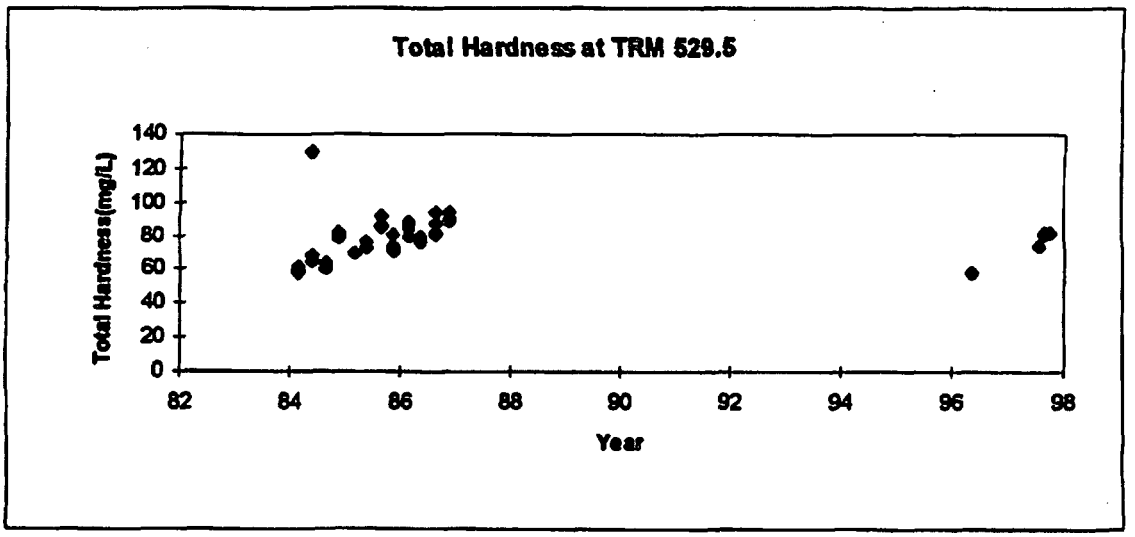
Appendix B-7 (Continued)







Appendix B-7 (Continued)



August 19, 1997

J. A. Scalice, ADM 1V-WBN

ADOPTION OF ENVIRONMENTAL ASSESSMENT (EA) AND FINDING OF NO SIGNIFICANT IMPACT (FONSI)—U.S. DEPARTMENT OF ENERGY, LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS WATTS BAR NUCLEAR PLANT, TENNESSEE AND HANFORD SITE, RICHLAND, WASHINGTON, EA-1210, JULY 1997

In 1995, the U.S. Department of Energy (DOE) completed a Programmatic Environmental Impact Statement for Tritium Supply and Recycling (TSR PEIS). In the TSR PEIS, DOE proposed several alternatives to provide a new source of tritium for the Nation's nuclear weapons program. The TSR PEIS included an analysis of the use of a commercial light water reactor (CLWR) as one of the alternatives. As part of the CLWR alternative, DOE considered the purchase of an operating or partially completed commercial power reactor, or purchasing irradiation services from an existing CLWR.

DOE seeks to confirm the viability of using a CLWR as a potential source for maintaining the Nation's tritium supply by performing a limited scale confirmatory test on a CLWR. In order to assess the environmental impacts of this confirmatory testing, DOE prepared an environmental assessment (EA). DOE's EA tiered from the TSR PEIS and covers those activities that would be necessary to conduct a test involving irradiation of tritium-producing burnable absorber rods (TPBARs) in a CLWR and post-irradiation examination (PIE) of the TPBARs. DOE's Proposed Action which includes activities at TVA's Watts Bar Nuclear Plant (WBN) would confirm the results of developmental testing conducted previously at DOE facilities and provide DOE with information regarding the actual performance of the TPBARs.

TVA activities associated with the Proposed Action include replacing four conventional pressure water reactor burnable absorber assemblies with assemblies containing the TPBARs (referred to as TPBARs-LTAs) during the next refueling outage at WBN, Unit 1. A typical fuel reload would contain more than 1,000 burnable absorber rods, of which 32 would be replaced by the TPBARs in the proposed test. The TPBAR-LTAs would be irradiated for one complete operating cycle of about 18 months following which they would be removed from the integrated assemblies and stored in the spent fuel pool. The TPBAR-LTAs would be shipped by DOE to the Pacific Northwest National Laboratory (PNNL) at Hanford for PIE.

DOE considered the use of another commercial reactor to conduct the LTA program. WBN was proposed for these tests because its refueling schedule provided optimum

LAST COPY: DO NOT REMOVE
Index No: [redacted]318
Title: Adoption of EA and Finding of No Significant Impact - US Dept. of Energy (DOE), Lead Test Assembly Irradiation and

timing for obtaining the performance data needed by DOE, and because it was the only reactor of compatible design that was not encumbered by vendor restrictions on use of its fuel or other components for defense-related research. All other U.S. PWRs of this design obtain their fuel from foreign vendors that impose contractual restrictions on use of their products for defense-related purposes. Use of any facility other than WBN would have required DOE to replace all of the reactor's fuel, resulting in possible delay of the tests as well as substantially increased cost.

The environmental impacts of the proposed action would be well within the limits of existing state and federal standards, and are not expected to have a significant impact on the environment. There would be no nonradiological environmental permit modifications or new environmental permits generated at WBN as a result of this action. The important impacts pertaining to WBN are summarized below.

Air Quality - The TPBARs are designed to retain tritium in a solid matrix. Should any tritium enter the reactor coolant it would remain in liquid form, offsite consequences in terms of air quality are not expected.

Water Quality - Small quantities of tritium (up to a maximum of 214 Ci/yr) may be released from the TPBARs during irradiation. This potential release is a negligible increase to normal operating releases. Exchange of the primary reactor coolant to maintain water chemistry could ultimately release tritiated water to the environment. However, the dose to the maximally exposed offsite individual from the plant's liquid effluents (either with or without the tritium contribution from the TPBARs) was estimated to be 0.70 mrem/yr which is about 23% of the 3 mrem/yr standard for demonstrating compliance with the requirements of 10 CFR Part 50, Appendix I. Irradiation of the TPBAR-LTAs would not alter the plant's compliance status with respect to the standard.

Waste Management - The quantity of waste (low-level radioactive liquids and solids) generated at WBN during this test is expected to be less than 1% of the waste generated annually at WBN. These wastes would be appropriately treated and disposed of at a licensed commercial facility with similar types of wastes from routine reactor operations.

Facility Accidents - Accidents during irradiation of the TPBAR-LTAs at WBN were evaluated to determine whether substituting TPBARs for the standard burnable absorber rods in the reactor's fuel assemblies could affect the frequencies or consequences associated with off-normal events or accidents previously evaluated for the reactor. It was determined that the TPBAR-LTAs would not likely affect the course or severity of such events.

Health and Safety - During refueling, workers at WBN would handle the TPBAR-LTAs in a manner similar to standard fuel and absorber assemblies and would not likely receive an increased dose from that activity.

Comments received from the Tennessee Valley Energy Reform Coalition (TVERC) after the public comment period were addressed by DOE in a separate document. Upon review, TVA has determined that these responses address the concerns raised by TVERC without detracting from the finding of insignificance. DOE's responses to TVERC's comments are attached.

TVA was a cooperating agency with DOE during the preparation of the EA. TVA has critically reviewed DOE's EA and determined that the scope, alternatives considered, and content of the EA are adequate. TVA has decided to adopt the DOE EA. The DOE EA, incorporated by reference, and the DOE FONSI are attached.

We concluded that TVA activities at WBN in support of the proposed LTA irradiation test would not be a major federal action significantly affecting the quality of the environment. Accordingly, an environmental impact statement is not required. The Office of the General Counsel concurs in this determination.

Original Signed By

Jon M. Loney, Manager
Environmental Management
WT 8C-K

DBN
Attachments (2)
cc: G. L. Askew, WT 8C-K (Attachments)
J. S. Chardos, OSA 1A-BLN (Attachments)
E. S. Christenbury, ET 10A-K (Attachments)
P. F. X. Dunigan, Jr., DOE
K. J. Jackson, WT 11A-K
O. E. Hickman, MOB 1T-WBN (Attachments)
O. D. Kingsley, Jr., LP 6A-C
W. C. McArthur, BR 5D-C (Attachments)
R. W. Williams, CTR 2C-M
Files, EM, WT 8C-K (Attachments)

Prepared by Diedre Nida (EM) with concurrence by Khurshid Mehta (OGC).

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

AUG 14 1997

97-STP-557

Dr. Stephen A. Smith
Executive Director
Tennessee Valley Energy
Reform Coalition (TVERC)
P. O. Box 1842
Knoxville. Tennessee 37901-1842

Dear Dr. Smith:

COMMENTS ON THE DRAFT ENVIRONMENTAL ASSESSMENT (DOE/EA-1210) LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS WATTS BAR NUCLEAR PLANT. TENNESSEE AND HANFORD SITE. RICHLAND. WASHINGTON

Thank you for your comments on the subject draft Environmental Assessment (EA). A "Finding of No Significant Impact (FONSI)" was issued on July 22. 1997. prior to the arrival of your comments. Upon receipt of your comments we evaluated them with respect to the final EA and the approved FONSI to see if we needed to amend or withdraw the documents in consideration of your comments. We determined that the comments did not impact the analysis in the EA and did not change the FONSI determination. We are. however. responding to your comments. and our responses are enclosed. Also enclosed is a copy of the final EA and the FONSI determination.

If you have any questions. please contact Julie Turner. NEPA Document Manager, on (509) 372-4015 or myself on (509) 376-6667.

Sincerely.

Paul F. X. Dunigan, Jr.

Paul F. X. Dunigan. Jr.
NEPA Compliance Officer

STP:JKT

Enclosures:
1. Responses to Comments
2. Environmental Assessment/
   Finding of No Significant Impact

cc w/enclosure 1:
C. M. Borgstrom. EH-42
S. M. Sohinki. DP-62
D. Nida. TVA
J. Chardos. TVA

DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE
RESPONSES TO COMMENTS FROM
TENNESSEE VALLEY ENERGY REFORM COALITION
ON THE DRAFT ENVIRONMENTAL ASSESSMENT
LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS

In 1995, DOE completed a Programmatic Environmental Impact Statement for Tritium Supply and Recycling (TSR PEIS). Based on this report DOE described the need for a new source of tritium for defense purposes and has now completed a draft EA which describes DOE's need to confirm the viability of using a commercial light water reactor (CLWR) as a potential source for maintaining the nation's supply of tritium.

According to the 1995 report, since 1945 nuclear weapons have been a nuclear deterrent and the cornerstone of our nation's defense policy and national security.

Tritium is used to enhance the yield of current nuclear weapons and allows for the production of smaller or more powerful bombs. According to the DOE, the U.S. has based its strategic nuclear systems on designs that use tritium and therefore requires a reliable source of this material in order to maintain the nuclear weapons stockpile as required by law.

Question: How does DOE plan to promote and retain consistency with the ratified START I and negotiations with START II by advocating this policy?

Response: The Department's plans for assuring the availability of a new source of tritium by 2005 are dictated by requirements mandated by the President in his 1996 Nuclear Weapons Stockpile Plan. This classified Plan, issued annually, specifies the types and numbers of weapons that will be included in the stockpile. In turn, this plan dictates tritium requirements to support those weapons that are to remain in the stockpile. Thus, the Department's plans are consistent with the President's direction, which is given after taking into account the status of arms control agreements such as START I and START II.

Ironically all of the DOE facilities that were once used to maintain this stockpile are not operational today. DOE's previous analysis indicated that our country would not need a tritium source until the year 2011, but by some stroke of genius analysis, DOE revised its numbers and the agency now believes that we will need a new source by the year 2005.

Question: DOE should provide the analysis that indicates the need for a revision in this schedule with respect to the START treaties and the current recycling schedule for tritium - that is DOE should make public this analysis of revision from 2011 to 2005 and how long the current tritium recycling schedule will meet this need.

Response: As stated above, the need date for tritium is determined from the requirements set forth by the President in the Nuclear Weapons Stockpile Plan. Based upon the types and numbers of weapons specified in the latest Plan, a new supply of tritium will be required as early as 2005.

DOE's decision in the TSR PEIS was to use a combination of a CLWR and accelerator alternatives to provide for this so-called need for tritium. A decision will be made in by 1998 to determine which will be used as the primary source and which will serve as the backup source.

Question: What is the status of the accelerator project, where will it be conducted, and will a pilot project be conducted?

Response: The accelerator project is well underway and making good progress. It is roughly at the mid-point of a development program to completely characterize all of the technologies needed for the plant. A conceptual design and a firm cost estimate were completed in March. The program will begin engineering design in October. If the accelerator plant is built, it will be built on the DOE Savannah River Site. The development and design efforts are underway at Los Alamos National Laboratory. There will be no "pilot" project to produce tritium. However, a full scale demonstration of the low-energy portion of the accelerator will be done at Los Alamos.

Aspects of the actual tritium production program or operations at the CLWR used to irradiate the TPBARs are, or would be, addressed by separate NEPA documentation.

Question: Will this be addressed by a separate NEPA document and if so what is this document and when do you expect it to be produced?

Response: A draft Environmental Impact Statement (EIS) for the production operations is scheduled to be issued 4/98.

TPBARs have been designed to only be used in PWR reactors developed by Westinghouse.

Question: Are these the only TPBARs expected to be produced and if so can you provide a list of those facilities that are Westinghouse PWR?

Response: If a decision is made to supply the stockpile with tritium produced in a CLWR, additional TPBARs will be produced but will not necessarily be irradiated in a Westinghouse PWR. A Request for Proposals (RFPs) for the production mission has been issued with responses due mid September.

Other Westinghouse PWRs include those operated by: Carolina Power & Light, Commonwealth Edison, Consolidated Edison, Duke Power, Duquesne Light, Florida Power & Light, Georgia Power, Houston Lighting & Power, Indiana/Michigan Power, New York Power Authority, Pacific Atlantic Energy Service Corp., Northeast Utilities, Northern States Power Co., Pacific Gas & Electric, South Carolina Electric & Gas, Southern Nuclear Operating Co., Tennessee Valley Authority, Texas Utilities Electric Co., Union Electric Co., Virginia Power, Wisconsin Electric Power Co., Wisconsin Public Service Corp., and Wolf Creek Nuclear Operating Corp.

DOE's rationale for choosing a nuclear power plant with Watt Bar's track record and barely one year of operational history--wiring concerns, fire protection material concerns, poor QA/QC program, $6.8 billion and 22 years under construction, and shut down by the NRC in 1985 when the TVA was about to get an operating license--was because of the plants optimum refueling schedule and because it was the only reactor "of compatible design that was not encumbered by vendor restrictions on use of its fuel or other components for defense-related research. All other U.S. PWRs of this design obtain their fuel from foreign vendors that impose contractual restrictions on use of their products for defense-related purposes."

Question: How does DOE plan to address this restriction?

Response: There are two possible methods of dealing with this restriction. First, the Department could provide, at market price, uranium from its own supplies. Second, the utility or utilities involved in the program could purchase unencumbered uranium and the Department could pay the differential, if any, between the purchase price and the price they would have paid for uranium which was under the restriction.

Question: How does DOE plan to prevent this program from being a bailout of nuclear power plants that otherwise could not compete on the open market in a deregulated utility market?

Response: While there will be some financial benefit to the utilities involved in the program, the Department's tritium program would not be a "bailout" for any utility. Rather, the Department is responding to direction from the President, and will obtain tritium in a manner which protects national security at a reasonable cost to the taxpayer.

Other problems with conducting this activity at WBN are the fact that the EA has not adequately addressed the results of annual effluent monitoring and ambient air quality monitoring because the data was supposedly not available when the EA was issued.

Question: This information should be available now and DOE should address this concern before the test occurs. WBN celebrated one year of operation on May 23, 1997. I would request that DOE make this information available to the public.

Response: WBN is required to report its annual environmental and effluent monitoring results to the Nuclear Regulatory Commission at the end of each calendar year, and the reports for all commercial nuclear facilities should be available from the NRC. The most recent report would consist of data obtained during calendar year 1996. Because the plant began operation in May of 1996 and the year's activities included a period of testing prior to reaching full power, the results for that year would not be representative of those for a typical year's operation. In section 4.3, the EA addresses the expected annual emissions from WBN using data provided in the plant's Environmental Statement (NRC 1995). That document was prepared in April 1995, and the expected emissions are based on operational data from other commercial facilities of the same design. The values reported in both documents are expected to bound the actual emissions from

the facility. DOE's conducting the LTA program at WBN is not anticipated to have a measurable impact on normal operating effluents at the facility.

DOE should have weighed the differences in making a revision to a current facility's contract with respect to its origin of fuel versus the transportation costs of conducting the assembly at WBN.

Question: Can you explain why this was not considered in the draft EA? Only a minuscule amount of tritium will be produced with this project so would it not have helped to have this project confined to a small area instead of transporting the materials from the Atlantic to the Pacific?

Response: Irradiation of the LTA was a service the DOE needed to procure. Design and fabrication activities were already underway when the DOE solicited proposals to provide irradiation services for the LTA. The utilities that responded were in the same geographical area. Thus, DOE did not have an option to geographically confine the project.

What is DOE's estimation on the cost of this LTA?

Response: The contract for this first of a kind LTA is $7.5M. There is not expected to be a direct correlation between the cost of this LTA and production costs.

Water Quality. During irradiation of the TPBAR-LTAs at WBN, a small quantity of the tritium produced in the rods may be released into the reactor's primary coolant system - a total of 214 Ci/y. Exchange of the primary coolant to maintain water chemistry could ultimately release tritiated water to the environment. ...Because standards of exposure are established for a 70 kg man, there is no correlation for a developing fetus; in fact, several studies have been done that indicate this needs to be studied more and safety measures need to be established before this activity proceeds. ...Tritium can be incorporated into essentially all portions of the living machinery; and it is not innocuous - deaths have occurred in industry from occupational overexposure.

Question: It is incumbent on DOE to address this concern. How does DOE address this concern?

Response: The developmental effects of tritium compared to those from other radionuclides have been studied extensively, and have been summarized in a recent review article (Straume and Carsten 1993). The relative effectiveness of tritiated water in the developmental studies was 1-3 times that of external gamma radiation (commonly used as a standard). The lowest concentrations of tritium in water that produced effects in the offspring when water was consumed by the mother during pregnancy was in the range of 100 million pCi/L, whereas the EPA drinking water standard is 20,000 pCi/L.

Exposures to environmental tritium are not expected to increase in the vicinity of WBN as a result of the LTA program, compared with exposure to the plant's normal operating effluents. The tritium concentrations in drinking water supplies downstream of WBN are maintained well below the maximum drinking water standard. Therefore, no health effects in either adults or offspring of pregnant women would be expected, even accounting for the slightly increased effectiveness of tritium compared to external radiation exposure.

References:

U.S. Nuclear Regulatory Commission (NRC). 1995. *Final Environmental Statement Related to the Operation of Watts Bar Nuclear Plant, Units 1 and 2.* Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, D.C.

Straume, T. and A.L. Carsten. 1993. "Tritium Radiobiology and Relative Biological Effectiveness," Health Physics 65(6):657-672.

FINDING OF NO SIGNIFICANT IMPACT

LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS WATTS BAR NUCLEAR PLANT, TENNESSEE AND HANFORD SITE, RICHLAND, WASHINGTON

U. S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE

COOPERATING AGENCY:
TENNESSEE VALLEY AUTHORITY

July 1997

FINDING OF NO SIGNIFICANT IMPACT

AGENCY: U.S. Department of Energy

COOPERATING AGENCY: Tennessee Valley Authority

ACTION: Finding of No Significant Impact

SUMMARY: An environmental assessment (EA) has been prepared to assess potential environmental impacts associated with a U.S. Department of Energy (DOE) Proposed Action to conduct a lead test assembly (LTA) program to confirm the viability of using a commercial light water reactor (CLWR) to produce tritium. The Proposed Action described in the EA supports DOE's Record of Decision for the *Programmatic Environmental Impact Statement for Tritium Supply and Recycling* (TSR PEIS). The EA tiers from the TSR PEIS and covers only those activities necessary to conduct tests involving irradiation of tritium-producing burnable absorber rods (TPBARs) in a CLWR and post-irradiation examination (PIE) of the TPBARs. The Proposed Action would involve preparation and analysis activities at DOE facilities and irradiation of the TPBARs at a commercial nuclear power reactor. Based on the analysis in the EA and considering concerns expressed by the Yakima Indian Nation, and comments received from the states of Tennessee and Washington, DOE has determined that the Proposed Action is not a major federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969 (NEPA). Therefore the preparation of an environmental impact statement is not required.

ADDRESSES AND FURTHER INFORMATION:

Single copies of the EA and further information concerning the proposed action are available from

Debbie Trader, Director
Science and Technology Programs
U.S. Department of Energy
Richland Operations Office
Richland, Washington 99352
(509) 372-4015

For further information regarding the DOE NEPA Process, contact:

Carol Borgstrom, Director
Office of NEPA Policy and Assistance (EH-42),
U.S. Department of Energy,
1000 Independence Avenue, S.W.,
Washington, D.C. 20585
(202) 586-4600, or (800) 472-2756.

PURPOSE AND NEED: The U.S. Department of Energy (DOE) needs to confirm the viability of using a commercial light water reactor (CLWR) as a potential source for maintaining the nation's supply of

tritium. The Proposed Action discussed in this environmental assessment is a limited scale confirmatory test that would provide DOE with information needed to assess that option.

BACKGROUND: DOE's *Programmatic Environmental Impact Statement for Tritium Supply and Recycling* (TSR PEIS), described the need for a new source of tritium for defense purposes as summarized in the following.

> Since nuclear weapons were developed in 1945, a nuclear deterrent has been a cornerstone of the nation's defense policy and national security. Tritium is used to enhance the yield of current nuclear weapons and allows for the production of smaller or more powerful devices. The United States has based its strategic nuclear systems on designs that use tritium and therefore requires a reliable source of this material in order to maintain the nuclear weapons stockpile as required by law.
>
> Tritium has a relatively short radioactive half-life of 12.3 years. Because of this relatively rapid radioactive decay, tritium must be replenished periodically in nuclear weapons to ensure that they will function as designed. Over the past 40 years, DOE has built and operated 14 reactors to produce tritium and other nuclear materials for weapons purposes. Today, none of these reactors is operational, and no tritium has been produced since 1988.
>
> Until a new source of tritium is operational, DOE will continue to meet tritium requirements by recycling tritium from existing weapons as they are retired from the weapons stockpile. However, because tritium decays relatively rapidly, recycling can only meet tritium demands for a limited time. Current predictions of future stockpile scenarios indicate that recycled tritium will adequately support the nation's nuclear stockpile until approximately 2005. (At the time the TSR PEIS was published, a previous assessment of the need for new tritium had placed that date at 2011; the current target date of 2005 is based on a more recent analysis). The tritium supply and recycling facilities as proposed in the TSR PEIS would provide the capability to produce tritium safely and reliably in order to meet the nation's defense requirements well into the 21st century while also complying with environmental, safety, and health standards.

In the TSR PEIS, DOE proposed several alternatives to provide a new source of tritium for the nuclear weapons program (DOE 1995a). The TSR PEIS evaluated alternatives for the siting, construction, and operation of tritium supply technology and recycling facilities at each of five candidate sites: the Idaho National Engineering and Environmental Laboratory (INEEL) in Idaho, the Nevada Test Site (NTS) in Nevada, the Oak Ridge Reservation (ORR) in Tennessee, the Pantex Plant in Texas, and the Savannah River Site (SRS) in South Carolina.

The TSR PEIS included an analysis of the use of a light water reactor (LWR) as well as the use of an accelerator for production of tritium. As part of the LWR alternative, DOE considered the purchase of an operating or partially completed commercial power reactor, or purchasing irradiation services from an existing CLWR. A combination of the CLWR and accelerator alternatives (one option to serve as the primary tritium source with the other serving as the backup source) was selected in the TSR PEIS Record of Decision (60 FR 63877-63891). A decision is expected by the end of 1998 to determine which option will be the primary source for tritium and which will serve as the backup source.

This EA tiers from the TSR PEIS and covers only those activities that would be necessary to conduct tests involving irradiation of tritium-producing burnable absorber rods (TPBARs) in a CLWR and post-irradiation examination (PIE) of the TPBARs. Aspects of the actual tritium production program or operations at the CLWR used to irradiate the TPBARs are, or would be, addressed by separate NEPA documentation. The commercial reactor proposed to perform the irradiation in this EA may or may not be the reactor selected for actual tritium production in the future. If the CLWR alternative is selected to be a primary or backup tritium source, the selection of the specific reactor(s) eventually used for the production mission would be addressed by a separate site-specific NEPA analysis.

PROPOSED ACTION: The Proposed Action would confirm the results of developmental testing conducted previously at DOE facilities and provide DOE with information regarding the actual performance of the TPBARs in a CLWR. It would also demonstrate that tritium production could be carried out within the normal operating and regulatory constraints associated with a commercial nuclear power facility, without affecting the plant's safety systems, production capacity, or normal operations. These activities would provide added confidence to the utilities and the NRC, which regulates commercial power reactors, that tritium production in a CLWR could meet national security needs in a technically straightforward, safe and cost effective manner.

Activities associated with the Proposed Action include replacing four conventional PWR burnable absorber assemblies with assemblies containing the TPBARs (referred to as TPBAR-LTAs) during the next refueling outage at the Watts Bar Nuclear plant (WBN), Unit 1 in southeastern Tennessee. The TPBARs would be shipped from the Hanford Site near Richland, Washington to the Westinghouse fuel fabrication facility in Columbia, South Carolina, for assembly into TPBAR-LTAs. The TPBAR-LTAs would be inserted into four new fuel assemblies at Westinghouse. The fuel assemblies with the TPBAR-LTAs (hereafter referred to as "integrated assemblies") would then be shipped to WBN with the rest of the new fuel and stored until the next refueling outage, when they would be inserted into the reactor. A typical fuel reload would contain more than 1000 burnable absorber rods, of which 32 would be replaced by the TPBARs in the proposed test.

The TPBAR-LTAs would be irradiated for one complete operating cycle (approximately 18 months), following which they would be removed from the integrated assemblies and stored in the spent fuel pool. The fuel assemblies would be placed back in the reactor as part of the refueling process. The TPBAR-LTAs would be shipped to the Pacific Northwest National Laboratory (PNNL) at Hanford for post-irradiation examination (PIE). Because the fuel assemblies from the integrated assemblies could be returned to the reactor core during refueling, no shipment or disposal of spent nuclear fuel would be required as part of the Proposed Action.

As part of the PIE activities at Hanford, the TPBARs would be removed from the remaining hardware. The TPBARs would then be subjected to non-destructive evaluation (NDE), including a visual inspection and gamma radiography. The TPBARs would also be punctured to collect and analyze any gases that accumulate during irradiation, and the penetrations would be sealed before the TPBARs are stored or processed further.

The TPBARs may also be examined by neutron radiography at the Argonne National Laboratory-West (ANL-W) near Idaho Falls, Idaho. Upon completion of the neutron radiography, the TPBARs would be returned to PNNL for destructive examination. For this evaluation, laboratory wastes that result from the destructive examinations, intact spent TPBARs, and residual equipment and materials that remain from

cleaning out the facilities are assumed to be dispositioned as waste at the Hanford Site. The small quantities of radioactive waste that may be generated at other locations would be disposed with similar wastes from those facilities.

ALTERNATIVES CONSIDERED: The EA discussed several alternatives to the proposed action as well as the No Action Alternative.

No Action: Under a no-action alternative, DOE would not conduct the LTA program or post-irradiation examinations. The final selection of either a CLWR or an accelerator as the nation's primary tritium source would be made without the benefit of the results of this proposed project. The no-action alternative is not consistent with the Department's purpose and need and therefore was not considered reasonable. However, evaluation of the No Action alternative is required by NEPA as a baseline against which to assess the impacts of the Proposed Action and alternatives.

Irradiation at Other Reactor/Analysis at Other DOE Laboratory: DOE considered the use of another commercial reactor to conduct the LTA program, as well as the use of other DOE laboratory facilities for examining the TPBARs. WBN was proposed for these tests because its refueling schedule provided optimum timing for obtaining the performance data needed by DOE, and because it was the only reactor of compatible design that was not encumbered by vendor restrictions on use of its fuel or other components for defense-related research. All other U.S. PWRs of this design obtain their fuel from foreign vendors that impose contractual restrictions on use of their products for defense-related purposes. Use of any facility other than WBN would have required DOE to replace all of the reactor's fuel, resulting in possible delay of the tests as well as substantially increased cost. Therefore, DOE considered options other than use of WBN to be unreasonable for the proposed tests. A future, separate evaluation process would identify one or more facilities for the actual tritium production mission. Reactors owned by DOE (such as the Fast Flux Test Facility [FFTF] at Hanford or the Advanced Test Reactor at the INEEL) or reactors operated by universities were not considered reasonable alternatives because they do not meet the purpose of, and need for, the Proposed Action, which is to demonstrate the viability of producing tritium in a CLWR.

Other DOE laboratories could perform the post-irradiation activities if the technology were transferred to those laboratories, and if the laboratories possessed hot cells large enough to contain the full length of the TPBAR-LTAs. This alternative was not considered reasonable because Hanford has the technology for post-irradiation examination of the TPBARs. Further, Hanford has hot cells suited for this purpose and has conducted similar types of examinations in the past. Use of alternate facilities would introduce technical uncertainties and impact both the schedule and cost for the proposed tests; therefore, this alternative was not evaluated in detail.

Analysis at Private Facility: DOE also considered the use of a private hot cell facility to conduct the analysis on the irradiated TPBARs. However, hot cells with the ability to handle the quantities of radioactive materials involved and to accommodate the full-length assemblies are generally not available outside the DOE complex. The exception would be a commercial nuclear fuel fabrication facility which is owned by a foreign corporation. However, the security measures required to perform the work in a foreign-owned facility would be difficult to implement. For these reasons, use of non-DOE facilities was not considered reasonable and is not evaluated further.

ENVIRONMENTAL IMPACTS: The environmental consequences of the proposed action would be well within existing state and federal standards, and are not expected to result in any appreciable risks to

members of the public, workers, or the environment. The major impacts are summarized in the following section; other types of consequences were determined to be negligible and are not discussed in detail.

Air Quality - Radionuclide emissions to the atmosphere could occur during destructive examination of the TPBARs at Hanford. An upper bound estimate of the air emissions would result in a dose to an offsite member of the public that is less than 3% of the EPA and Washington State standards. The risk of latent cancer fatality (LCF) from those emissions would be less than 1 in 5 million for the maximally exposed individual, and less than 1 in 1400 for the offsite population within 50 miles (80 km) of the site. The risks from radionuclide air emissions would not increase at other locations participating in the proposed activities. In addition, emissions of regulated nonradiological materials to air are not expected to increase above current levels and would remain within applicable regulatory standards.

Water Quality - Routine emissions of radioactive or hazardous materials to groundwater or surface waters are not anticipated for any activity in the proposed action other than irradiation of the TPBARs at WBN. Small quantities of tritium that may be released from the TPBARs during irradiation would not increase the risk associated with WBN by comparison to the facility's normal operations.

Waste Management - Destructive examination of TPBARs at Hanford would generate less than 25m^3 of solid low level radioactive waste (LLW), and less than 0.5 m^3 of LLW at other facilities. Decontamination of the facility and disposal of equipment used for PIE could generate an additional 200 m^3 of LLW at an undetermined time in the future; however, the facilities and equipment would likely be retained and used for other research in addition to the proposed action. The proposed action would also result in the generation of small quantities of mixed waste and hazardous materials (e.g., solvents). All radioactive and hazardous materials would be managed and reused, recycled, or disposed of in accordance with applicable federal and state regulations. The volumes of waste generated by the proposed action are not anticipated to impact overall waste management activities at any of the participating facilities. Because of the relatively short-lived radionuclides that would be generated by the proposed actions, no long-term effects on groundwater are expected.

Transportation - The radiological consequences of incident-free transportation to members of the public were estimated as less than 3.4 person-rem, resulting in LCF risks of less than 1 in 500 to the entire population along the transportation routes. The radiological consequences for transport crews amounted to 0.9 person-rem, resulting in a collective LCF risk of 1 in 2500. The collective radiological risks from transportation accidents amounted to 1 in 3000 for members of the public. The nonradiological risks for transportation fatalities were about 1 in 25,000 from vehicle emissions and less than 1 in 1500 from traffic accidents.

Facility Accidents - A variety of accidents were evaluated for activities in the proposed action, ranging from low consequence, higher probability events to high consequence incredible events. The doses from accidental radiological releases at facilities participating in the proposed action amounted to less than 14 rem for an onsite non-involved worker and 1.6 rem for a member of the public. The maximum LCF risk for the accidents evaluated was 1 in 10,000 for an onsite individual and 1 in 100,000 for a member of the public. All of the hypothetical events fell within accepted safety guidelines for DOE facilities.

Health and Safety - The collective dose to workers during the proposed actions was estimated to be less than 3 person-rem, resulting in a LCF risk of about 1 in 800. Non-radiological industrial hazards are expected to result in at most one recordable event (injury or illness) over the course of the proposed action.

Other Environmental Impacts - The consequences of the proposed action are expected to be negligible for other types of impacts, including those on land use, socioeconomics, cultural resources, aesthetic or scenic resources, geologic resources, ecological resources, noise, or site services. A Biological Resource Review supports these expectations.

Cumulative Impacts - The proposed action is not expected to contribute substantially to the overall cumulative impacts from past or anticipated operations at WBN, ANL-W and HFEF, or on the Hanford Site.

Environmental Justice - Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, requires that Federal agencies identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of their programs and activities on minority and low-income populations. Because no adverse effects are anticipated as a result of the proposed actions, there would be no opportunity for disproportionately high and adverse consequences to minority, or low-income populations.

DETERMINATION: Based on the analysis in the EA, and after considering the preapproval review comments of the State of Tennessee, the State of Washington and concerns of the Yakama Indian Nation, I conclude that the proposed action, modified to include the administrative control measures recommended by the panel, does not constitute a major federal action significantly affecting the quality of the human environment within the meaning of NEPA. Therefore, an EIS for the proposed action is not required.

Issued at Richland, Washington, this 22ND day of July 1997.

John D. Wagoner,
Manager
Richland Operations Office

DOE/EA-1210

Environmental Assessment

LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS WATTS BAR NUCLEAR PLANT, TENNESSEE AND HANFORD SITE, RICHLAND, WASHINGTON

U. S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE

COOPERATING AGENCY:
TENNESSEE VALLEY AUTHORITY

July 1997

Acronyms and Abbreviations

ALARA	as low as reasonably achievable
ANL-W	Argonne National Laboratory-West
BWR	boiling water reactor
CFR	*Code of Federal Regulations*
CEDE	committed effective dose equivalent
CEQ	Council on Environmental Quality
Ci	Curie (unit of radioactivity)
CLWR	Commercial Light Water Reactor
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EA	environmental assessment
EDE	effective dose equivalent
EFPD	effective full power days
EIS	Environmental Impact Statement
FFTF	Fast Flux Test Facility
FONSI	Finding of No Significant Impact
FR	*Federal Register*
FSAR	Final Safety Analysis Report
HCRL	Hanford Cultural Resources Laboratory
HFEF	Hot Fuels Examination Facility
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
kW	kilowatt
LCF	latent cancer fatality
LTA	lead test assembly
LWR	light water reactor
MEI	maximally exposed individual
MTF	Memorandum-to-File
MWe	megawatt (electric)
NDE	nondestructive examination
NEPA	*National Environmental Policy Act of 1969*
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
ORR	Oak Ridge Reservation
PIE	post-irradiation examination
PWR	pressurized water reactor
R&D	research and development
RCRA	*Resource Conservation and Recovery Act of 1976*
rem	radiation equivalent man (unit of radiation dose equivalent)
Sv	Sievert (unit of radiation dose equivalent)
TPBAR	tritium-producing burnable absorber rod
TSR PEIS	(DOE) Programmatic EIS for Tritium Supply and Recycling
TVA	Tennessee Valley Authority
WAC	*Washington Administrative Code*
WBN	Watts Bar Nuclear Plant
WDFW	State of Washington Department of Fish and Wildlife

Metric Conversion Chart

If you know	Multiply by	To get
Length		
centimeters	0.394	inches
meters	3.281	feet
square meters	10.764	square feet
kilometers	0.621	miles
Area		
hectares	2.471	acres
square kilometers	0.386	square miles
Mass (weight)		
kilograms	2.205	pounds
Volume		
liters	0.264	gallons
cubic meters	35.315	cubic feet
Radiological Units		
disintegrations per second	2.7×10^{-11}	Curies
Sieverts	100	rem

From the *CRC Handbook of Chemistry and Physics,* Robert C. Weast, Ph.D., 70th Ed., 1989-1990, CRC Press, Inc., Boca Raton, Florida.

And

Eckerman, K. F., A. B. Wolbarst, and A. C. B. Richardson. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion.* Federal Guidance Report No. 11, EPA/520/1-88-020, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.

Numerical (Scientific or Exponential) Notation

Numbers that are very small or very large are often expressed in scientific or exponential notation as a matter of convenience. For example, the number 0.000034 may be expressed as 3.4×10^{-5} or 3.4E-05 and 65,000 may be expressed as 6.5×10^{4} or 6.5E+04. Multiples or sub-multiples of the basic units are also used. A partial list of multiples and sub-multiples follows:

Name	Symbol		Value Multiplied by:	
atto	a	0.000000000000000001	or 1×10^{-18}	or 1E-18
femto	f	0.000000000000001	or 1×10^{-15}	or 1E-15
pico	p	0.000000000001	or 1×10^{-12}	or 1E-12
nano	n	0.000000001	or 1×10^{-9}	or 1E-09
micro	μ	0.000001	or 1×10^{-6}	or 1E-06
milli	m	0.001	or 1×10^{-3}	or 1E-03
kilo	k	1,000	or 1×10^{3}	or 1E+03
mega	M	1,000,000	or 1×10^{6}	or 1E+06
giga	G	1,000,000,000	or 1×10^{9}	or 1E+09
tera	T	1,000,000,000,000	or 1×10^{12}	or 1E+12

The following symbols are occasionally used in conjunction with numerical expressions:

- $<$ less than
- $\leq$ less than or equal to
- $>$ greater than
- $\geq$ greater than or equal to

In this environmental assessment, numerical values that are less than 0.001 or greater than 9999 are generally expressed in exponential notation.

Preface

This environmental assessment (EA) has been prepared to assess potential environmental impacts associated with a U.S. Department of Energy (DOE) Proposed Action to conduct a lead test assembly (LTA) program to confirm the viability of using a commercial light water reactor (CLWR) to produce tritium. The Proposed Action described in this EA supports DOE's Record of Decision for the *Programmatic Environmental Impact Statement for Tritium Supply and Recycling* (TSR PEIS). This EA tiers from the TSR PEIS and covers only those activities necessary to conduct tests involving irradiation of tritium-producing burnable absorber rods (TPBARs) in a CLWR and post-irradiation examination (PIE) of the TPBARs. The Proposed Action would involve preparation and analysis activities at DOE facilities and irradiation of the TPBARs at a commercial nuclear power reactor. This confirmatory test draws on over 10 years of DOE research and development devoted to the safe and efficient production of tritium in CLWRs.

If the Proposed Action is found to be a major federal action that significantly affects the quality of the human environment, an environmental impact statement will be prepared. If the Proposed Action is not found to constitute a major federal action that significantly affects the quality of the environment, a Finding of No Significant Impact (FONSI) will be issued and the action will proceed. Criteria used to evaluate the significance can be found in the Code of Federal Regulations (CFR) at 40 CFR 1508.27.

This EA was prepared in compliance with the National Environmental Policy Act (NEPA) of 1969 (as amended), the Council on Environmental Quality (CEQ) regulations for Implementing the Procedural Provisions of NEPA (40 CFR 1500-1508), and the U.S. Department of Energy NEPA regulations (10 CFR 1021). The Tennessee Valley Authority (TVA) is participating with the DOE as a cooperating agency in the preparation of this EA, in accordance with its established procedures for implementing NEPA requirements. The following is a description of each section of this environmental assessment:

1.0 Purpose and Need for Agency Action provides a brief statement and background information concerning the issue the DOE is addressing with the Proposed Action.

2.0 Proposed Action contains a description of the Proposed Action.

3.0 Alternatives to the Proposed Action contains a description of alternative actions that meet DOE's defined purpose and need, as well as a description of a no-action alternative.

4.0 Affected Environment provides a brief description of the sites and associated environment in which the Proposed Action would occur.

5.0 Environmental Impacts identifies and describes the range of environmental impacts, beneficial and adverse, that might occur if the Proposed Action were implemented. Impacts of alternatives are also briefly discussed.

6.0 Permits and Regulatory Requirements identifies and describes regulatory requirements and permits that are applicable to the Proposed Action.

7.0 Agencies and Organizations Consulted identifies outside parties that were or will be contacted as part of the process of preparing the environmental documentation .

Table of Contents

Acronyms and Abbreviations ii

Metric Conversion Chart iii

Numerical (Scientific or Exponential) Notation iv

Preface v

1.0 Purpose and Need for Agency Action 1-1

2.0 Proposed Action 2-1
2.1 Background 2-1
2.2 Description of the Proposed Action 2-2
2.2.1 Pre-Irradiation Transport and Assembly of TPBAR-LTAs 2-3
2.2.2 Irradiation 2-4
2.2.3 Post-Irradiation Transportation 2-4
2.2.4 Post-Irradiation Examination 2-4
2.2.5 Interim Storage and Waste Disposition 2-5

3.0 Alternatives to the Proposed Action 3-1
3.1 No Action 3-1
3.2 Irradiation at Other Reactor/Analysis at Other DOE Laboratory 3-1
3.3 Examination at a Private Facility 3-1

4.0 Affected Environment 4-1
4.1 Hanford Site Description 4-1
4.2 The 300 Area of the Hanford Site 4-2
4.3 Watts Bar Nuclear Plant 4-2
4.4 Argonne National Laboratory-West 4-4

5.0 Environmental Impacts of the Proposed Action 5-1

5.1 Air Quality 5-1
5.1.1 Atmospheric Emissions of Radionuclides 5-1
5.1.1.1 Assembly and Incorporation of the TPBAR-LTAs into the Integrated Assemblies 5-1
5.1.1.2 Irradiation of TPBAR-LTAs, Transportation, and NDE 5-1
5.1.1.3 Post-Irradiation Examination of TPBARs 5-2
5.1.2 Atmospheric Emissions of Regulated Nonradioactive Materials 5-3

5.2 Water Quality 5-3

5.3 Waste 5-4
5.3.1 Assembly and Incorporation of TPBAR-LTAs into the Integrated Assemblies 5-4
5.3.2 Irradiation of TPBAR-LTAs 5-4
5.3.3 Post-Irradiation Examination of TPBARs 5-4

5.4 Facility Accidents 5-5
5.4.1 Assembly and Incorporation of TPBAR-LTAs into the Integrated Assemblies 5-5
5.4.2 Irradiation of TPBAR-LTAs 5-5

5.4.3 Post-Irradiation Examination of TPBARs 5-6

5.5 Transportation 5-7
5.5.1 Incident-Free Transportation Impacts 5-7
5.5.1.1 Potential Radiological Impacts 5-8
5.5.1.2 Potential Nonradiological Impacts 5-9
5.5.2 Transportation Accident Impacts 5-9
5.5.2.1 Radiological Impacts to the Public from Transportation Accidents 5-9
5.5.2.2 Nonradiological Impacts to the Public from Transportation Accidents 5-10

5.6 Health and Safety 5-10
5.6.1 Basis for Health and Safety Consequences 5-10
5.6.1.1 Basis for Radiological Health Consequences 5-10
5.6.1.2 Basis for Nonradiological Health Consequences 5-11
5.6.2 Worker Health and Safety Consequences of the Proposed Action 5-12
5.6.3 Public Health and Safety Consequences of the Proposed Action 5-13
5.6.4 Summary of Health and Safety Consequences of the Proposed Action 5-14

5.7 Other Environmental Impacts 5-17
5.7.1 Land Use 5-18
5.7.2 Socioeconomics 5-18
5.7.3 Cultural Resources 5-18
5.7.4 Aesthetic and Scenic Resources 5-18
5.7.5 Geologic Resources 5-18
5.7.6 Ecological Resources 5-18
5.7.7 Noise 5-19
5.7.8 Site Services 5-19

5.8 Environmental Justice 5-19

5.9 Cumulative Impacts 5-20
5.9.1 Cumulative Impacts on Air Quality 5-20
5.9.2 Cumulative Impacts on Water Quality 5-21
5.9.3 Cumulative Impacts on Waste 5-21
5.9.4 Cumulative Impacts on Transportation 5-21
5.9.5 Cumulative Impacts on Health and Safety 5-21

5.10 Impacts of Alternatives to the Proposed Action 5-22
5.10.1 No-Action Alternative 5-22
5.10.2 Use of an Alternate Reactor for Irradiation of the TPBAR-LTAs, or Use of Alternate DOE Laboratories for Examination of the TPBARs 5-22
5.10.3 Use of Non-DOE Facilities for Examination of the TPBARs 5-22

6.0 Permits and Regulatory Requirements 6-1

7.0 Agencies Consulted 7-1

8.0 References 8-1

1.0 Purpose and Need for Agency Action

The U.S. Department of Energy (DOE) needs to confirm the viability of using a commercial light water reactor (CLWR) as a potential source for maintaining the nation's supply of tritium. The Proposed Action discussed in this environmental assessment is a limited scale confirmatory test that would provide DOE with information needed to assess that option.

Background

DOE's *Programmatic Environmental Impact Statement for Tritium Supply and Recycling* (TSR PEIS), described the need for a new source of tritium for defense purposes as summarized in the following (DOE 1995a).

> Since nuclear weapons were developed in 1945, a nuclear deterrent has been a cornerstone of the nation's defense policy and national security. Tritium is used to enhance the yield of current nuclear weapons and allows for the production of smaller or more powerful devices. The United States has based its strategic nuclear systems on designs that use tritium and therefore requires a reliable source of this material in order to maintain the nuclear weapons stockpile as required by law.
>
> Tritium has a relatively short radioactive half-life of 12.3 years. Because of this relatively rapid radioactive decay, tritium must be replenished periodically in nuclear weapons to ensure that they will function as designed. Over the past 40 years, DOE has built and operated 14 reactors to produce tritium and other nuclear materials for weapons purposes. Today, none of these reactors is operational, and no tritium has been produced since 1988.
>
> Until a new source of tritium is operational, DOE will continue to meet tritium requirements by recycling tritium from existing weapons as they are retired from the weapons stockpile. However, because tritium decays relatively rapidly, recycling can only meet tritium demands for a limited time. Current predictions of future stockpile scenarios indicate that recycled tritium will adequately support the nation's nuclear stockpile until approximately 2005. *(Note: At the time the TSR PEIS was published, a previous assessment of the need for new tritium had placed that date at 2011; the current target date of 2005 is based on a more recent analysis).* The tritium supply and recycling facilities as proposed in the TSR PEIS would provide the capability to produce tritium safely and reliably in order to meet the nation's defense requirements well into the 21st century while also complying with environmental, safety, and health standards.

In the TSR PEIS, DOE proposed several alternatives to provide a new source of tritium for the nuclear weapons program (DOE 1995a). The TSR PEIS evaluated alternatives for the siting, construction, and operation of tritium supply technology and recycling facilities at each of five candidate sites: the Idaho National Engineering and Environmental Laboratory (INEEL) in Idaho, the Nevada Test Site (NTS) in Nevada, the Oak Ridge Reservation (ORR) in Tennessee, the Pantex Plant in Texas, and the Savannah River Site (SRS) in South Carolina.

The TSR PEIS included an analysis of the use of a light water reactor (LWR) as well as the use of an accelerator for production of tritium. As part of the LWR alternative, DOE considered the purchase of an operating or partially completed commercial power reactor, or purchasing irradiation services from an existing CLWR. A combination of the CLWR and accelerator alternatives (one option to serve as the primary tritium source with the other serving as the backup source) was selected in the TSR PEIS Record of Decision (60 FR 63877-63891). A decision is expected by the end of 1998 to determine which option will be the primary source for tritium and which will serve as the backup source.

This EA tiers from the TSR PEIS and covers only those activities that would be necessary to conduct tests involving irradiation of tritium-producing burnable absorber rods (TPBARs) in a CLWR and post-irradiation examination (PIE) of the TPBARs. Aspects of the actual tritium production program or operations at the CLWR used to irradiate the TPBARs are, or would be, addressed by separate NEPA documentation. The commercial reactor proposed to perform the irradiation in this EA may or may not be the reactor selected for actual tritium production in the future. If the CLWR alternative is selected to be a primary or backup tritium source, the selection of the specific reactor(s) eventually used for the production mission would be addressed by a separate site-specific NEPA analysis.

2.0 Proposed Action

The Department of Energy's Proposed Action is described in the following sections.

2.1 Background

Irradiation of TPBARs in a CLWR is being evaluated as a reasonable alternative for meeting the need to replenish the supply of tritium for nuclear weapons. It is also being considered as a backup source, should the accelerator alternative be selected as the primary tritium source, in order to ensure that adequate supplies of tritium would be available. The TPBARs used in the proposed tests would both replace and function as a standard burnable absorber assembly in a CLWR. The function of the reactor, the absorber assembly and the TPBARs is described below.

The TPBARs have been designed for use in a pressurized water reactor (PWR) of the type developed commercially by Westinghouse. The LWRs used to generate electric power in the United States utilize both PWR and boiling water reactor (BWR) technologies. However, use of a BWR to produce tritium would require technology different from that involved in using a PWR of the design proposed for this test. Specifically, to produce tritium most BWR designs would require production of specially designed fuel or reconfiguration of the reactor core to accommodate separate tritium targets. As a result of these considerations, and because of the extensive research and development that has already occurred using PWR technology, the Proposed Action described in this EA involves the use of a PWR.

Commercial PWRs produce electricity by creating steam to drive a steam turbine generator. In a typical large PWR, heat is generated by nuclear fission in the reactor core and transferred to the turbine via steam produced in a heat exchanger. The side of the heat exchanger that is connected to the reactor vessel (referred to as the "primary" side) is isolated from the side that supplies steam to the turbine (the "secondary" side of the heat exchanger) so that water in contact with the reactor core is effectively contained within the reactor vessel and the primary side of the heat exchanger under normal operating conditions.

The reactor core contains fuel assemblies, coolant, a neutron moderator (a material that slows neutrons), and devices to control the nuclear fission reaction. In U.S. commercial power reactors, the fuel consists of uranium slightly enriched (less than 5%) in the fissile isotope uranium-235 (U-235), which is typically fabricated into fuel elements as a series of stacked pellets within a cylindrical metal cladding. A number of individual fuel elements are then bundled into a larger unit, referred to as a fuel assembly, for ease of handling during shipping and refueling.

Water provides both the coolant and neutron moderator functions in a LWR. The moderator in a reactor serves to reduce the energy of neutrons generated by the fission process. The lower energy neutrons are more readily absorbed by U-235 in the fuel to produce additional fissions, thereby sustaining a fission "chain reaction." The primary coolant circulates through the reactor core to remove heat and carry it to the heat exchanger, where the heat is transferred to the secondary coolant (also water in the case of commercial PWRs) which is converted to steam to drive the turbine generator.

The power level in the core of the reactor is regulated in part by devices that contain neutron-absorbing materials, typically cadmium or boron, which prevent neutrons from interacting with fuel to produce fission reactions. These materials are incorporated into "control rods" which can be inserted into spaces within or between the fuel assemblies to control the power level in that region of the core. The control rods are configured in such a way that the nuclear reaction is completely shut down when all of the control rods are fully inserted.

The power level in the region of new fuel assemblies can also be regulated by incorporating neutron absorbing materials directly into the fuel elements or assemblies, thereby maintaining a more uniform power density throughout the core and extending the useful life of the new fuel elements. The absorbers in the fuel assemblies consist of isotopes that readily absorb neutrons, and in the process are transformed into different isotopes that absorb neutrons less efficiently (hence, they are referred to as "burnable" absorbers). As the active fuel in the assembly is depleted, the neutron absorber in the assembly is also depleted. When a fuel assembly becomes sufficiently depleted of fissile material that it cannot sustain the required power level, it must be removed from the reactor and replaced by a new fuel assembly. CLWRs typically replace part of their fuel on a rotating schedule every 12-18 months, a process referred to as the "refueling cycle."

The fuel assemblies in PWRs of the design proposed for the TPBAR irradiation consist of fuel element lattices that contain spaces in the lattice into which either burnable absorber rods or control rods may be inserted. If the fuel assemblies are to contain burnable absorbers, the absorber material is incorporated into separate rods that fit into the lattice openings. The absorber material used for many commercial PWRs consists of borosilicate glass encased in a stainless steel cladding. The absorber rods are attached to a hold-down plate that, in turn, fits into the top of the fuel assembly. The burnable absorber assemblies can be removed from the fuel assemblies after the fuel has been through one operating cycle. This fuel configuration is convenient for the proposed tests because the TPBARs can be incorporated into fuel assemblies in place of the conventional burnable absorber rods. The major difference between conventional PWR burnable absorber rods and the TPBARs would be the use of a lithium aluminate ceramic as a neutron absorber in place of the standard borosilicate glass. At the end of the operating cycle, the TPBAR assemblies could then be removed from the host fuel assemblies and shipped for examination without the need to transport or handle the irradiated fuel.

When a utility desires to implement design modifications in a commercial reactor that may affect fuel performance or other systems that provide reactivity control (such as substituting TPBARs for the conventional burnable absorber rods), a lead test assembly (LTA) program can be conducted to confirm specific expected behavior in a reactor. An LTA program usually consists of a limited number of assemblies of the proposed new design (typically an even number for symmetry), which are inserted into the reactor core at the beginning of an operating cycle in order to demonstrate satisfactory performance of the components. Such a program is appropriate for the use of TPBARs containing lithium in place of the standard boron neutron absorbers in a PWR burnable absorber assembly.

The Proposed Action expands upon more than ten years of DOE research and development activities associated with tritium production targets for LWRs. As part of this research, target irradiation, PIE, and safety testing has been performed entirely at DOE facilities. During the Proposed Action, the NRC would oversee activities that take place at its licensee facilities. The NRC has reviewed a technical report prepared by DOE to document the performance and safety basis for the TPBAR design (Erickson et al 1997), and has issued a safety evaluation report with regard to the proposed tests. (NRC 1997).

2.2 Description of the Proposed Action

The Proposed Action would confirm the results of developmental testing conducted previously at DOE facilities and provide DOE with information regarding the actual performance of the TPBARs in a CLWR. It would also demonstrate that tritium production could be carried out within the normal operating and regulatory constraints associated with a commercial nuclear power facility, without affecting the plant's safety systems, production capacity, or normal operations. These activities would provide added confidence to the utilities and the NRC, which regulates commercial power reactors, that tritium production in a CLWR could meet national security needs in a technically straightforward, safe and cost effective manner.

Activities associated with the Proposed Action include replacing four conventional PWR burnable absorber assemblies with assemblies containing the TPBARs (referred to as TPBAR-LTAs) during the next refueling outage at the Watts Bar Nuclear plant (WBN), Unit 1 (operated by the Tennessee Valley Authority (TVA)) in southeastern Tennessee. See Figure 2.1 for a graphical depiction of the Proposed Action. The TPBARs would be shipped from the Hanford Site near Richland, Washington to the Westinghouse fuel fabrication facility in Columbia, South Carolina, for assembly into TPBAR-LTAs (see Figure 2.2). The TPBAR-LTAs would be inserted into four new fuel assemblies at Westinghouse. The fuel assemblies with the TPBAR-LTAs (hereafter referred to as "integrated assemblies") would then be shipped to WBN with the rest of the new fuel and stored until the next refueling outage, when they would be inserted into the reactor. A typical fuel reload would contain more than 1000 burnable absorber rods, of which 32 would be replaced by the TPBARs in the proposed test.

The TPBAR-LTAs would be irradiated for one complete operating cycle (approximately 18 months), following which they would be removed from the integrated assemblies and stored in the spent fuel pool. The fuel assemblies would be placed back in the reactor as part of the refueling process. The TPBAR-LTAs would be shipped to the Pacific Northwest National Laboratory (PNNL) at Hanford for post-irradiation examination (PIE). Because the fuel assemblies from the integrated assemblies could be returned to the reactor core during refueling, no shipment or disposal of spent nuclear fuel would be required as part of the Proposed Action.

As part of the PIE activities at Hanford, the TPBARs would be removed from the remaining hardware. The TPBARs would then be subjected to non-destructive evaluation (NDE), including a visual inspection and gamma radiography. The TPBARs would also be punctured to collect and analyze any gases that accumulate during irradiation, and the penetrations would be sealed before the TPBARs are stored or processed further.

After the initial NDE at PNNL, the TPBARs may also be examined by neutron radiography at a facility yet to be determined. For the purposes of this analysis, neutron radiography was assumed to take place at the Hot Fuels Examination Facility (HFEF) located at the Argonne National Laboratory-West (ANL-W) near Idaho Falls, Idaho. Upon completion of the neutron radiography, the TPBARs would be returned to PNNL for destructive examination. For this evaluation, laboratory wastes that result from the destructive examinations, intact spent TPBARs, and residual equipment and materials that remain from cleaning out the facilities are assumed to be dispositioned as waste at the Hanford Site. The small quantities of radioactive waste that may be generated at other locations would be disposed with similar wastes from those facilities. Additional information about each phase of the Proposed Action is provided in the following sections.

2.2.1. Pre-Irradiation Transport and Assembly of TPBAR-LTAs

Initially, the TPBARs would be shipped from the Hanford Site to the Westinghouse fuel fabrication facility for assembly into the TPBAR-LTAs and integrated assemblies. Prior to placement in the reactor, the TPBARs are not radioactive nor do they contain hazardous materials as defined by the Department of Transportation (DOT) in 49 CFR Part 171-178. (Figure 2.3 depicts transportation route options for the Proposed Action.)

Thirty-two TPBARs (plus a limited number of spares) would be required for the Proposed Action. General information regarding the TPBAR design is included in this section; Appendix A contains additional information. The exterior dimensions of the TPBAR are compatible with those of a standard Westinghouse burnable absorber rod - approximately 0.381 inch (1 cm) in diameter and 152 inches (390 cm) long. The TPBARs contain lithium aluminate absorber in the form of stacked cylindrical elements, a Zircaloy-4 liner, and a nickel-plated zirconium "getter" to trap and retain the tritium in a solid matrix. The getter is an effective mechanism to contain the tritium. In fact, it is extremely difficult to extract the tritium

from the getter which requires very high temperatures for an extended period of time. The TPBAR cladding consists of Type 316 stainless steel with a wall thickness of 0.0225 inch (0.057 cm). The cladding also has an aluminum coating to minimize permeation of hydrogen through the cladding. The TPBAR end plugs are of a standard Westinghouse design and are seal-welded in place.

At the Westinghouse fuel fabrication facility, 8 TPBARs and 16 thimble plugs would be attached to a hold-down assembly to make up a single TPBAR-LTA (which contains 24 possible burnable absorber rod locations). Figure 2.2 depicts the TPBAR-LTA. Each TPBAR-LTA would undergo a standard acceptance inspection before incorporating it into an integrated fuel assembly. Four TPBAR-LTAs would be prepared, each of which would be placed into one fuel assembly to provide the four integrated assemblies required for the LTA program. The integrated assemblies containing the TPBAR-LTAs would be loaded into standard unirradiated fuel shipping containers and transported to WBN. The shipments would likely utilize a commercial carrier authorized to transport radioactive materials of low-specific-activity on interstate highways.

2.2.2. Irradiation

The integrated assemblies containing the TPBAR-LTAs would be received at WBN and transported through the truck bay door, into the truck bay, and through the truck bay overhead hatches to the refueling floor. The integrated assemblies and the rest of the new fuel would undergo a receiving inspection, following which they would be stored in preparation for loading into the reactor core during the refueling outage.

The TPBAR-LTAs would remain in the core for one operating cycle and would receive approximately 450 to 550 effective full power days of exposure. After one cycle of irradiation, during the next refueling outage, the integrated assemblies would be removed from the reactor core and transported under water to the spent fuel pool. The TPBAR-LTAs would then be removed from the integrated assemblies, and the fuel assemblies that held the TPBAR-LTAs would be reloaded into the reactor core with the new reload fuel.

2.2.3. Post-Irradiation Transportation

Following the refueling, an NRC-certified Type B shipping cask would be shipped to WBN and transported to the spent fuel pool floor through the previously described path. No cool down period is necessary for transport of the TPBAR-LTAs; therefore, the shipment would likely occur after the refueling outage to minimize operational impacts on the WBN restart. The cask would be placed in the fuel cask loading area in the spent fuel pool, and one or two of the TPBAR-LTAs would be loaded into the cask under water. The loaded cask would be lifted out of the spent fuel pool and moved to the cask wash down area. The cask would be washed down, drained, decontaminated, transported to the truck bay, and loaded on a truck. Up to 4 exclusive use shipments would be used to transport the cask containing the irradiated TPBAR-LTAs to the 325 Building at Hanford.

2.2.4. Post-Irradiation Examination

Post-irradiation examinations would be performed at the Hanford Site 325 Building and possibly at a neutron radiography facility to be identified in the future. PNNL would conduct all PIE activities other than the neutron radiography.

The 325 Building in the Hanford Site 300 Area houses a variety of laboratories, three hot cells and a cask unloading gallery in the rear of the cells. (See Figure 2.4) Some construction would be necessary in order to accept and unload the shipping cask at the 325 Building. The construction would consist of making a

new penetration in the south wall of the "A" hot cell and installing an access door. Some additional modifications would be required to relocate a stairway inside the building but external to the hot cell. However, all of the planned construction activities would be performed inside the current building footprint, and no construction external to the building would be required.

After the cask is unloaded at the Hanford 325 Building, the TPBAR-LTAs would be moved to the "A" cell facility through the new access port. The TPBAR-LTAs would be disassembled inside the "A" cell, and all ancillary hardware (such as the hold down assembly, attachment nuts, and thimble plugs) would be packaged and dispositioned as low level radioactive waste. The TPBARs would undergo an initial non-destructive evaluation, including a visual inspection and gamma radiography. All of the TPBARs may then be punctured to collect and analyze any gases that accumulated during irradiation, and the penetrations would be resealed prior to storage or further handling.

If neutron radiography is to be performed, all of the TPBARs would be loaded into an NRC-certified Type B shipping cask and transported to the neutron radiography facility for additional non-destructive examination. The HFEF at ANL-W was analyzed as a representative location for this activity. The HFEF is used by DOE for neutron radiography on a variety of materials including components similar to the TPBARs. The HFEF can only radiograph a 9' 6" (2.9 m) length; thus each rod would be flipped end-to-end such that a radiograph of the full length of the rod can be obtained. Upon completion of neutron radiography, the TPBARs would be reloaded into the shipping cask and returned to Hanford.

The TPBARs would be stored in sealed containers within the 325 Building hot cell facility until they are removed for destructive examination. Destructive examination of the TPBARs involves 2 major activities:

- Sectioning the TPBARs into small pieces to examine structural changes in the cladding and internal components as a result of irradiation and

- Extracting tritium from the TPBARs to determine production and recovery levels.

For sectioning, at least one TPBAR from each TPBAR-LTA would be moved into the "B" cell facility and cut in preparation for examination. Helium, lithium, tritium, and protium assays would be performed on various sections from the TPBARs. Metallographic examinations would also be performed on various components including the cladding. Extraction of tritium from the TPBARs involves puncturing and heating the TPBARs in a closed system to drive off tritium trapped in the solid components. The gases are then collected and analyzed to determine the quantity and chemical state of recovered tritium. In addition to the PIE tests, additional experiments to evaluate the permeability of the TPBAR cladding material to tritium would also be conducted using tritium from a commercial source. Examination of small samples from the TPBARs may take place in other laboratories within the 325 building or at another appropriate laboratory in the 300 Area. Depending on the results of the destructive examinations, additional TPBARs (up to all 32) may be selected for further examination.

2.2.5. Interim Storage and Waste Disposition

Any TPBARs that are not subjected to destructive examination would be stored at Hanford until another use for them is identified or DOE decides to dispose of them. Prior to disposal, the tritium would be extracted from any remaining intact TPBARs and recovered for other purposes or packaged separately for disposal.

Preparation of the integrated assemblies at the Westinghouse fuel fabrication facility would not produce any radioactive or hazardous wastes in addition to those typically generated at the facility. Wastes associated with irradiation of the integrated assemblies at WBN would consist of low-level radioactive liquids and solids generated as the TPBAR-LTAs are removed from the spent fuel pool and packaged for

shipment to Hanford. These wastes would be treated as appropriate and disposed of at an NRC-licensed commercial facility with wastes from routine operations at WBN.

Wastes produced during disassembly of the TPBAR-LTAs and NDE of the TPBARs at Hanford would consist of laboratory materials and protective clothing used to prevent possible spread of contamination during receipt, handling, and examination. Those wastes would be disposed of at Hanford in facilities appropriate to the waste type. Likewise, any radioactive waste generated by neutron radiography at ANL-W would consist of small quantities of laboratory materials used to survey the shipping cask for external contamination and disposable protective clothing such as gloves. Waste generated during activities at ANL-W would be managed onsite at the INEEL.

The quantities of low-level radioactive waste generated during PIE of the TPBARs at Hanford would consist of cuttings and small sections of the cladding and internal components, laboratory materials used to control spread of contamination, and either solid molecular sieve or bubbler liquids used to trap the tritium contained in gaseous effluents from the sectioning and extraction processes. Smaller quantities of mixed low-level waste could be produced during liquid scintillation counting of tritium samples, and a small quantity of nonradioactive hazardous wastes would be produced during the laboratory activities as well. Additional radioactive wastes would result from decontamination of the hot cells and removal of unneeded equipment after the work is completed. All radioactive and hazardous wastes generated at Hanford would be disposed of either at the onsite burial grounds or in permitted commercial disposal facilities in accordance with applicable state and federal regulations. Mixed low-level wastes would be stored onsite in permitted facilities. Section 5.3 of this EA contains additional information concerning waste management.

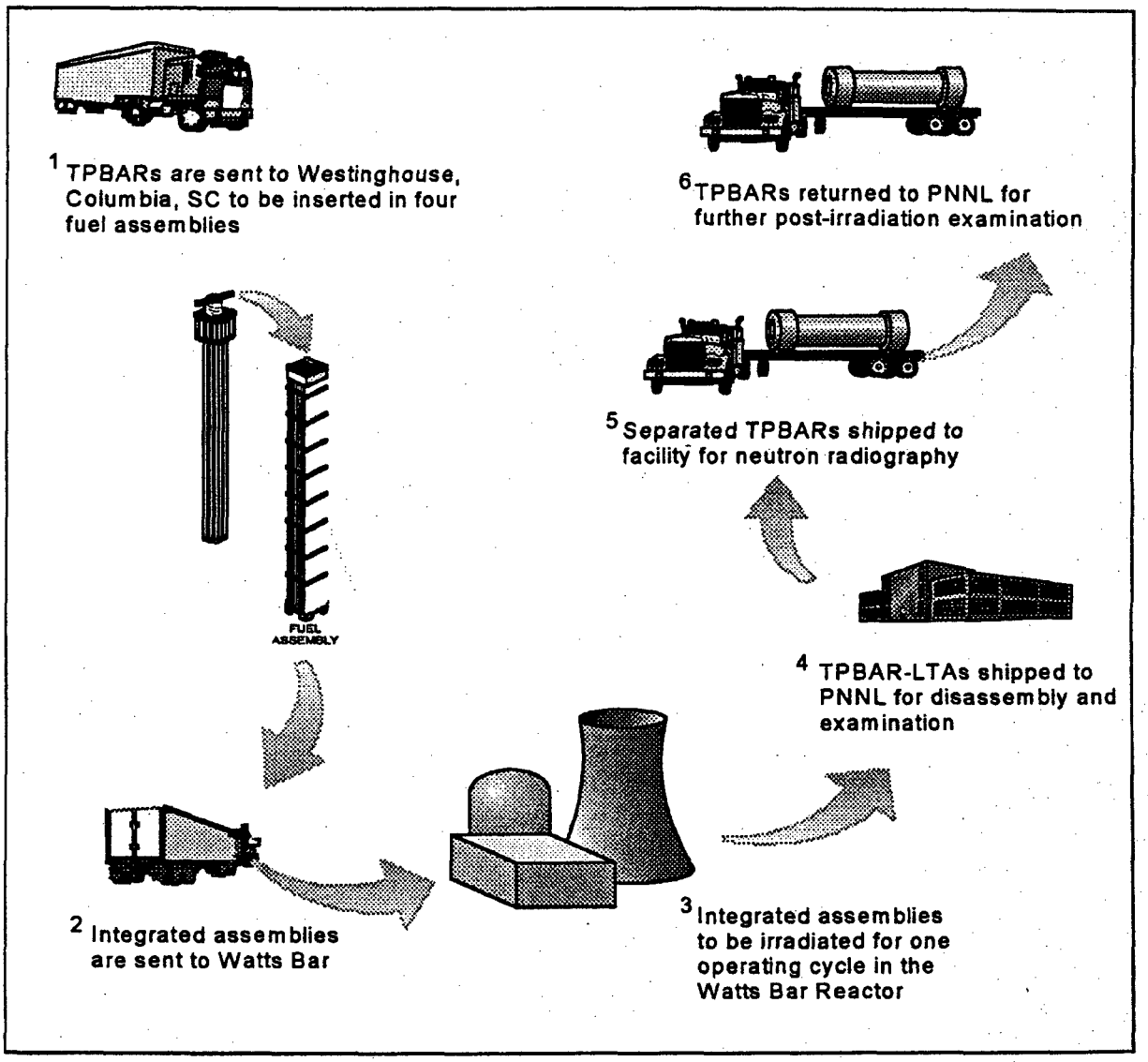


Figure 2.1 General Depiction of the Proposed Action

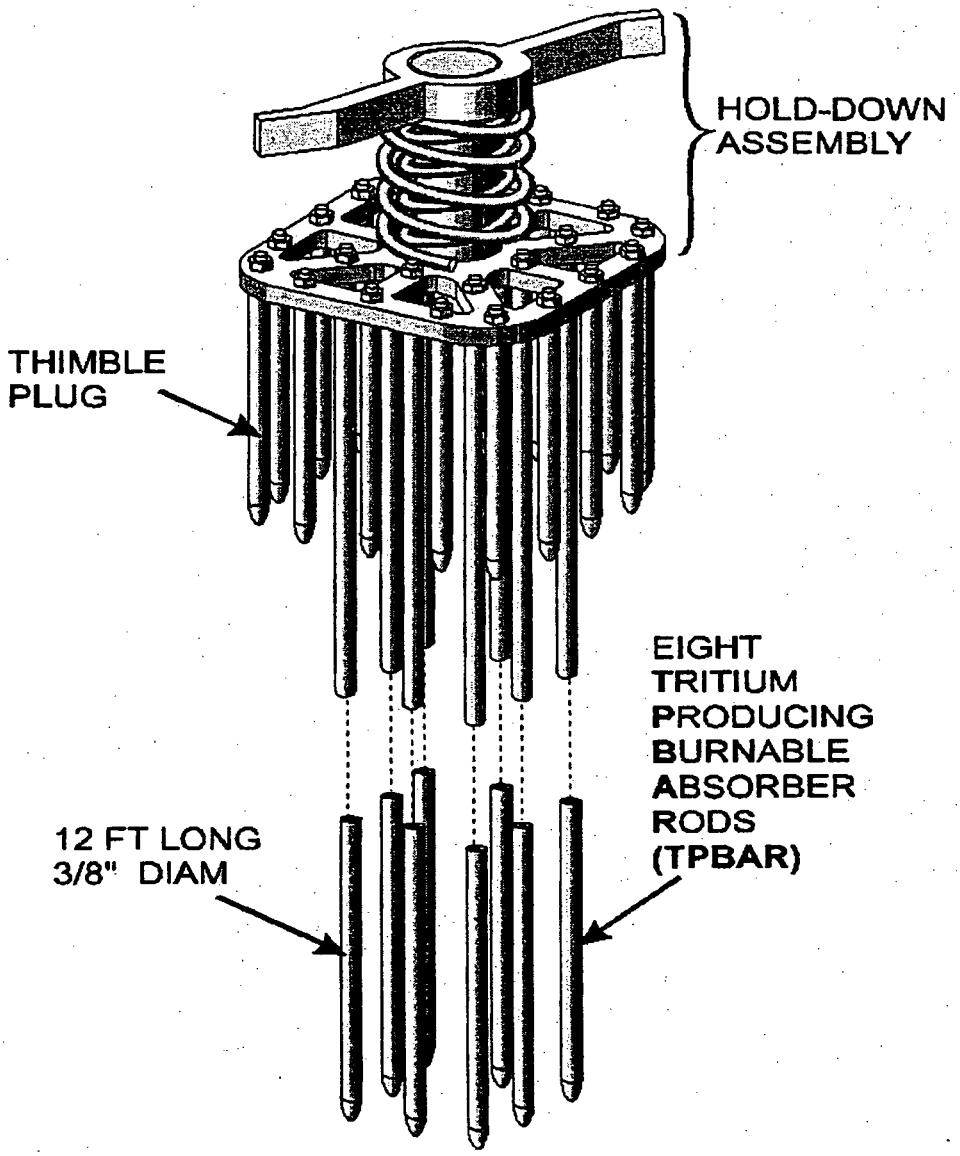
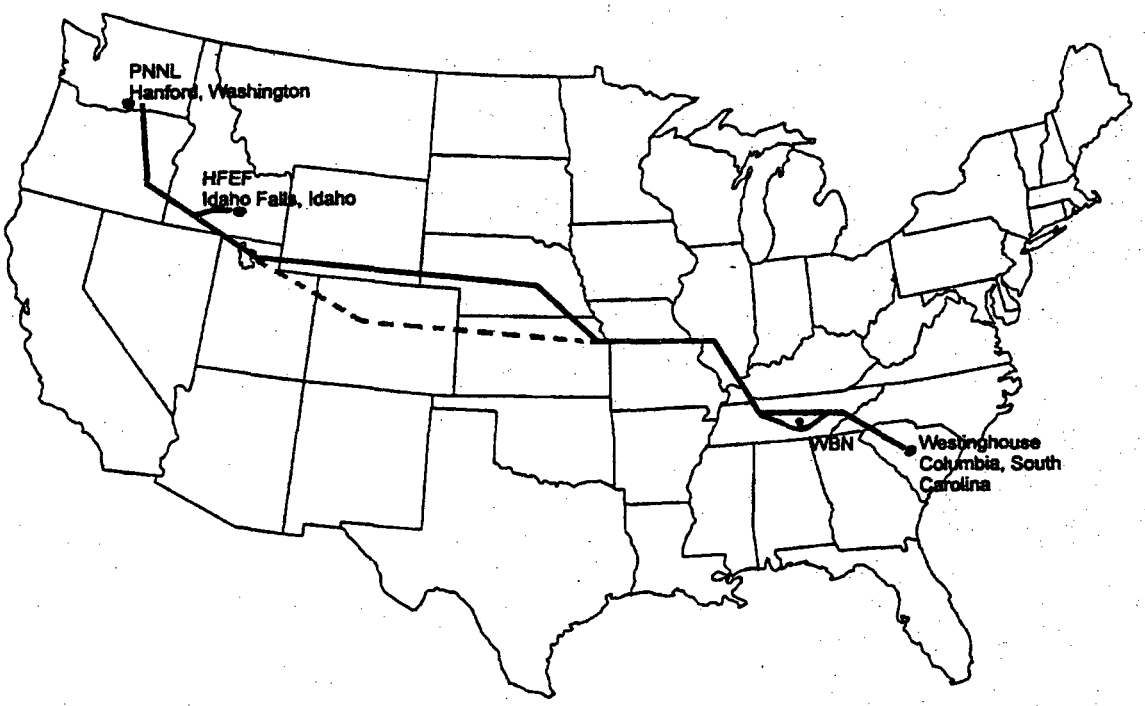


Figure 2.2 Tritium Producing Burnable Absorber Rods - Lead Test Assembly (TPBAR-LTA)



— Proposed Transportation Route
- - - - Alternate Transportation Route

Figure 2.3 Proposed Action Transportation Routes

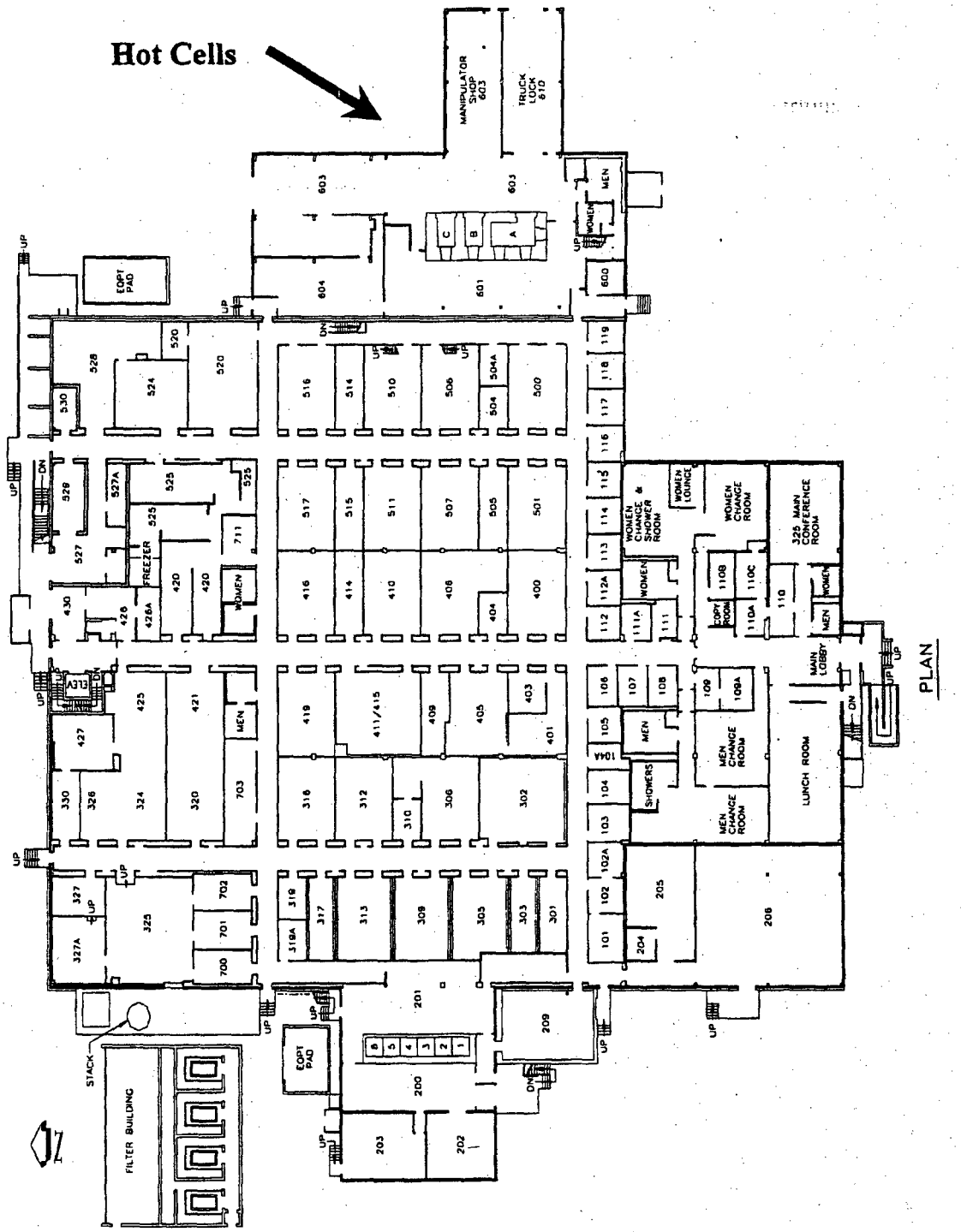


Figure 2.4 Hanford Site 325 Building and Hot Cells

3.0 Alternatives to the Proposed Action

The Department has considered three alternatives to the Proposed Action, including: no action; irradiation at another reactor, with analysis at other DOE laboratories; and use of a private hot cell facility to analyze the irradiated TPBARs. Each alternative is discussed in this section.

3.1 No Action

Under a no-action alternative, DOE would not conduct the LTA program or post-irradiation examinations. The final selection of either a CLWR or an accelerator as the nation's primary tritium source would be made without the benefit of the results of this proposed project. The no-action alternative is not consistent with the purpose and need. However, evaluation of the No Action alternative is required by NEPA as a baseline against which to assess the impacts of the Proposed Action and alternatives.

3.2 Irradiation at Other Reactor/Analysis at Other DOE Laboratory

DOE has considered the use of another commercial reactor to conduct the LTA program, as well as the use of other DOE laboratory facilities for examining the TPBARs. WBN was proposed for these tests because its refueling schedule provided optimum timing for obtaining the performance data needed by DOE, and because it was the only reactor of compatible design that was not encumbered by vendor restrictions on use of its fuel or other components for defense-related research. All other U.S. PWRs of this design obtain their fuel from foreign vendors that impose contractual restrictions on use of their products for defense-related purposes. Use of any facility other than WBN would have required DOE to replace all of the reactor's fuel, resulting in possible delay of the tests as well as substantially increased cost. Therefore, DOE considered options other than use of WBN to be unreasonable for the proposed tests. A future, separate evaluation process would identify one or more facilities for the actual tritium production mission. Reactors owned by DOE (such as the Fast Flux Test Facility [FFTF] at Hanford or the Advanced Test Reactor at the INEEL) or reactors operated by universities do not meet the purpose and need for the Proposed Action, which is to demonstrate the viability of producing tritium in a CLWR.

Other DOE laboratories could perform the post-irradiation activities if the technology were transferred to those laboratories, and if the laboratories possessed hot cells large enough to contain the full length of the TPBAR-LTAs. This alternative was not considered reasonable because Hanford has the technology for post-irradiation examination of the TPBARs. Further, Hanford has hot cells suited for this purpose and has conducted similar types of examinations in the past. Use of alternate facilities would introduce technical uncertainties and impact both the schedule and cost for the proposed tests; therefore, this alternative has not been evaluated in detail.

3.3 Examination at a Private Facility

DOE has also considered the use of a private hot cell facility to conduct the examination on the irradiated TPBARs. However, hot cells with the ability to handle the quantities of radioactive materials involved and to accommodate the full-length assemblies are generally not available outside the DOE complex. The exception would be a commercial nuclear fuel fabrication facility which is owned by a foreign corporation. However, the security measures required to perform the work in a foreign-owned facility would be difficult to implement. For these reasons, use of non-DOE facilities is not evaluated in detail.

4.0 Affected Environment

This section provides an overview of the environmental characteristics of the Hanford Site, WBN, and the ANL-W facilities, as well as site-specific characteristics of Hanford's 300 Area where most of the proposed post-irradiation examination activities would take place. Additional information about the Hanford Site can be found in the *Hanford Site National Environmental Policy Act (NEPA) Characterization* (Neitzel 1996), and the WBN environment is described in the *Final Environmental Statement related to the Operation of Watts Bar Nuclear Plant, Units 1 and 2* (NRC 1995).

4.1 Hanford Site Description

The proposed analysis activities would take place in the 300 Area of the Hanford Site. (See Figure 4.1) The Hanford Site covers 1450 square kilometers (560 square miles) of south-central Washington State. It is a semi-arid region of rolling topography, with some trees along the Columbia River. Two topographical features dominate the landscape: Rattlesnake Mountain, a treeless 1074-meter (3525 feet) anticline located on the southwest boundary, and Gable Mountain, a small ridge 339 meters (1,112 feet) high, located on the northern portion of the Site.

The Hanford Site is located in the Pasco Basin, one of the structural and topographic basins of the Columbia Plateau. Thick basalt flows (greater than 3650 meters [12,000 feet] thick) underlie sedimentary material consisting of silts, sands, and gravel (Hanford Formation and Ringold Formation). The sedimentary deposits are moisture deficient and have a high capacity to adsorb and retain cations (Neitzel 1996).

The Columbia River, the dominant river in the region, flows through the northern part of the Hanford Site and forms part of the Hanford Site's eastern boundary. An 84-kilometer (52-mile) stretch of the Columbia River between the 300 Area and Priest Rapids Dam (river mile 345 to 396) is known as the Hanford Reach. This section of the river has been evaluated by the National Park Service for possible inclusion in the National Wild and Scenic Rivers system, but no final action has been taken by Congress.

The Hanford Site is a shrub-steppe community of sagebrush and rabbitbrush, with an understory consisting primarily of cheatgrass and Sandberg's bluegrass. More than 300 species of insects, 39 species of mammals, 36 common species of birds, and 12 species of reptiles and amphibians have been identified on the Hanford Site.

Areas adjacent to the Hanford Site are primarily agricultural lands. The city of Richland, Washington (population 32,315), located in Benton County, adjoins the southernmost portion of the Hanford Site boundary and is the nearest population center.

The leading employers who affect the local economy are the DOE and its contractors; the Washington Public Power Supply System; and the agricultural sector, including food processing plants. Other major employers include a nuclear fuel fabrication plant, a meat packing plant, a pulp and paper mill, railroad, and small manufacturing firms.

Non-DOE facilities located at the Hanford Site include a commercial nuclear power plant operated by the Washington Public Power Supply System (WNP-2) and a commercial low-level radioactive waste disposal facility administered by the State of Washington and operated by U.S. Ecology, Inc. A privately owned specialty metal products fabrication enterprise is also located in a former DOE facility at the north end of the 300 Area.

Government facilities located on the Hanford Site include the following: waste management facilities (solid and liquid wastes), nuclear materials storage facilities, research laboratories, decontamination facilities, a research reactor (the FFTF, which is now on standby status), and deactivated facilities. Also, nine inactive production reactors and three inactive spent fuel reprocessing plants exist on the site.

During 1995, DOE facilities at the Hanford Site discharged approximately 6.7 Ci of tritium to the atmosphere, most of which originated in the 300 Area. Other atmospheric releases of radionuclides amounted to about 80 Ci of radon, 0.0007 Ci of transuranic isotopes, and 0.01 Ci of other fission and activation products. These estimated emissions did not result in air concentrations at the site perimeter that were statistically elevated compared with background concentrations at distant communities, with the exception of air concentrations for I-129. The Hanford Site complied with all federal, state, and local standards for radiological and nonradiological air quality in 1995 (Dirkes and Hanf 1996).

In addition to emissions from DOE facilities, the WNP-2 commercial nuclear power facility at Hanford discharges radionuclides to the atmosphere. In 1993, a year when the plant was operating at near capacity, these emissions amounted to 150 Ci of tritium, 140 Ci of noble gases, and 10 Ci of other fission and activation products (Tichler et al 1995).

Radioactive and hazardous wastes generated at the Hanford site in 1995 amounted to 1900 metric tons (4.2 million lb) of radioactive waste, 130 metric tons of mixed radioactive and hazardous waste, and 800 metric tons (1.8 million lb) of hazardous solids and liquids. Those radioactive and mixed wastes contained about 27,000 Ci of tritium, 44,000 Ci of activation products, and 34,000 Ci of other radionuclides (Dirkes and Hanf 1996). Low-level radioactive wastes are buried onsite in the 200 Areas, and mixed wastes are stored in permitted facilities in the 200-W Area. Nonradioactive hazardous wastes are shipped offsite for treatment and disposal at permitted facilities.

4.2 The 300 Area of the Hanford Site

The 300 Area of the Hanford Site is north of the city of Richland and is contiguous to the Columbia River (see Figure 4.2). The 300 Area served as the research and development center and housed fuel fabrication facilities during the operational phase of the Hanford Site's production reactors. The 325 Building is located about 1.9 kilometers (1.2 miles) north of Richland and 1.3 km (0.8 mile) from the far shore of the Columbia River.

The 300 Area of the Hanford Site is characterized by relatively cool, mild winters and warm summers with an average of about 15 to 18 centimeters (6 to 7 inches) of annual precipitation and occasional high winds of up to 129 kilometers (80 miles) per hour. No tornados have been reported on site; the area has low to moderate seismicity.

The terrestrial and aquatic ecology of the 300 Area closely resembles those ecological characteristics associated with being near the Columbia River. In this area, communities of willow-riparian vegetation are prominent. California quail, Chinese ring-necked pheasants, and mammals such as raccoons, beavers, and porcupines are likely to be found near the river. A Biological Review was completed for the 300 Area in May 1996 (see Appendix B).

4.3 Watts Bar Nuclear Plant

The following has been excerpted from the Final Safety Analysis Report for WBN (TVA 1991).

WBN occupies approximately 710 ha (1770) acres in Southeastern Tennessee (see Figure 4.3). The facility is situated on the west shore of Chickamauga Lake and is approximately 80 km (50 miles) northeast of Chattanooga and 50 km (31 miles) northeast of the Sequoyah Nuclear Plant site.

The plant is located in the Valley and Ridge Province of the Appalachian Highlands. The province is made up of a series of folded and faulted mountains and valleys which are underlain by Paleozoic sedimentary formations totaling 12,000 m (40,000 ft) in thickness. The plant site is situated in a bend of the Tennessee River that has been covered by alluvial terrace deposits. Beneath these deposits lies the Middle Cambrian Conasauga Formation, an interbedded shale and limestone unit upon which the Category I structures are founded.

The controlling feature of the geologic structure at the site is the Kingston thrust fault, which developed 250 million years ago. The fault has been inactive for many millions of years, and recurrence of movement is not expected. The fault lies to the northwest of the site area and is not involved in the foundation for any of the major plant structures.

WBN was designed based on the largest historic earthquake to occur in the Southern Appalachian Tectonic Province - the 1897 Giles County, Virginia earthquake. This earthquake is estimated to have had a body wave magnitude of 5.8. The Safe Shutdown Earthquake for the plant has been established as having a maximum horizontal acceleration of 0.18 g and a simultaneous maximum vertical acceleration of 0.12 g.

Because of the contours of the land and strata there is little likelihood of abnormal releases of liquid wastes at the plant contaminating industrial or drinking water supplies derived from ground water sources.

No known meteorological measurements other than rainfall have been recorded in the immediate vicinity of the Watts Bar site. Therefore, the climatological appraisal of the site has been developed from meteorological data collected at stations within 80 km (50 mi). A permanent onsite meteorological facility has been in operation since May 1973 to meet NRC requirements. The FSAR indicates that there are no limiting meteorological factors present at the site.

The population density of the area surrounding the site is relatively low, and only two cities within 100 km (60 mi) of the plant (Chattanooga and Knoxville) have populations exceeding 100,000 people.

Radionuclide emissions to the atmosphere from WBN were estimated to consist of 13,000 Ci of noble gases and 0.34 Ci of iodine-131 per year with both units operating (NRC 1995). Because only one of the units is currently operational, the atmospheric emissions are estimated to be approximately half of those reported for both units, or 6500 Ci of noble gases and 0.17 Ci/yr of iodine-131. WBN has been operating for less than 1 year; therefore, results of annual effluent monitoring and ambient air quality monitoring are not yet available. However, the impacts of these emissions are expected to be well within NRC and EPA standards.

Liquid effluents discharged from WBN are regulated by the State of Tennessee under a permit issued in accordance with the federal Clean Water Act. These effluents are not expected to affect water quality in the Tennessee River or to limit public uses of the waterway. Annual releases of radionuclides in liquid effluents were estimated to amount to 2600 Ci of tritium and 6.6 Ci of other radionuclides when both units are operating (NRC 1995). The estimated emissions for operation of one unit are therefore about 1300 Ci/yr of tritium and 3.3 Ci/yr of other radionuclides. These emissions are also expected to be well within federal and state standards for members of the public.

Low-level radioactive wastes generated at WBN for operation of both units are expected to amount to 150 m^3 (200 yd^3) of ion exchange resins and filters, 40 m^3 (53 yd^3) of other dry waste (after compaction), and 3

m^3 (4 yd^3) of irradiated components per year (NRC 1995). Radioactive wastes generated at the plant are shipped to a commercial facility licensed by the NRC for disposal.

4.4 Argonne National Laboratory-West

Argonne National Laboratory-West (ANL-W), located at a desert site in Idaho on the INEEL, is part of the Argonne National Laboratory (ANL). ANL is a non-profit research Laboratory operated by the University of Chicago for the Department of Energy.

The ANL-W and INEEL are located in southeastern Idaho, about 44 km (27 mi) west of Idaho Falls (Figure 4.4). ANL-W is located in the southeast portion of the site, approximately 8.7 km from the site boundary. The northern and western borders of the INEEL site are roughly formed by the Bitterroot, Lemhi, and Lost River mountain ranges. The site encompasses 2312 km^2 (893 mi^2) in Butte, Bingham, Jefferson, Bonneville, and Clark counties, Idaho. About 145 km (90 mi) of paved public highways run through the INEEL site, including U.S. highways 20 and 26, and state routes 22, 28, and 33. Other transportation routes include Interstate 15 and U.S. highways 93A and 191.

The INEEL is located in southeastern Idaho with Mud Lake to the east; Arco, Butte City, and Howe to the west; and Atomic City to the south. The larger communities of Idaho Falls, Rexburg, Blackfoot, Pocatello, and Chubbock are to the east and southeast of the INEEL site. The Fort Hall Indian Reservation is to the southeast of the INEEL. The Bitterroot, Lemhi, and Lost River mountain ranges border the INEEL site on the north and west. Most of the INEEL site consists of open undeveloped land, covered predominantly by large sagebrush and grasslands. Pasture and irrigated farmland border much of the INEEL site. The Craters of the Moon National Monument is about 24 km (15 mi) southwest of the INEEL site western boundary.

Examinations conducted in the Hot Fuels Examination Facility (HFEF) provide data that are essential for determining the performance of fuels and materials irradiated in the Experimental Breeder Reactor II (EBR-II), Transient Test Facility (TREAT), and other DOE reactor facilities. HFEF, which went into operation in 1975, consists of two shielded hot cells, the decontamination cell which contains an air atmosphere and the main cell which contains an argon gas atmosphere. Both cells are surrounded by high-density concrete walls, four feet thick, that protect workers from the high radiation levels present in the cells. Each of the twenty-one workstations in HFEF are equipped with shielded windows (also four feet thick) and master/slave manipulators. The main cell, with its inert argon gas atmosphere, is utilized for work involving exposure of materials such as sodium, plutonium, and other materials that would react chemically with air.

HFEF has several features that make it suited for examining irradiated fuels and materials experiments. The main cell is designed for containment of any plutonium contamination that may be released during the handling and examination of irradiated experiments. The cell is also designed for the vertical handling, cutup, and examination of experiments up to about 9 m (30 ft) in length. Much of the in-cell examination equipment for fuel elements is automated or semi-automated. All of the in-cell equipment is carefully designed to permit remote maintenance. No personnel entry has been required into the main cell.

Non-destructive in-cell examination capabilities include macro viewing and photography, weighing, precision dimensional surveys, gamma-ray spectroscopy, eddy-current testing, neutron radiography, and fission-gas sampling and assay. Destructive examination capabilities include in-cell equipment for cutting specimens from irradiated hardware or fuel and the preparation of samples for physical testing, chemical analysis. or microscopic examinations. Samples in the main cell are transferred by pneumatic "rabbit" to the ANL-W Analytical Laboratory or to a small HFEF hot cell, where optical microscopy and scanning electron microscopy are available.

The capability to examine and characterize contact-handled transuranic waste destined for the Waste Isolation Pilot Plant in New Mexico was added to HFEF in 1990. A 250-kW research reactor is located in the basement of HFEF and provides a source of neutrons for neutron radiography. The Neutron Radiography Facility is equipped with two beam tubes and two separate radiography stations.

Specimens are lowered from the HFEF main cell to intersect one of the collimated neutron beams. The second neutron radiography station is outside of the main cell and permits neutron radiography of either unirradiated or irradiated specimens without introducing them into the contaminated main cell.

Other HFEF features include: a computer system for data acquisition and in-cell process control; a microdensitometer that supports neutron tomography (a process similar to medical CAT scanning); and facilities for decontaminating and repairing hot cell equipment and manipulators.

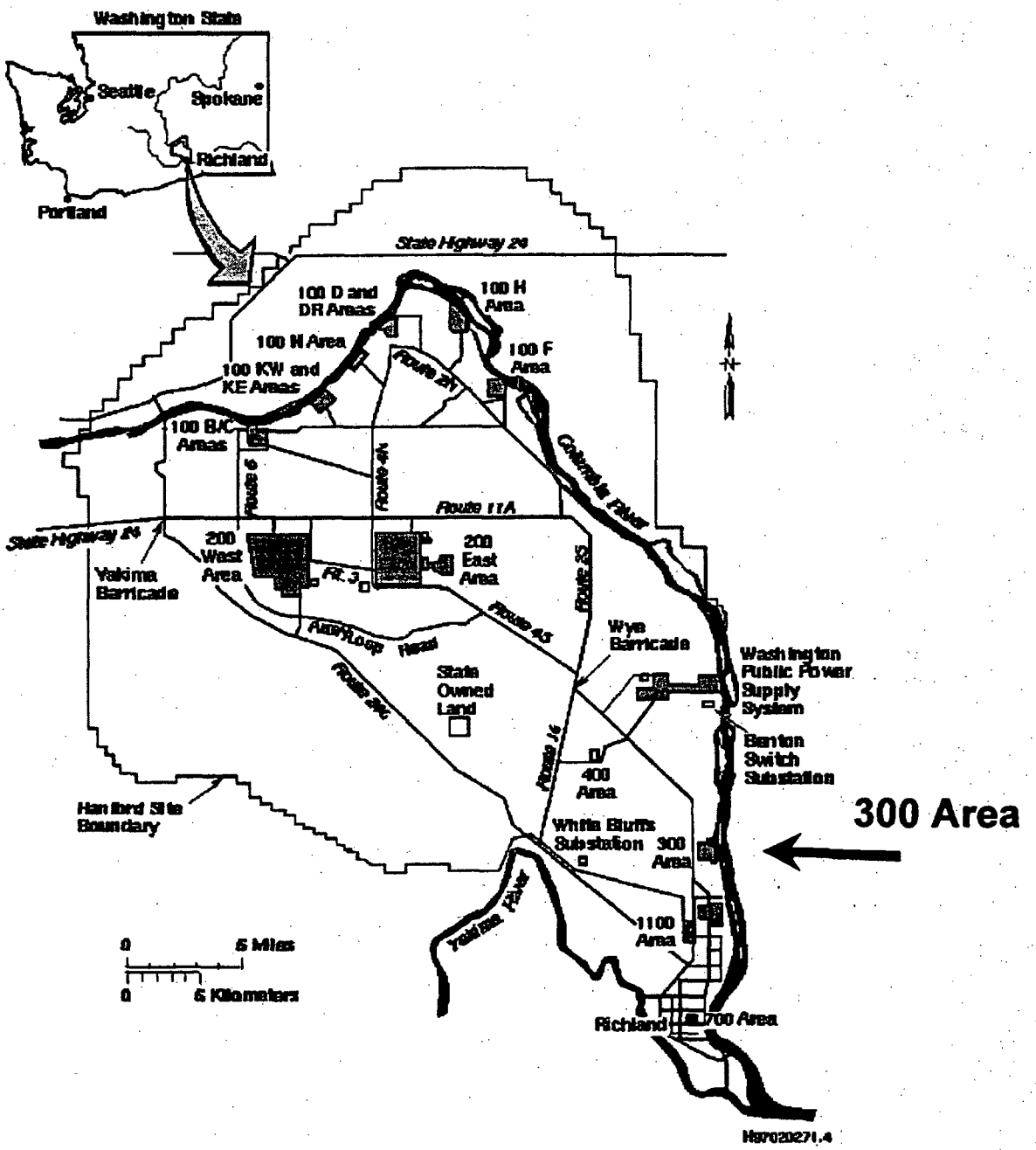


Figure 4.1 Hanford Site

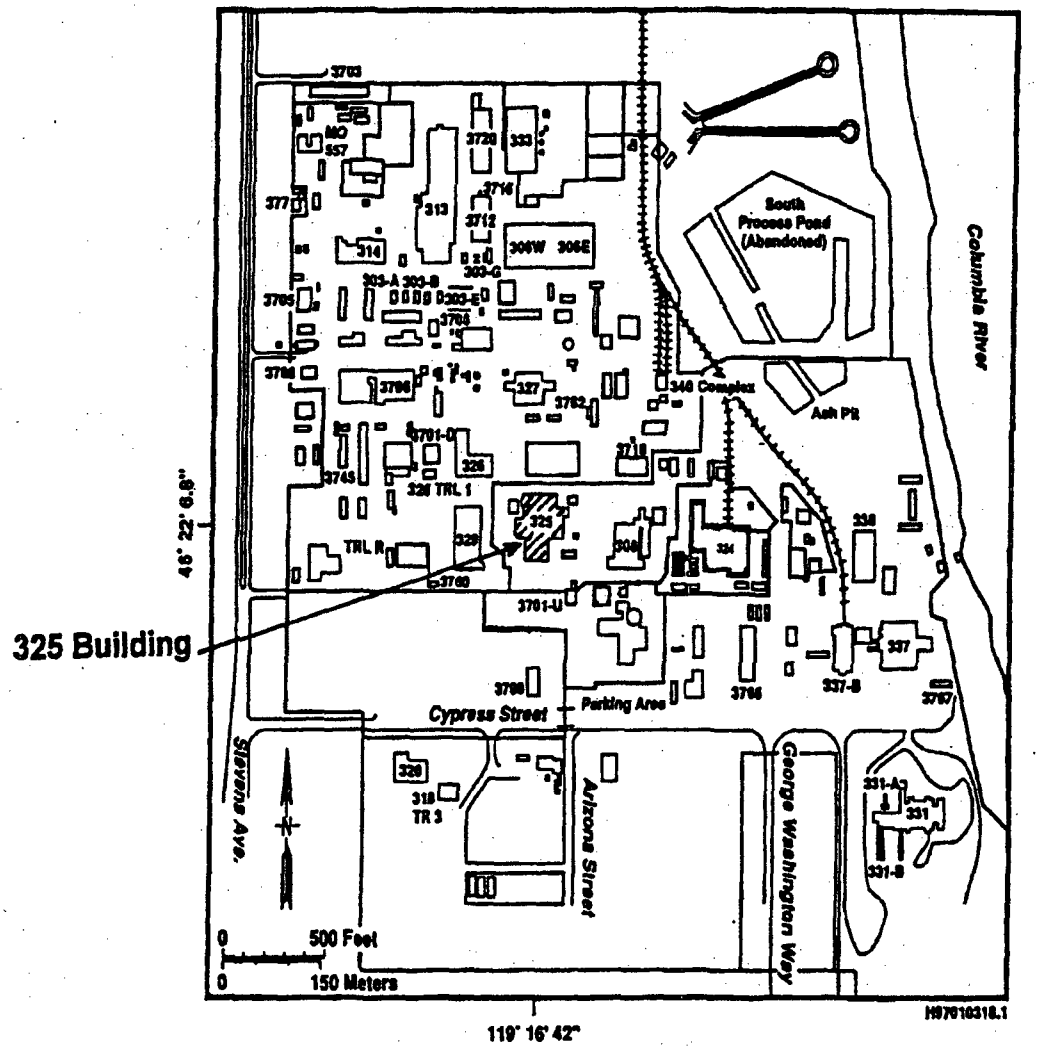


Figure 4.2 300 Area of the Hanford Site

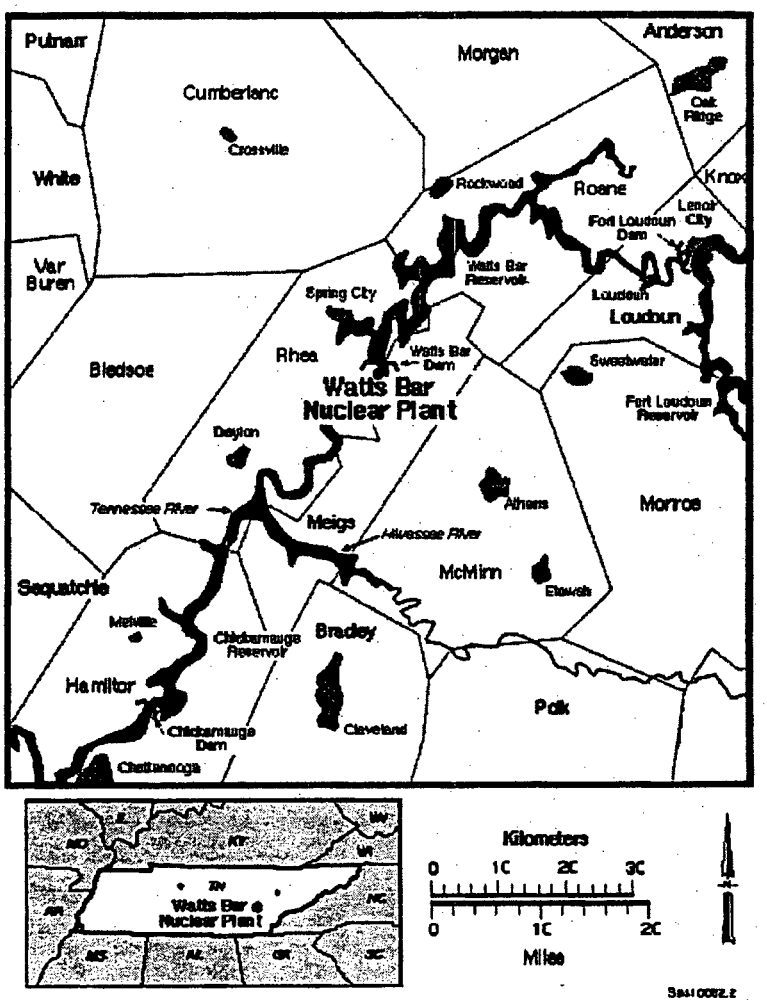
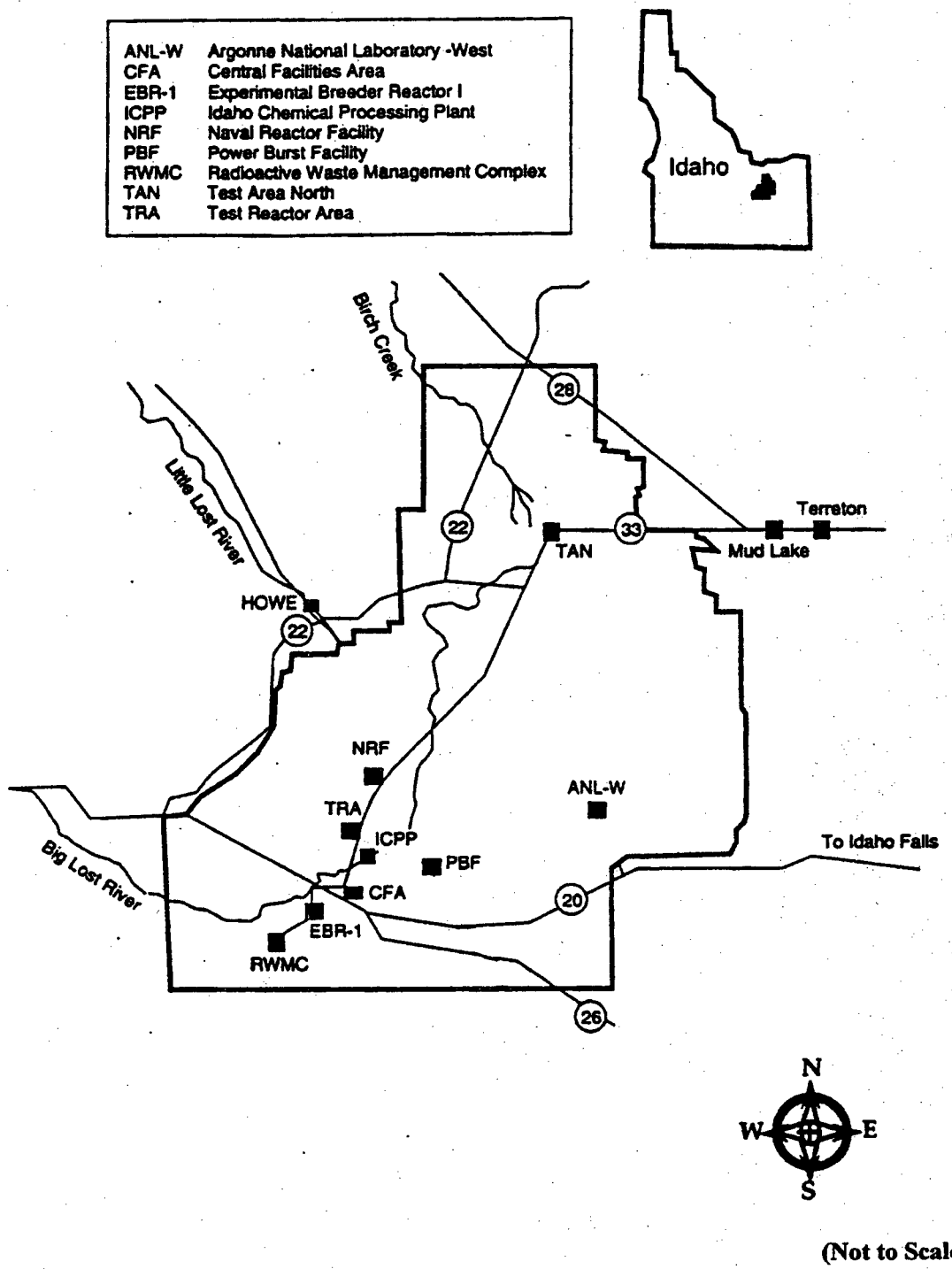


Figure 4.3 Location of the Watts Bar Nuclear Plant



(Not to Scale)

Figure 4.4 Location of Argonne National Laboratory-West

5.0 Environmental Impacts of the Proposed Action

The potential environmental impacts associated with the Proposed Action and alternatives are discussed in this section. Activities associated with the Proposed Action are described in Section 2. Most of these activities would be conducted in conjunction with ongoing operations at each site and would result in minor changes, if any, to the existing impacts of those operations. The impacts of routine operations at the Westinghouse fuel fabrication facility, WBN, and the neutron radiography facility at ANL-W are addressed in this document in the context of cumulative impacts where appropriate.

Consequences associated directly with transporting, irradiating, and examining TPBARs at the identified facilities are discussed in this section. The types of potential impacts evaluated in detail include air quality, water quality, waste disposal, facility accidents, transportation, and health and safety. Impacts in other areas are considered to be minimal and are discussed only as necessary to demonstrate the absence of potential consequences.

5.1 Air Quality

The potential consequences of the Proposed Action on radiological and non-radiological air quality at the respective locations where they would occur are discussed in the following sections.

5.1.1 Atmospheric Emissions of Radionuclides

Emissions of radionuclides to air from normal operations at DOE facilities are regulated under Subpart H of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radionuclides (40 CFR Part 61). Emissions from commercial nuclear power reactors are regulated under 10 CFR Part 50, and doses to the public are limited to the standards in 10 CFR Part 20. Standards for DOE facilities provide that they may not emit radionuclides to air in quantities that would cause any member of the public to receive a dose greater than 10 mrem (1×10^{-4} Sv) effective dose equivalent (EDE) in any year. Standards in 10 CFR Part 20 for NRC facilities provide that their operations may not result in a dose of greater than 100 mrem/yr (1×10^{-3} Sv/yr) to any individual from all pathways. State and local standards for radionuclide emissions to the atmosphere are consistent with federal standards at the locations considered in this EA. All facilities used in the Proposed Action would comply with state and federal regulations.

5.1.1.1 Assembly and Incorporation of the TPBAR-LTAs into the Integrated Assemblies

Incorporation of TPBARs into TPBAR-LTAs at the Westinghouse fuel fabrication facility would not result in radionuclide releases because all materials are nonradioactive prior to irradiation in the reactor. Emissions would not be increased by incorporation of TPBAR-LTAs into the integrated assemblies.

5.1.1.2 Irradiation of TPBAR-LTAs, Transportation, and NDE

Tritium releases from the TPBAR-LTAs during irradiation at WBN are expected to be less than 214 Ci per year to the reactor's primary coolant system because the TPBARs are designed to retain tritium in a solid matrix (Erickson et al 1997). Because most of the tritium that enters the coolant would remain in liquid form, offsite consequences in terms of air quality are not expected. Tritium emissions during transport and NDE of the TPBARs at Hanford and ANL-W are likewise not anticipated because the TPBARs and hardware would be maintained at all times in a shielded environment or sealed within an NRC-licensed Type B transportation cask.

5.1.1.3 Post-Irradiation Examination of TPBARs

Most of the radionuclide releases that could occur would take place during destructive PIE of the TPBARs at the Hanford Site as they are cut or punctured to determine tritium production levels and to examine their internal structure (see section 2 for a description of the TPBARs). Three major activities associated with PIE have the potential to result in radionuclide releases:

- sectioning of TPBARs to examine their internal structure,
- puncturing and extraction of tritium from TPBARs to determine production and recovery levels, and
- permeability tests of the TPBAR cladding material using a commercial source containing 2000 Ci of tritium.

For this analysis, the range of potential impacts was estimated by assuming that tests are conducted on either the planned number of TPBARs, as noted in Table 5.1, or on all 32 TPBARs as a maximum. The tritium inventory of a single TPBAR was assumed to be 1.2 g (about 12,000 Ci), which represents an upper bound based on their design (Erickson et al 1997).

The consequences of the PIE activities with respect to air quality are summarized in Table 5.1; a detailed description of the assumptions for these estimates appears in Appendix C, Section C.2. The maximum total impact of the planned TPBAR post-irradiation examination activities would amount to less than 0.095 mrem/yr (9.5×10^{-7} Sv/y) to a maximally exposed member of the public, if all of the activities were conducted within a 1-year period. This represents less than 1% of the 10 mrem/yr (1×10^{-4} Sv/yr) standard for radionuclide emissions from DOE facilities (40 CFR Part 61, Subpart H). For the maximum case in which all 32 TPBARs are examined, the total would be 0.33 mrem (3.3×10^{-6} Sv), which corresponds to 3.3% of the standard if all releases occurred within a single year. In reality, these activities would likely be conducted over a longer period, thereby reducing the annual dose to the maximally exposed member of the public.

The dosimetry models incorporated into software used for the analysis assume that tritium is released in the form of water vapor. If any of the estimated releases occur as elemental tritium gas, the dose would be lower than the estimates presented in this section, as discussed in Appendix C, Section C.1. Atmospheric emissions of radionuclides during interim storage or disposal of the TPBAR-LTA hardware and TPBARs are not anticipated.

Table 5.1 Consequences of Routine Radionuclide Emissions from Post-Irradiation Examination of TPBARs at the Hanford Site 325 Building

PIE Activities:	Estimated Tritium Emissions (Ci)	Dose to the Maximally Exposed Offsite Resident (mrem)	% of 10 mrem/y Regulatory Standard (40 CFR Part 61)	Collective Dose to Population within 80 km (person-rem)
Sectioning TPBARs				
- 1 TPBAR (see Appendix C)	48	2.6×10^{-3}	-	1.2×10^{-2}
- Planned (4 TPBARs)	190	1.1×10^{-2}	0.11	4.6×10^{-2}
- Maximum (32 TPBARs)	1500	8.5×10^{-2}	0.85	3.7×10^{-1}
Tritium Extraction				
- 1 TPBAR (see Appendix C)	130	7.3×10^{-3}	-	3.1×10^{-2}
- Planned (10 TPBARs)	1300	7.3×10^{-2}	0.73	3.1×10^{-1}
- Maximum (32 TPBARs)	4200	2.3×10^{-1}	2.3	1.0×10^{0}
Cladding Permeability Tests	200	1.1×10^{-2}	0.11	4.8×10^{-2}
Total				
- Planned	1700	9.5×10^{-2}	0.95	4.1×10^{-1}
- Maximum	6000	3.3×10^{-1}	3.3	1.4×10^{0}

5.1.2 Atmospheric Emissions of Regulated Nonradioactive Materials

Emissions of nonradioactive pollutants that are regulated under other provisions of the Clean Air Act are expected to be within regulatory limits, and they would consist largely of combustion products associated with generating primary or auxiliary power, producing process steam, or heating facilities. These emissions occur in conjunction with ongoing operations at each facility and would not increase because of the Proposed Action.

5.2 Water Quality

Of the activities considered in the Proposed Action, only irradiation of the TPBAR-LTAs at WBN has the potential to generate liquid effluents that are routinely released to groundwater or surface waters. None of the other activities, including production of the integrated assemblies, neutron radiography, and PIE, are expected to produce liquid effluents (other than the operating effluents typically generated at the facilities) that might affect water quality at the locations where these activities occur. Small quantities of liquid wastes that may be generated in association with these activities would be treated as appropriate and disposed of as described in section 5.3.

During irradiation of the TPBAR-LTAs at WBN, a small quantity of the tritium produced in the TPBARs may be released into the reactor's primary coolant system (up to a maximum of 6.7 Ci/y per TPBAR, or a total of 214 Ci/yr). Exchange of the primary coolant to maintain water chemistry could ultimately release tritiated water to the environment. However, the dose to the maximally exposed offsite individual from the plant's liquid effluents was estimated to be 0.70 mrem/yr (7.0×10^{-6} Sv/yr) either with or without the tritium contribution from the TPBARs (Erickson et al 1997). That dose represents about 23% of the 3 mrem/yr (3×10^{-5} Sv/yr) standard for demonstrating compliance with the requirements of 10 CFR Part 50,

Appendix I, and irradiation of the TPBAR-LTAs would not alter the plant's compliance status with respect to the standard. The contribution of tritium from the Proposed Action to the plant's liquid effluents at the point of release to the river would not cause them to exceed the maximum concentration limits established in 10 CFR 20, Appendix C (1×10^{-3} µCi/mL).

5.3 Waste

Wastes generated as a result of the Proposed Action would consist of relatively small quantities of low-level radioactive waste, mixed low-level radioactive and hazardous waste, and nonradioactive hazardous waste, in addition to the non-hazardous solid and liquid wastes typically associated with operation of the facilities. No transuranic or high-level radioactive wastes would be produced. Waste minimization practices would be used to reduce, to the extent possible, the quantities of radioactive and hazardous wastes generated at all facilities.

5.3.1 Assembly and Incorporation of TPBAR-LTAs into the Integrated Assemblies

Preparation of the integrated assemblies, including incorporation of TPBARs at the Westinghouse fuel fabrication facility, would not produce any radioactive or hazardous wastes in addition to those typically generated at the plant.

5.3.2 Irradiation of TPBAR-LTAs

Wastes associated with irradiation of the integrated assemblies at WBN would consist of low-level radioactive liquids and solids generated as the TPBAR-LTAs are removed from the spent fuel pool, decontaminated, and packaged for shipment to Hanford. The quantity of waste generated during this activity is expected to be less than 1% of the waste generated annually at WBN (i.e., less than 0.4 m^3 or 5 yd^3). These wastes would be treated as appropriate and disposed of at a licensed commercial facility with similar types of wastes from routine reactor operations. The fuel assemblies that initially contained the TPBAR-LTAs would be returned to the reactor core during refueling.

5.3.3 Post-Irradiation Examination of TPBARs

Construction at the 325 building to provide an access port into the hot cells could generate radioactive waste in the process of penetrating the hot cell wall. The volume of potentially contaminated materials removed from the wall and associated construction materials is not expected to exceed 1 m^3 (1.3 yd^3) of low-level radioactive waste. Wastes produced during disassembly of the TPBAR-LTAs at Hanford and NDE of the TPBARs at Hanford and ANL-W would consist of laboratory materials and protective clothing used to prevent possible spread of contamination during receipt, handling, and examination. At each facility, the volume of these wastes is expected to be less than 0.1 m^3 (0.13 yd^3) of low-level radioactive waste, which would be disposed of at onsite facilities.

The greatest quantities of low-level radioactive waste, about 20 m^3 (26 yd^3), would be generated during destructive examination of the TPBARs at Hanford. These materials would consist of cuttings and small sections of the rod cladding and tubing, laboratory materials used to control spread of contamination, and either solid molecular sieve or bubbler liquids used to trap the tritium contained in gaseous effluents from the sectioning and extraction processes. Smaller quantities of mixed low-level waste, less than 1 m^3 (1.3 yd^3), could be produced during liquid scintillation counting of tritium samples. An estimated 5 m^3 (6.6 yd^3) of nonradioactive hazardous wastes would be produced during the laboratory activities as well. Ultimately, decontamination of the hot cells and disposal of unneeded equipment could generate up to 200 m^3 (260 yd^3) of low-level radioactive waste. However, it is anticipated that the laboratory would retain this equipment for an indefinite period to use in future studies following completion of the Proposed Action.

Prior to disposal, the tritium inventory would remain either in the TPBARs that are not used for PIE tests, or within laboratory wastes consisting of molecular sieve or bubbler trap liquids that retain tritium which has been extracted from the test TPBARs. TPBARs that are not destructively examined would be placed in interim storage in sealed containers until DOE identifies another purpose for them or decides to dispose of them as low level radioactive waste. If the remaining TPBARs are to be disposed of, tritium would be extracted from them and they would be placed in appropriate packaging. The consequences of extracting the tritium would be bounded by the maximum PIE activities as described in section 5.1.1.3. The tritium-depleted TPBARs would contain less than 5% of their original tritium inventory in addition to neutron activation products in the structural components. Tritium extracted from the TPBARs that are not subject to PIE could either be disposed as low level radioactive waste, sold to a commercial enterprise, or collected on a tritium storage device for future DOE use.

If all of the TPBARs and hardware from the TPBAR-LTAs are disposed of at Hanford, they would consist of less than 1 m^3 (1.3 yd^3) of solid low-level radioactive waste (exclusive of packaging) in addition to that generated during laboratory activities. All of the radionuclides remaining in the TPBARs and hardware would be bound in solid components, where they would be relatively immobile following disposal. In addition, the TPBARs, hardware and other radioactive laboratory wastes would be appropriately packaged prior to disposal. All radioactive and hazardous wastes generated at Hanford would be disposed of either at the onsite low level radioactive waste burial grounds or in permitted commercial disposal facilities, in accordance with applicable state and federal regulations. Mixed low-level wastes would be stored onsite in permitted facilities.

5.4 Facility Accidents

Consequences of potential accidents at facilities that would be involved in the Proposed Action are discussed in this section. These events have been evaluated, or would be evaluated prior to implementing any proposed activities, in sufficient detail to ensure that they would not affect the operational safety basis for those facilities. Operational restrictions and any needed modifications identified as a result of those evaluations would be implemented before work commences to ensure that the facilities remain within their safety guidelines. Accidents during transport of the unirradiated or irradiated TPBARs are addressed in Section 5.5.

5.4.1 Assembly and Incorporation of TPBAR-LTAs into the Integrated Assemblies

Because the unirradiated TPBAR-LTAs are non-radioactive and contain no hazardous materials, preparation of the TPBAR-LTAs and integrated assemblies at the Westinghouse fuel fabrication facility would not affect the frequency or consequences of potential accidents associated with that facility.

5.4.2 Irradiation of TPBAR-LTAs

Accidents during irradiation of the TPBAR-LTAs at WBN were evaluated to determine whether substituting TPBARs for the standard burnable absorber rods in the reactor's fuel assemblies could affect the frequencies or consequences associated with off-normal events or accidents previously evaluated for the reactor (Erickson et. al 1997). The analysis determined that the presence of TPBAR-LTAs in the reactor core would not be likely to affect the course or severity of such events. This section contains a brief summary of that analysis.

An assumed event, in which the entire tritium inventory from one failed TPBAR might leak into the reactor coolant system over a 1-year period, could increase the offsite dose from the plant's projected liquid effluents from 0.700 to 0.713 mrem/yr (7.0×10^{-6} to 7.13×10^{-6} Sv/yr). The incremental increase of 0.013 mrem/yr (1.3×10^{-7} Sv/yr) to the maximally exposed offsite member of the public would represent

less than 2% of the annual dose from the plant's typical liquid effluents, and would be well within the regulatory standards for routine reactor operation. Evaporation of coolant water released into the reactor's fuel handling area following a hypothetical event of this type could increase the tritium concentration in the facility air to about 5.8 % of the derived air concentration limit. Inhalation of tritium by an individual worker who spent 200 hours in the area during refueling operations would result in a cumulative dose of less than 50 mrem (5.0×10^{-4} Sv). Although the likelihood of such an event was not estimated in detail, conditions severe enough to fail the TPBAR cladding are not anticipated during the LTA program.

Evaluation of more severe events indicated that the presence of TPBAR-LTAs in the reactor would also have a minimal impact on their consequences. Releases to the environment following a steam generator tube rupture or steam line break would amount to less than 9 Ci of tritium that could be in the primary coolant due to the presence of the TPBARs. The TPBAR-LTAs would not measurably increase the individual doses resulting from these events, or from other types of events such as a fuel handling accident.

A large break loss of coolant accident could involve conditions severe enough to release up to the entire end-of-cycle tritium inventory from all of the TPBARs to the reactor containment. The estimated offsite dose from this event would be 3.3 rem (0.033 Sv) to an individual at the exclusion area boundary for 2 hours or 2.0 rem (0.020 Sv) to an individual in the low population zone over 30 days, either with or without a contribution from the TPBAR-LTAs (Erickson, et. al.1997, values rounded to two significant figures). Therefore, the TPBAR-LTAs would not contribute to the overall risk associated with such an accident. Doses to plant personnel in the reactor control room over a period of 30 days following the event would amount to about 30 mrem (3.0×10^{-4} Sv) from the TPBAR tritium, which is much lower than the contributions from other radionuclides that might be released from the reactor core. The TPBAR-LTAs are also not expected to affect the operation or effectiveness of plant safety systems, such as the emergency core cooling system or the combustible gas control system, during such an event.

5.4.3 Post-Irradiation Examination of TPBARs

The consequences of potential accidents during PIE of the TPBARs were evaluated for a spectrum of events having different severities and expected frequencies. A detailed safety analysis of the PIE activities would be performed before work commences; however, the scenarios evaluated for this assessment are representative of the types of events that are typically considered in safety assessments. Three accidents were evaluated for PIE activities, including: 1) breach of a single TPBAR during handling, 2) a localized fire involving the maximum quantity of tritium "at risk" during PIE, and 3) a seismic event and fire, which could involve all 32 TPBARs.

Accidents during PIE at Hanford are expected to bound those for similar types of events at ANL-W because the facilities are farther from the nearest offsite receptors than those at Hanford (greater than 8 km [5 mi] vs 0.58 km [0.36 mi]). In addition, the localized fire scenario would not apply to NDE activities because the TPBARs would remain intact and therefore would not be considered at risk for that type of accident. Accidents during interim storage and disposal of the TPBARs and hardware would be bounded by the accident consequences for PIE activities and transportation, as discussed in this section and in Section 5.5.

The assumptions for this assessment, as discussed in Appendix C, represent a bounding case for the purposes of preparing this EA and to demonstrate that the consequences of potential accidents are within established safety guidelines. The TPBARs were designed to retain tritium in the solid matrix of the components, even under the relatively severe conditions encountered during irradiation in the reactor. The quantity of free tritium is expected to be a small fraction of the total inventory. Therefore, both a mechanism to damage the TPBAR cladding and an extended period at high temperature would be required to release substantial quantities of tritium from the TPBARs. The probability of an accident that would produce these conditions is not known with accuracy. However, such an event (for example, the severe

earthquake and fire) is assumed to be credible, although extremely unlikely, for the purposes of this analysis.

An accident involving damage to a single TPBAR with release of the free tritium would result in a dose of 3.5 mrem (3.5×10^{-5} Sv) to an onsite worker, 0.40 mrem (4.0×10^{-6} Sv) to an individual at the Hanford Site boundary, and 1.4 person-rem (0.014 person-Sv) to the population within 50 miles (80 km). That type of event is expected to occur with a frequency between 0.01 and 1.0 per year, or once in 1 to 100 years.

The dose from a localized fire that might release the maximum tritium inventory at risk during PIE (assumed to be 70,000 Ci) would be 2,500 mrem (0.025 Sv) to an onsite worker, 290 mrem (2.9×10^{-3} Sv) for an individual at the site boundary, and 1,100 person-rem (11 person-Sv) to the population within 50 miles (80 km). A bounding localized fire that might result in these consequences was estimated to occur no more than once in 10 years, and the duration of the activity is estimated to be less than 0.5 year. Therefore the combined probability for the release was assumed to be 0.05. The upper bound frequency of such an event was supported by the fire loss history at Hanford over a 45-year period, during which time the site experienced 10 fires that resulted in significant property loss. Of those fires, 6 potentially involved radioactive materials, and 2 of the 6 events occurred in laboratory facilities. No fires of that magnitude have occurred in the 325 building since it was occupied in 1953, and they would not be expected to occur routinely in that facility because of the facility design, administrative controls on conduct of operations, and the fire protection program. These mitigating factors, as well as the fact that the maximum "at risk" inventory would not actually be vulnerable during the entire activity, are more difficult to quantify. Therefore, they have not been accounted for in the assumed frequency for the release associated with the localized fire. This analysis is extremely conservative and defines the upper bound of risk associated with this activity. However, administrative controls would be maintained at the 325 building to reduce the risk of potential adverse health effects. Examples of such measures include limitations on the quantity of combustible materials in the work areas, minimizing ignition sources, limiting the inventory at risk, and implementation of fire control measures.

The severe earthquake and fire scenario has an assumed frequency between 10^{-4} and 10^{-6} per year, or 1 event in 10,000 to 1 million years. If this combination of events occurred, the dose from a hypothetical release of the tritium inventory in all 32 TPBARs (about 385,000 Ci) would amount to 14,000 mrem (0.14 Sv) for the onsite worker 1,600 mrem (0.016 Sv) to an individual at the site boundary, and 5,800 person-rem (58 person-Sv) to the population within 50 miles (80 km).

5.5 Transportation

The consequences of transporting both unirradiated and irradiated TPBARs and TPBAR-LTAs are discussed in this section. Both incident-free transport and accidents during transport are addressed. Additional background information and the basis for the results of the analysis presented in the following sections is contained in Appendix D.

5.5.1 Incident-Free Transportation Impacts

This section addresses the incident-free transportation impacts associated with the shipments. The transportation impacts include external radiation exposures and the nonradiological impacts due to pollutants emitted by the transport vehicles.

For the analysis, all overland transportation was assumed to be by truck. It was also assumed that one shipment would be required to ship the unirradiated TPBARs to the Westinghouse fuel fabrication facility, and that one shipment of the integrated assemblies would be made from Westinghouse to WBN. Because the unirradiated TPBARs contain no radioactive material, they would not be regulated under the provisions

of 49 CFR Parts 171-178. Unirradiated integrated assemblies would consist of low specific activity radioactive material, and they would be transported using a commercial carrier authorized to perform such shipments.

An NRC-licensed Type B shipping cask would be used to ship the irradiated TPBAR-LTAs from WBN to Hanford. For the purposes of this analysis, the transport was assumed to require two to four shipments, with either one or two TPBAR-LTAs per shipment. At Hanford, the TPBAR-LTAs would be disassembled and the 32 irradiated TPBARs would be transported in one shipment to a facility such as the HFEF at ANL-W. Following neutron radiography, the TPBARs would be returned to Hanford for additional PIE.

The hardware from the disassembled TPBAR-LTAs would eventually be placed in approved shipping containers and transported from the 325 Building to a Hanford Site solid waste facility for disposal. Following completion of the PIE, the spent TPBARs and other radioactive wastes would also be placed in approved shipping containers and transported from the 325 Building to a Hanford Site solid waste facility for disposal. It is assumed that a total of five shipments would be required to transport the TPBAR-LTA hardware, the TPBARs, and the laboratory wastes.

For this analysis, HIGHWAY 3.3 (Johnson et al. 1993) was used to develop transportation routing information including total distance traveled, en route population densities, and travel distances within three population zones (i.e., rural, suburban, and urban). It was assumed that all shipments of irradiated TPBAR-LTAs and TPBARs (except for those on the Hanford Site) would use "exclusive use" routes and all other shipments would use "commercial" routes. For exclusive use shipments, highway route controlled quantities are shipped on interstate highways or state-designated alternate routes (49 CFR 171-177). This was assumed for shipments of the irradiated TPBAR-LTAs due to the radionuclide inventories and sensitive nature of the shipments (i.e., tritium). Commercial routes are those used for truck shipments of ordinary freight, as designated by local ordinances or other restrictions based only on vehicle size or weight.

5.5.1.1 Potential Radiological Impacts

The radiological impacts associated with incident-free transport of the irradiated TPBAR-LTAs and TPBARs have been analyzed using RADTRAN 4 (Neuhauser and Kanipe 1992). The potential radiological impacts involve in-transit doses to the public or to Hanford Site workers from radiation emitted from the shipping cask and doses to the transport workers in the vicinity of the shipment during cask-handling activities (e.g., moving the cask on or off the truck trailer). In-transit doses have been estimated for the truck drivers and the general public, including persons at truck stops, persons living or working adjacent to the transport route, and nearby travelers (moving in the same and opposite directions).

No radiological impacts are associated with transporting the TPBARs to the Westinghouse fuel fabrication facility or with transporting the integrated assemblies from the Westinghouse fuel fabrication facility to WBN. No radiological impacts are expected to be associated with returning the empty shipping cask to WBN for reloading. Therefore, the routine radiological impacts have been estimated for shipments from WBN to Hanford, from Hanford to ANL-W, from ANL-W back to Hanford, and from the 325 Building to the Hanford Site solid waste facility.

Because of the lack of actual cask exposure rate measurement data, the exposure rate at the surface of the shipping cask was assumed for the purposes of this analysis to be the maximum allowable in 10 CFR 71.51. The total estimated dose to the truck crew for all shipments (WBN to PNNL, PNNL to HFEF, HFEF to PNNL, PNNL to a Hanford Site solid waste facility) would be less than 0.90 person-rem (0.009 person-Sv). The total estimated collective dose to the public along the transportation route for those shipments would be less than 3.4 person-rem (0.034 person-Sv).

The estimated dose to the public for shipments from WBN to PNNL was compared with the estimated dose to the public from natural background radiation along the same transportation route. The comparative evaluation determined that the estimated dose to the public along the transportation route due to natural background radiation would be greater than 13 times the estimated dose to the public for all shipments from WBN to PNNL. (See Appendix D)

5.5.1.2 Potential Nonradiological Impacts

Impacts to the public from nonradiological causes were also evaluated. According to Rao et al. (1982), the types of air pollutants that are generated by transportation and which could affect the public would be sulfur oxides (SO_x), particulates, nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and photochemical oxidants (O_x). Rao et al. (1982) determined that most health effects are due to SO_x and particulates.

For all shipments, approximately 210 km (132 mi) is within the urban population zone; therefore, according to the methodology described in Rao et al. (1982), the number of expected fatalities due to fugitive vehicle emissions is essentially zero (i.e., less than 4.2×10^{-5} fatalities for all shipments).

5.5.2 Transportation Accident Impacts

This section addresses radiological and nonradiological impacts of accidents during transport. Potential nonradiological accident impacts consist of fatalities resulting from vehicular accidents involving the shipments.

Radiological impacts are calculated for the public as well as for a maximum onsite and offsite individual. The maximum individual doses have been calculated using GENII (Napier et al 1988). The collective impacts to the public are presented in this section as integrated population risks (i.e., accident frequencies multiplied by consequences of all shipments). Population risk calculations were performed using the RADTRAN 4 computer code (Neuhauser and Kanipe 1992).

5.5.2.1 Radiological Impacts to the Public from Transportation Accidents

Potential accident impacts can result from breaches in the shipping cask or damage to the cask shielding. However, the shipping casks are designed, tested, and certified to withstand specified conditions that would not be exceeded in most transportation accidents (i.e., for this analysis, the shipping casks for irradiated TPBAR-LTAs or their components were assumed to meet the Type B packaging requirements specified in 49 CFR Part 173 and 10 CFR Part 71). Therefore, only a small fraction of transportation accidents involve conditions that are severe enough to result in release of radioactive materials.

If radionuclides were released to the environment, they would be dispersed and diluted by weather action; and a small quantity would be deposited on the ground through plume depletion. Access to the area adjacent to the transportation accident would be controlled by emergency response personnel until the area could be remediated and the radiation monitoring personnel had declared the area safe.

The input data used to calculate the radiological dose to the public (i.e., population densities, travel times, and distances) were the same as the inputs used to calculate the incident-free dose to the population. The accident frequency data used in the analysis were based on a review of local or state-specific accident data (Saricks and Kvitek 1994). The Hanford Site accident rates (expressed as accidents/km) used in this analysis were taken from Bergsman et al. (1995) The accident rate used for truck shipments is 8.86×10^{-8} accidents/km (5.50×10^{-8} accidents/mi). The radiological impacts to the public (including non-involved

Hanford Site workers) associated with truck transportation accidents are estimated to be less than 0.65 person-rem (0.0065 person-Sv).

The maximum dose to an individual was calculated for a bounding accident that could occur during shipment of the TPBARs between Hanford and ANL-W. An accident during that portion of the shipments could potentially involve all 32 irradiated TPBARs; any other shipment would involve a smaller number. For accidents outside of DOE facility boundaries, an individual at 100 m from the release was evaluated. For accidents within DOE facility boundaries, the minimum distance to the Hanford Site boundary from the 325 Building (580 m or 0.36 mi) was evaluated as a bounding case (distances between ANL-W and the INEEL boundary are substantially greater). Assumptions related to this analysis are detailed in Appendices C and D. The estimated doses for such an event would be 3,100 mrem (0.031 Sv) to an individual at 100 m, and 160 mrem (0.0016 Sv) to the offsite receptor at 580 m (0.36 mi). As noted at the beginning of this section, the NRC-certified Type B casks are designed to prevent release of radioactive materials under conditions encountered in most transportation accidents. The frequency of an event severe enough to result in substantial tritium releases during the round trip between Hanford and ANL-W was estimated to be less than 2×10^{-5}. Because the TPBARs are designed to retain tritium even under severe conditions, accidents that would involve both extensive mechanical damage and a fire of sufficient duration and intensity to release greater quantities of tritium would be considered incredible (that is, they would have an estimated frequency lower than 1×10^{-7}, or 1 in 10 million).

5.5.2.2 Nonradiological Impacts to the Public from Transportation Accidents

Potential nonradiological accident impacts consist of fatalities resulting from vehicular accidents involving the shipments. The fatalities are due to vehicle crashes with solid objects, rollovers, or collisions. Impacts to the public, i.e. individuals on or immediately adjacent to roadways, have been estimated using unit risk factors (i.e., fatalities per kilometer). It is assumed that a vehicle accident that would result in a release from a shipping cask would also result in crew fatalities; therefore, nonradiological vehicular accident impacts are calculated for the public only. No impacts to the public are associated with the transport of the unirradiated and irradiated TPBARs, TPBAR-LTAs, and integrated assemblies (i.e., less than 6.1×10^{-4} acute fatalities).

5.6 Health and Safety

The consequences of the Proposed Action in terms of health and safety are discussed in this section, and are based in part on the potential impacts identified in sections 5.1 through 5.5. The methods used to estimate health consequences are described in section 5.6.1. The expected nature and magnitude of the consequences for workers and for the public are discussed in sections 5.6.2 and 5.6.3, and a summary of the health consequences appears in section 5.6.4.

5.6.1 Basis for Health and Safety Consequences

The methods used to estimate health consequences of the Proposed Action are discussed in the following sections. Given the nature of the Proposed Action, the potential health consequences include those that might result from radionuclide emissions during irradiation and laboratory examination of the TPBARs, direct radiological exposures to workers and the public from transportation or laboratory activities, and potential radiological and nonradiological accidents associated with transportation and laboratory activities.

5.6.1.1 Basis for Radiological Health Consequences

Estimates of consequences from radiological exposures to workers and the public are based on recommendations of the International Commission on Radiological Protection (ICRP 1991). The

consequences in terms of latent cancer fatalities and total detrimental health effects are presented in Table 5.2 for both adult workers and the general population. The total incidence of detrimental health effects includes both fatal and nonfatal cancers and severe hereditary effects. The higher rates for health effects in the general population account for the presence of more sensitive individuals, such as children, compared with the relatively homogeneous population of healthy adults in the work force.

Table 5.2 Summary of Basis for Health Consequences from Radiological Exposures (from ICRP 1991)

Type of Effect	Effects per Unit Radiation Dose[a]	Radiation Dose to Produce 1 Effect[a]
Latent Cancer Fatality		
Adult Workers	4×10^{-4} /person-rem	2500 person-rem
General Population	5×10^{-4} /person-rem	2000 person-rem
Total Detriment [b]		
Adult Workers	5.6×10^{-4} /person-rem	1800 person-rem
General Population	7.3×10^{-4} /person-rem	1400 person-rem

[a] These estimates include a reduction factor of 2 to account for the lower risk of low dose, low dose rate exposures as discussed in ICRP (1991). To convert person-rem to person-Sv, multiply by 0.01.
[b] Total Detriment includes fatal and nonfatal cancers and severe hereditary effects.

The ICRP estimates are based on radiation exposures to populations at higher doses and dose rates, and by different pathways, than those normally encountered in the environment. As a result, the health effects coefficients in Table 5.2 are presented in terms of collective dose to a relatively large population. Collective dose is defined as the sum of doses to all individuals in the population, who may exhibit a wide range of susceptibility to radiation-induced health effects. The health effects coefficients are therefore associated with substantial uncertainty when applied to dose estimates for individuals, whose sensitivity may differ from the population average. However, the assumptions used to develop the health effects coefficients are sufficiently conservative that they would be "unlikely to underestimate the risks" (ICRP 1991).

Risk, as defined for this analysis, refers to the potential health consequences of an activity to a population or an individual weighted by the frequency with which that activity or event is expected to occur. Estimates of the latent cancer fatality (LCF) risk associated with routine operations assume that the consequences would occur; that is, the events that produce the dose to an individual or population have an expected frequency of 1.0. In the case of accidents, the risk of LCF incorporates the expected frequency of the event that produces a potential dose. Therefore, the risk for radiological accidents is numerically equal to the hypothetical dose to an individual or population (if the event occurs) multiplied by the health effects coefficient and the estimated event frequency. Risks for accidents are reported per year of operation where the exact duration of the proposed action is not known.

5.6.1.2 Basis for Nonradiological Health Consequences

Consequences to workers and the public from exposure to hazardous process chemicals were not evaluated in detail for the Proposed Action because the activities that would be conducted do not require sufficient quantities of such materials to present a substantial risk. Nonradiological risks from incident-free transportation are based on human health impacts from vehicular emissions, and those from transportation accidents are based on traffic statistics specific for the states and population densities along the proposed transportation routes as described in Section 5.5.

Nonradiological risks to workers from occupational illness or injury are based on statistics for DOE and DOE contractor experience (DOE 1996). The average "total recordable case rate" for the years 1990-1994 was 4.1 per 200,000 worker hours. Using the standard assumption for DOE and contractors of 1830 hours per year for a full-time-equivalent worker (FTE), the average total recordable case rate amounts to about 0.038 per FTE, or about 1 for every 27 FTEs. The rates were somewhat higher for construction activities, which accounted for about 18% of the reportable cases and about 10% of the work force in 1995 (or about 1 case per 15 FTEs). Total recordable cases include all work-related deaths, illnesses, and injuries that impair worker performance or require medical treatment beyond first aid. Of DOE's total recordable cases in 1995, 0.06% were fatalities, 45% were lost workday cases, and slightly less than 55% were nonfatal cases without lost work time.

5.6.2 Worker Health and Safety Consequences of the Proposed Action

Radiological doses to workers during activities associated with the Proposed Action would not be expected to change substantially compared with those that the involved workers would typically receive during the course of their activities at all facilities. All of the proposed activities would be conducted to maintain worker radiation doses "as low as reasonably achievable" (ALARA).

Preparation of integrated assemblies at the Westinghouse fuel fabrication facility could be associated with radiological exposure to workers, but the exposures would be the same as those for production of standard fuel assemblies and would not increase measurably for assemblies containing the TPBARs.

During refueling, workers at WBN would handle the integrated assemblies and TPBAR-LTAs in a manner similar to standard fuel and absorber assemblies and would not likely receive an increased dose from that activity. Tritium released from TPBARs to the reactor coolant during irradiation may result in exposure to workers during refueling (Erickson et al 1997); however, the doses from evaporation of cooling water in the area around the spent fuel pool are expected to amount to less than 2 mrem (2×10^{-5} Sv). The risk of LCF associated with that incremental dose is less than 8×10^{-7}. Preparing the TPBAR-LTAs for return shipment to Hanford may involve some worker exposures, but these are not expected to increase the total exposure workers receive during the course of their typical activities at the plant. Transportation workers are expected to accumulate a collective dose of less than 0.9 person-rem (0.009 person-Sv) during shipments associated with the Proposed Action (see Section 5.5.1.1).

Worker exposures during PIE activities are likely to be the largest source of occupational dose associated with the Proposed Action, although this work would take place in shielded facilities designed to provide protection from high-activity radionuclide sources. Radiological doses to DOE workers are limited to 5 rem/yr (0.05 Sv/yr) EDE by standards in 10 CFR Part 835, and in practice they are typically controlled to 0.5 rem/yr (0.005 Sv/yr) by site-specific administrative procedures unless special justification and approval are obtained. During 1995, the collective dose to workers in the 325 Building laboratories, including the shielded facilities, was about 10 person-rem (0.10 person-Sv), or an average of 0.1 rem/y (0.001 Sv/yr) for the 100 workers employed in the facility. The 325 Building average worker dose was similar to the Hanford Site average for workers with a measurable (i.e., non-zero) dose during 1995, which was 0.12 rem (0.0012 Sv). Assuming that the 6-8 workers performing PIE experience similar radiological doses, their collective dose would be less than 1 person-rem/yr (0.01 person-Sv/yr). The collective radiological doses to workers during neutron radiography and those resulting from construction of the hot cell access port are also expected to be less than 1 person-rem.

The total collective dose to all workers directly associated with the Proposed Action (including transportation, irradiation, construction, and PIE) is estimated to amount to less than 3 person-rem (0.03 person-Sv). Therefore the maximum LCF risk for involved workers would be about 0.001, or 1 in 800, and the total collective dose is well below the 1800 person-rem (18 person-Sv) that might result in long-term health effects in a worker population. Exposures to noninvolved (co-located) workers could result

from air emissions during PIE activities, but the collective doses would be much smaller than those for directly involved workers. The individual doses to a co-located worker would typically be lower than that estimated for an offsite resident. As a result, these exposures are not likely to contribute to the overall risk associated with the Proposed Action.

The risk to an individual onsite worker from radiological accidents evaluated for WBN and the PIE laboratories, as described in section 5.4, is lower than 1 in 10,000. The risks associated with specific events are listed in Section 5.6.4, Table 5.3.

Transportation accident statistics are based on total fatality rates per mile traveled over the likely transport routes. Therefore, the risk of fatality among transportation workers from vehicle accidents during shipments associated with the Proposed Action would be bounded by the risk estimated for members of the public in section 5.5.2.2 (6×10^{-4} or 1 in 1600).

The risk of occupational injury or illness to facility workers is based on the labor requirements for the Proposed Action and recordable case rates for DOE contractors. The labor requirements for PIE are estimated at about 20 FTEs, of which about 5 FTEs would be involved in construction activities. Other activities associated with the Proposed Action are not expected to increase labor needs relative to current employment at the participating facilities. The labor requirements for the Proposed Action are below the DOE average 27 FTEs overall or 15 FTEs for construction that correspond to one recordable case of occupational injury or illness. Therefore, at most, one recordable case might occur during the project activities, and it is most likely to be a relatively minor event that does not result in lost work time.

5.6.3 Public Health and Safety Consequences of the Proposed Action

Government agencies have increasingly attempted to enact regulations governing use and emissions of potentially hazardous materials in which the standards are based on risk to members of the public. For radiological exposures, the maximum regulatory limits established by these agencies generally correspond to a risk of LCF on the order of 1 in 10,000 to 1 in 1,000,000 for an "average" member of the population. Therefore, activities that operate within these limits would result in risks that are no greater than those associated with the risk-based standards. The DOE regulatory standard of 100 mrem/yr (0.001 Sv/yr) maximum dose to a member of the public from normal operations results in an estimated risk of LCF equal to about 1 in 20,000. The more restrictive 10 mrem/yr (1×10^{-4} Sv/yr) EPA standard for air emissions corresponds to a maximum individual risk of 1 in 200,000, whereas the 3 mrem/yr (3×10^{-5} Sv/yr) NRC ALARA standard for liquid effluents represents an individual risk of 1 in 670,000.

The radiological consequences of the Proposed Action under normal operating conditions, as discussed in sections 5.1 and 5.2, are lower than the limits specified in applicable regulatory standards. The individual risk of LCF associated with the 0.095 mrem (9.5×10^{-7} Sv) dose from planned PIE activities (section 5.1) amounts to less than 5×10^{-8}, or 1 in 20 million. Irradiation of the TPBAR-LTAs at WBN would not be expected to increase the LCF risk to a maximally exposed member of the public (sections 5.1 and 5.2). The 3.4 person-rem (0.034 person-Sv) from incident-free transportation results in collective risks of LCF that are less than 0.002, or 1 in 600, for the entire population along the transportation routes (section 5.5).

Public consequences from potential radiological accidents at facilities, as discussed in section 5.4, result in risks to individual members of the public that are less than 1×10^{-5}, or 1 in 100,000, and collective risks that are less than 3×10^{-2} to the population within 50 miles (80km). The risks associated with specific types of events are listed in Section 5.6.4, Table 5.3. The collective risk of LCF to the population from radiological accidents along transportation routes (Section 5.5.2.1) amounts to 3×10^{-4}, or less than 1 in 3000. The individual radiological risk from a bounding credible accident during transportation (Section 5.5.2.1) would be less than 3×10^{-8}, or 1 in 30 million.

Nonradiological health consequences for the public largely result from transportation of both unirradiated and irradiated TPBAR assemblies between the facilities participating in the Proposed Action. The collective risk of fatality associated with vehicle emissions during incident-free transport amounts to less than 1 in 24,000 for the population along shipping routes (Section 5.5.1.2). The risk of fatality from vehicle accidents would be about 1 in 1600 for the same population (Section 5.5.2.2).

5.6.4 Summary of Health and Safety Consequences of the Proposed Action

Table 5.3 contains a summary of the potential health and safety consequences of the Proposed Action, as described in sections 5.1 through 5.6.3.

Table 5.3 Summary of Health and Safety Consequences of Proposed Action

Activity or Event	Units of Measure	Consequences/Risk of Activity or Event[a]	Estimated Frequency (yr^{-1}) or Probability of Event
Air Emissions (Section 5.1)			
- Planned PIE			1.0
Offsite Individual Dose	mrem	9.5×10^{-2}	
Offsite Individual Risk	LCF	5×10^{-8}	
Offsite Collective Dose	person-rem	4.1×10^{-1}	
Offsite Collective Risk	LCF	2×10^{-4}	
- Maximum PIE			1.0
Offsite Individual Dose	mrem	3.3×10^{-1}	
Offsite Individual Risk	LCF	2×10^{-7}	
Offsite Collective Dose	person-rem	1.4×10^{0}	
Offsite Collective Risk	LCF	7×10^{-4}	

Activity or Event	Units of Measure	Consequences/Risk of Activity or Event[a]	Estimated Frequency (yr^{-1}) or Probability of Event
Transportation (Section 5.5)			
- Incident-Free Transport (Section 5.5.1)			
Collective Dose to Crew	person-rem	9.0×10^{-1}	1.0
Collective Risk to Crew	LCF	4×10^{-4}	
Collective Dose to Public	person-rem	3.4×10^{0}	
Collective Risk to Public	LCF	2×10^{-3}	
Non-radiological Public Risk (Vehicle Emissions)	Fatality (all causes)	4×10^{-5}	
- Transportation Accidents (Section 5.5.2)			
Collective Dose to Public	person-rem	6.5×10^{-1} [c]	[c]
Collective Risk to Public	LCF	3×10^{-4}	
100-m Individual Dose	mrem	3.1×10^{3}	$<2 \times 10^{-5}$
Individual Worker Risk	LCF	$<2 \times 10^{-8}$	
Individual Public Risk	LCF	$<3 \times 10^{-8}$	
Offsite Individual Dose	mrem	1.6×10^{2}	$<2 \times 10^{-5}$
Offsite Individual Risk	LCF	$<2 \times 10^{-9}$	
Non-radiological Public Risk (Transportation Accidents)	Acute Fatality	6×10^{-4}	[d]

Activity or Event	Units of Measure	Consequences/Risk of Activity or Event[a]	Estimated Frequency (yr^{-1}) or Probability of Event
Facility Accidents (Section 5.4)			
- Irradiation - TPBAR Breach			[b]
Onsite Individual Dose	mrem	$<5.0 \times 10^{1}$	
Onsite Individual Risk	LCF	$<2 \times 10^{-5}$	
Offsite Individual Dose	mrem	1.3×10^{-2}	
Offsite Individual Risk	LCF	$<6 \times 10^{-9}$	
- PIE - TPBAR Breach			1×10^{-2} to 1.0
Onsite Individual Dose	mrem	3.5×10^{0}	
Onsite Individual Risk	LCF	$<1 \times 10^{-6}$	
Offsite Individual Dose	mrem	4.0×10^{-1}	
Offsite Individual Risk	LCF	$<2 \times 10^{-7}$	
Offsite Collective Dose	person-rem	1.4×10^{0}	
Offsite Collective Risk	LCF	$<7 \times 10^{-4}$	
- PIE - Localized Fire			$<5 \times 10^{-2}$
Onsite Individual Dose	mrem	2.5×10^{3}	
Onsite Individual Risk	LCF	$<1 \times 10^{-4}$	
Offsite Individual Dose	mrem	2.9×10^{2}	
Offsite Individual Risk	LCF	$<1 \times 10^{-5}$	
Offsite Collective Dose	person-rem	1.1×10^{3}	
Offsite Collective Risk	LCF	$<3 \times 10^{-2}$	
- PIE - Severe Earthquake + Fire			1×10^{-6} to 1×10^{-4}
Onsite Individual Dose	mrem	1.4×10^{4}	
Onsite Individual Risk	LCF	$<6 \times 10^{-7}$	
Offsite Individual Dose	mrem	1.6×10^{3}	
Offsite Individual Risk	LCF	$<8 \times 10^{-8}$	
Offsite Collective Dose	person-rem	5.8×10^{3}	
Offsite Collective Risk	LCF	$<3 \times 10^{-4}$	

Activity or Event	Units of Measure	Consequences/Risk of Activity or Event[a]	Estimated Frequency (yr^{-1}) or Probability of Event
Worker Health and Safety (Section 5.6.2)			
- Irradiation			1.0
Individual Worker Dose	mrem	<2	
Individual Worker Risk	LCF	$<8 \times 10^{-7}$	
- PIE			1.0
Individual Worker Dose	mrem	<500	
Individual Worker Risk	LCF	$<2 \times 10^{-4}$	
Collective Worker Dose	person-rem	<3	
Collective Worker Risk	LCF	$<1 \times 10^{-3}$	
Non-radiological Worker Risk (Occupational Accidents & Illness)	Recordable Cases	<1	3.8×10^{-2} per FTE[e]

[a] Risk is defined as the consequence of an event or activity, if the event occurs, multiplied by the expected frequency of the event. Radiological doses are converted to risk of LCF using the method described in Section 5.6.1. The total risk from all long-term health effects (including both fatal and non-fatal cancers and hereditary effects) is less than 1.5 times the risk of LCF. Risks are calculated on a per year of operation basis.

[b] The estimated frequency of a TPBAR breach during irradiation is not known, but is assumed to be less than 1/yr for risk estimates.

[c] The transportation accident dose calculated by RADTRAN is the sum of doses for each accident severity category weighted by the expected frequency of accidents in each category over the entire transport distance.

[d] The risk of fatality from vehicle accidents is based on the combined frequencies of traffic fatalities for each state and population zone weighted by the number of miles traveled in each zone.

[e] The frequency of occupational accidents and illnesses is based on the recordable case rate for DOE and contractors

5.7 Other Environmental Impacts

The types of environmental impacts for which the Proposed Action is expected to have minimal, if any, consequences are discussed in this section. The types of impacts in this category include those on land use, socioeconomics, cultural resources, aesthetic and scenic resources, geologic resources, ecological resources, noise, and site services.

5.7.1 Land Use

No new facilities would be constructed for the Proposed Action at any of the locations involved. Only minor modifications would be made to the Hanford Site 325 Building to accommodate transfer of the TPBARs and TPBAR-LTAs into the hot cells. The modifications would not affect present or future land use in the surrounding area.

5.7.2 Socioeconomics

The number of employees participating in the Proposed Action would be relatively small and would utilize existing staff at all of the facilities involved. Therefore, impacts on the local economy or community infrastructure at these locations would be negligible.

5.7.3 Cultural Resources

The Proposed Action would not involve excavation in previously undeveloped areas of the participating sites. Therefore, the opportunity to discover artifacts that might be of cultural or archeological significance is very low. If items of potential significance were discovered, work at the site would be suspended; and the disposition of the find would be determined in consultation with representatives of appropriate cultural groups and regulatory agencies.

The Hanford Site 325 Building played an important role in its association with nationally significant Cold War era activities such as pioneering programs in chemical separations, waste management and vitrification, and other radiochemistry projects. Thus, DOE has concluded that Building 325 is eligible for inclusion in the National Register of Historic Places under criterion A as a contributing property within the Hanford Site Manhattan Project and Cold War Historic District.

In the Programmatic Agreement among the U. S. Department of Energy Richland Operations Office, the Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office for the Maintenance, Deactivation, Alteration, and Demolition of the Built Environment on the Hanford Site, Washington, Building 325 is listed as a contributing property to the historic district and is recommended for mitigation under the Sitewide Treatment Plan. Any modifications to this facility included in the Proposed Action would be performed in accordance with the National Historic Preservation Act and guidance from the state historic preservation officer to preserve information that might be of historic value.

5.7.4 Aesthetic and Scenic Resources

None of the proposed activities would require extensive construction of facilities or infrastructure that might impact scenic resources, nor would they result in air emissions that could affect visibility. The program would, therefore, have no effects on aesthetic or scenic resources.

5.7.5 Geologic Resources

The Proposed Action would not require use of scarce geologic resources for which there are competing uses, nor would they involve activities that might make valuable resources unavailable for other uses.

5.7.6 Ecological Resources

The Proposed Action would not require construction of new facilities or infrastructure at any of the participating sites, except for minor modifications to the Hanford Site 325 Building, as discussed previously. No areas designated as flood plains, wetlands, or other sensitive natural habitats would be affected by the Proposed Action. Therefore, the potential impact on ecological resources is minimal.

A biological survey of the 325 Building vicinity was conducted on May 21, 1996 (See Appendix B). The area has been previously disturbed and exhibits characteristics typical of disturbed areas. The surrounding substrate consists primarily of packed gravel and pavement, supporting sparse amounts of cheat grass (Bromos tectorum) and Russian thistle (Salsola kali). No migratory birds were observed in the project area. The minimal activity that would be involved in any modifications to the 325 Building during the proposed activities, along with the absence of unique or sensitive ecological resources in this developed area of the Hanford Site, makes any substantial consequences to plant or animal populations unlikely.

5.7.7 Noise

The Proposed Action would not generate large volumes of traffic at any of the participating sites, nor would they involve noise-generating equipment other than that associated with normal operation of the facilities. Therefore the program would not result in an increased noise level at any location.

5.7.8 Site Services

The Proposed Action would not involve activities that require large quantities of power, process heat, fossil fuels, or water. Therefore, use of site services at any of the participating facilities would not be expected to change substantially as a result of the Proposed Action.

5.8 Environmental Justice

Impacts of the Proposed Action on ethnic or low-income groups in the surrounding area were considered in this assessment. An evaluation of environmental justice impacts of proposed federal actions, as required by Executive Order 12898, must consider a range of factors that may place disproportionate adverse environmental impacts on minority and low-income populations. Although the executive order does not directly apply to the TVA, that agency typically includes an evaluation of potential impacts on low income and minority populations in conducting its NEPA reviews. Environmental justice impacts from the Proposed Action considered in this EA are not expected to result in either disproportionate adverse human health risks from exposure to radiation or hazardous chemicals or disproportionate adverse socioeconomic impacts to minority or low-income segments of the community.

Compared with the average for the State of Tennessee, WBN is located in a predominately non-minority, low-income area (NRC 1995). Although nearby low-income residents would experience greater exposure to facility effluents, the operational impacts of the Proposed Action are not expected to result in health consequences to even the most exposed individuals (See sections 5.1 through 5.6). Therefore, the surrounding populations would not be expected to suffer adverse and disproportionate consequences as a result of the plant's routine operation or of the Proposed Action considered in this EA. Minority population centers are generally at a greater distance from the facility, therefore it is unlikely that they would be disproportionately affected by the Proposed Action, whether adverse or beneficial.

Minority populations and low-income populations are present in some locations near the Hanford Site. However, the demographic composition in the areas that would receive the greatest exposure to routine effluents from the 325 Building activities (east and south of the 300 Area) are generally comparable to those of the surrounding counties and the State of Washington. (Neitzel 1996). The Proposed Action is not expected to have substantial impacts in terms of routine radiological or hazardous effluents; therefore, there would be no opportunity for disproportionate and adverse impacts on minority or low-income groups in the surrounding population.

Accidental radionuclide emissions during irradiation of TPBAR-LTAs at WBN, neutron radiography of the TPBARs at ANL-W, or PIE activities at Hanford could disproportionately affect minority or low-

income populations adjacent to those facilities, depending on atmospheric conditions prevailing at the time of the event. However, the consequences of those events, other than the extremely low-frequency accidents, are generally within the regulatory standards for routine operations. The probability that such events would have disproportionate adverse impacts on minority or low-income populations is therefore very low, and is not expected to differ from the likelihood of potential impacts on other segments of the population.

5.9 Cumulative Impacts

Cumulative impacts of the Proposed Action and other anticipated or ongoing actions are estimated for those categories of environmental effects where the Proposed Action might represent an identifiable increase compared with current or future activities. Cumulative impacts are not discussed for the types of consequences that would not change substantially as a result of the Proposed Action. The types of impacts for which cumulative effects could occur include emissions to air or water, waste, transportation, and health and safety of workers and the public.

5.9.1 Cumulative Impacts on Air Quality

The only emissions that could have a cumulative effect on air quality are tritium emissions associated with PIE of the TPBARs at Hanford. About 1700 Ci of tritium could be released in emissions from the 325 Building stack over the course of the planned PIE activities, and up to 6000 Ci might be associated with the maximum Proposed Action (see Table 5.1). For comparison, 6.6 Ci of tritium were discharged from Hanford facilities during 1995 (Dirkes and Hanf 1996).

The dose to a maximally exposed member of the public from the potential tritium emissions could range from 0.095 to 3.3 mrem (9.5×10^{-7} to 3.3×10^{-5} Sv, see Table 5.1), compared to the 1995 dose from air emissions (0.0065 mrem [6.5×10^{-8} Sv]) or the total dose (0.023 mrem [2.3×10^{-7} Sv]) from Hanford Site activities during 1995 (Dirkes and Hanf 1996). However, planned PIE activities would amount to less than 1% of the 10 mrem/yr (1×10^{-4} Sv/yr) standard for air emissions from DOE facilities, and the dose from the maximum potential emissions would represent less than 3.3% of the standard (Table 5.1). The Proposed Action would not likely all take place during a single year, thereby lowering the relative annual contribution. In addition, these activities would not continue over the long-term, and any cumulative impacts in conjunction with future research, waste management or remediation activities at the site would be temporary.

The collective dose from air emissions to the population within 50 mi (80 km) of the Hanford Site from planned PIE activities (0.41 person-rem) or maximum PIE (1.4 person-rem) is comparable in magnitude to the dose from Hanford operations in recent years (0.5 to 1 person-rem/yr, Dirkes and Hanf 1996). Therefore if the PIE activities were conducted within a period of 1 year, the collective dose to the population surrounding Hanford might increase by a factor of 2-3. However, the collective dose from Hanford Site activities is much lower in recent years than during the peak years of its defense mission, and the additional dose from PIE would be inconsequential compared with 100,000 person-rem from past site operations (TSP 1994). The collective dose from PIE would also be much lower than the dose from natural background radiation to the population surrounding the site, which amounts to 85,000 person-rem/yr.

Routine air emissions of radionuclides are not anticipated during other activities associated with the Proposed Action, nor would emissions of nonradiological air pollutants increase at any location where these activities take place. Therefore, there would be no potential for cumulative impacts associated with air emissions at locations other than the Hanford Site.

5.9.2 Cumulative Impacts on Water Quality

The maximum estimated tritium emissions to surface water during irradiation of TPBAR-LTAs at WBN (less than 214 Ci/yr) would increase the normal operating emissions of that radionuclide by less than 20%, compared with the estimated 1300 Ci annual emissions under typical operating conditions (see section 4.3 and NRC 1995). The estimated dose to a maximally exposed individual downstream from the TPBAR emissions would not measurably increase the 0.7 mrem/yr (7.0×10^{-6} Sv/yr) routine dose from the reactor's liquid effluents (see Section 5.2). Routine liquid effluents from other activities associated with the Proposed Action are not expected.

5.9.3 Cumulative Impacts on Waste

The maximum quantity of low-level radioactive waste that might be disposed of at Hanford as a result of the Proposed Action (approximately 220 m^3 or 290 yd^3, including eventual disposal of contaminated equipment) is a very small fraction of the 89,000 m^3 (120,000 yd^3) of low-level waste currently awaiting disposition or that is expected to be generated over the next 20 years at the site (DOE 1997). No impacts on site waste disposal capabilities are expected. The quantities and persistence of radionuclides in the waste are such that no impact of waste disposal on groundwater or surface water is expected.

Quantities of mixed or hazardous waste are expected to be small compared with those of low-level radioactive waste and, likewise, would not affect overall site waste management capacity for those waste types. To minimize their future impact on the environment, all hazardous and radioactive wastes would be disposed of according to state and federal regulations.

The quantities of wastes generated at locations other than Hanford are much smaller than the volumes of waste typically handled at those facilities, and are not expected to impact waste management practices at those facilities.

5.9.4 Cumulative Impacts on Transportation

The radiological consequences of transportation to the transport crew and the public, 0.9 and 3.4 person-rem (0.009 and 0.034 person-Sv), respectively, are very small compared with other ongoing or anticipated transportation activities such as those associated with activities regulated by the NRC (5600 person-rem/yr [56 person-Sv/yr] to workers and 4200 person-rem/yr [42 person-Sv/yr] to the public) or by DOE shipments to a geologic repository (up to 8600 person-rem [86 person-Sv] to workers and 48,000 person-rem [480 person-Sv] to the public) (DOE 1995b). The risk of LCF from transportation accidents is much less than one over the course of the Proposed Action, which represents a negligible increase in the risk of such events over the routes that would be used.

Non-radiological transportation impacts resulting from vehicle emissions or transportation accidents are not anticipated to increase because of the Proposed Action.

5.9.5 Cumulative Impacts on Health and Safety

The risk of LCF from routine radiological exposures to both workers and the public is much less than one, and the small increase in risk would not be observable against the background of natural cancer cases, which averaged 173 per 100,000 nationwide in 1996 (ACS 1996). The risk to the public associated with routine activities is also generally lower than that from exposure to natural background radiation, which averages about 300 mrem/yr to an average individual (1 in 7000 risk of LCF).

The collective radiation dose to workers from routine activities, expected to be less than 3 person-rem (0.03 person-Sv), is much lower than the estimated annual collective dose to workers at WBN (190 person-

rem/y [1.9 person-Sv/yr], NRC 1995) or the Hanford Site (290 person-rem [2.9 person-Sv] in 1995) and would not be expected to increase the risk to workers at those facilities.

5.10 Impacts of Alternatives to the Proposed Action

The consequences of alternatives to the Proposed Action are discussed in this section. Alternatives that were considered include: no action, use of alternate reactors to irradiate the TPBAR-LTAs, use of alternate DOE laboratories to perform the PIE, and use of non-government facilities for examination of the TPBARs. In general, the types of activities described for the Proposed Action would also be conducted under each of the alternatives, except that none of the activities would be conducted under the no-action alternative. The potential impacts associated with each alternative are discussed in the following sections.

5.10.1 No-Action Alternative

Under the no-action alternative by definition the Proposed Action would not take place. The major impacts of this alternative would be programmatic, in that information obtained by the irradiation and examination of the TPBARs would not be available. Lack of that data would impair DOE's ability to make decisions related to long-term options for tritium production as described in the programmatic EIS for tritium supply and recycling (DOE 1995a). As part of the Record of Decision for that EIS, DOE decided to pursue a dual track strategy for maintaining the supply of tritium for defense purposes and would evaluate tritium production using either an accelerator or a CLWR. The Proposed Action would aid in establishing whether the latter option might prove feasible as a long-term source of tritium.

Because the environmental impacts of the Proposed Action are minimal, the environmental risks would not change substantially if these activities were not performed. The operations and environmental impacts associated with each of the sites and facilities under consideration would remain as described in section 4 of this EA.

5.10.2 Use of an Alternate Reactor for Irradiation of the TPBAR-LTAs, or Use of Alternate DOE Laboratories for Examination of the TPBARs

A number of commercial reactors similar in design to WBN are currently operating in the United States, and could potentially be used for the proposed tests. However, these facilities would not provide the optimal schedule for conducting the tests, and the managing utilities may not be willing to participate in the project. Use of an alternate facility for the irradiation task could result in a delay in obtaining the information needed to make a timely decision regarding options for tritium production and would substantially increase costs. Restrictions by some commercial fuel vendors on use of their products for weapons-related research would also preclude use of reactors that obtain their fuel from those suppliers. The environmental impacts of the tests would be very similar at any facility of comparable design and would only differ to the extent that the size and location of the surrounding population may affect the consequences to a maximum individual or the collective population.

Examination of the TPBARs at an alternate DOE facility would necessitate transferring technology that is currently in use at the proposed facilities and could therefore result in delays and additional costs in performing the tests. As with an alternate reactor location, the types of activities to be performed at the alternate facilities would be the same as those proposed, and the environmental impacts would depend on their location relative to the surrounding residents. To the extent that relocating the PIE tasks might involve facility modifications or new construction, the environmental consequences would be greater than those associated with using the proposed existing facilities.

5.10.3 Use of Non-DOE Facilities for Examination of the TPBARs

The feasibility of using non-government facilities to examine the TPBARs is limited by the security needed to perform classified work for the DOE. Implementing appropriate procedures and obtaining security clearances would delay the conduct of the proposed tests, as would the need to transfer the technology and equipment required to perform them. Few facilities are equipped to handle the quantities of radioactive materials that would be generated during irradiation of the TPBARs, and relocation of the examination task would likely necessitate construction of new facilities or extensive modification of existing laboratories.

6.0 Permits and Regulatory Requirements

It is the policy of DOE to carry out its operations in compliance with all applicable federal, state, and local laws and regulations, Presidential Executive Orders, and DOE Orders. The Proposed Action would follow pollution prevention requirements under *Executive Order 12856: Federal Compliance with Right-To-Know Laws and Pollution Prevention Requirements.*

Environmental regulatory authority over the Hanford Site is vested in federal and Washington State agencies. The Proposed Action would comply with applicable regulations and requirements. Prior to receipt of the TPBAR-LTAs, a Notice of Construction may need to be submitted to the State of Washington Department of Health for modification to the air permit that the 325 Building is operating under. Additional information on laws and regulations applicable to DOE actions at Hanford is detailed in Neitzel (1996).

Placement of the TPBAR-LTAs in WBN will require that the TVA submit a license amendment request to the NRC. The purpose of the license amendment is to obtain NRC review and approval of the use of TPBARs in WBN prior to the actual placement of the TPBARs in the reactor. The process used by the NRC to grant this approval is through an amendment to the facility operating license (through the plant Technical Specifications, which are incorporated in the license).

7.0 Agencies Consulted

This environmental assessment was sent to the following for a 15-day review period:

- Nez Perce Tribe
- the Confederated Tribes of the Umatilla Indian Reservation
- the Wanapum
- the Yakama Indian Nation
- State of Idaho
- State of Tennessee
- State of Washington
- City of Richland, Washington
- Benton County, Washington
- U.S. Fish and Wildlife Service
- U.S. Nuclear Regulatory Commission
- Other Interested Parties

The TVA was cooperating agency with DOE in preparation of this EA in anticipation of its application to NRC for amendment of the WBN operating license, as discussed in Section 6.0.

During preparation of the draft EA, a comment letter prepared by the Yakama Indian Nation was received. The letter requested that an environmental impact statement (EIS) be prepared. This comment and any comments received during the review period of this document were considered by DOE in making a determination to proceed with an EIS or in making a finding of no significant impact (FONSI).

A comment letter from the State of Washington, Department of Ecology, was received during the 15 day comment period. The comment letter requested that the proposed activities be conducted in a manner that supports the work and schedules identified in the Hanford Federal Facility Agreement and Consent Order. The activities proposed will be conducted in accordance with the agreement and Consent Order.

A comment letter was also received from the State of Tennessee. The comment letter asked for clarification on the specific performance of the TPBARs. Much of the information requested is contained in the Erickson, et al 1997 reference cited in the document and was provided to the State of Tennessee in a response letter.

8.0 References

10 CFR 1021.1996, "National Environmental Policy Act; Implementing Procedures and Guidelines," *Code of Federal Regulations*, as amended.

60 FR 63877-63891. December 12, 1995. U.S. Department of Energy. "Record of Decision: Selection of Tritium Supply Technology and Siting of Tritium Supply and Recycling Facilities." *Federal Register*.

Executive Order 12856. *Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements.*

American Cancer Society (ACS). 1996. "Cancer Facts and Figures 1996." American Cancer Society, Atlanta, Georgia.

Atomic Energy Act of 1954, 42 USC 2011 et seq.

Bergsman, K.E, T.B Bergman, D.W. Bergmann, G.E. Costley, M.T. Jansky, M. Kummerer, R.L. McCormack, M.J. Monthey, A.N. Praga, I.K. Ullah, W.L. Willis, and A.G. Hosler. 1995. *K Basin Environmental Impact Statement Technical Input.* WHC-SD-SNF-TI-013, Rev. 0. Westinghouse Hanford Company, Richland, Washington.

Brown, R. M., G. L. Ogram, and F.S. Spencer. 1990. "Oxidation and Dispersion of HT in the Environment: The August 1986 Field Experiment at Chalk River," *Health Phys.* 58(2):171-181.

Dirkes, R.L. and R.W. Hanf (eds). 1996. *Hanford Site Environmental Report for Calendar Year 1995.* PNNL-11139. Pacific Northwest National Laboratory, Richland, Washington.

Endangered Species Act of 1973, 16 USC 1531 et seq.

Erickson, LW, A. Lopez, E.F. Love, B.E. Schmitt, E.R. Gilbert, R.L. Van Witbeck, 1997. *Report on the Evaluation of the Tritium Producing Burnable Absorber Rod Lead Test Assembly.* PNNL-11419, Rev. 1. Pacific Northwest National Laboratory, Richland, Washington.

International Commission on Radiological Protection (ICRP). 1991. *1990 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 60, Annals of the ICRP Vol 21 (1-3), Pergamon Press, Oxford.

Johnson, P.E., D.S. Joy, D.B. Clarke, and J.M. Jacobi. 1993. *HIGHWAY 3.3, An Enhanced Highway Routing Model: Program Description, Methodology, and Revised User's Manual.* ORNL/TM-12124. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Napier, B.A., R.A. Peloquin, J.V. Ramsdell, and D.L. Strenge. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System.* PNL-6584, Vol. 1-3, Pacific Northwest Laboratory, Richland, Washington.

Neitzel, D.A. (ed.). 1996. *Hanford Site National Environmental Policy Act (NEPA) Characterization.* PNL-6415, Rev. 8. Pacific Northwest National Laboratory, Richland, Washington.

National Environmental Policy Act of 1969, 42 U.S.C. 4321 et seq.

Neuhauser, K. S., and F. L. Kanipe. 1992. *RADTRAN 4: Volume 3 -- User Guide*. SAND89-2370, Sandia National Laboratories, Albuquerque, New Mexico.

Rao, R. K., E. L. Wilmot, and R. E. Luna. 1982. *Non-Radiological Impacts of Transporting Radioactive Material*, SAND81-1703, Sandia National Laboratories, Albuquerque, New Mexico.

Saricks, C., and T. Kvitek. 1994. *Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight*. ANL/ESD/TM-68, Argonne National Laboratory, Argonne, Illinois.

Tennessee Valley Authority (TVA). 1991. *Watts Bar Nuclear Plant. Final Safety Analysis Report*. Tennessee Valley Authority, Chattanooga, TN.

Tichler, J., K. Doty, and K. Lucadamo. 1995. *Radioactive Materials Released from Nuclear Power Plants. Annual Report 1993*. NUREG/CR-2907, BNL-NUREG-51581, Vol. 14. U.S. Nuclear Regulatory Commission, Washington, D.C.

TSP (Technical Steering Panel of the Hanford Dose Reconstruction Project). 1994. *Summary: Radiation Dose Estimates from Hanford Radioactive Material Releases to the Air and to the Columbia River*. Centers for Disease Control and Prevention, Atlanta, Georgia.

U.S. Department of Energy (DOE). 1995a. *Final Programmatic Environmental Impact Statement for Tritium Supply and Recycling*. DOE/EIS-0161. U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy (DOE). 1995b. *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement*. DOE/EIS-0203-F, Volume 2, Part A. Office of Environmental Management, Idaho Operations Office, U.S. Department of Energy, Idaho Falls, Idaho.

U.S. Department of Energy (DOE). 1996. *DOE Performance Indicators for Environment, Safety and Health. Report Period Ending March 1996*. Office of Environment, Safety and Health U.S. Department of Energy, Washington, D.C. (Available on the World Wide Web at: http://www.eh.doe.gov/pi)

U.S. Department of Energy (DOE). 1997. *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*. DOE/EIS-0200-F. Office of Environmental Management, U.S. Department of Energy, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1995. *Final Environmental Statement Related to the Operation of Watts Bar Nuclear Plant, Units 1 and 2*. NUREG-0498, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1997. Safety Evaluation Report Related to the Department of Energy's Proposal for the Irradiation of Lead Test Assemblies Containing Tritium-Producing Burnable Absorber Rods in Commercial Light-Water Reactors. NUREG-1607, U.S. NRC, Washington, D.C.

Appendix A

Description of the Tritium-Producing Burnable Absorber Rod for The CLWR Lead Test Assembly

DESCRIPTION OF THE TRITIUM-PRODUCING BURNABLE ABSORBER ROD FOR THE CLWR LEAD TEST ASSEMBLY

TRITIUM TARGET QUALIFICATION PROJECT

TTQP-1-015

REVISION 0

September 1996

Authorized Derivative Classifier

E. F. Love, Jr.
Senior Development Engineer
Pacific Northwest National Laboratory
Date 9/9/96

DESCRIPTION OF THE TRITIUM-PRODUCING BURNABLE ABSORBER ROD FOR THE CLWR LEAD TEST ASSEMBLY

TRITIUM TARGET QUALIFICATION PROJECT

SEPTEMBER 1996

TTQP-1-015
Revision 0

Prepared by: E.R. Gilbert, Contractor
Mohr and Associates, Richland, Washington

Concurrence: R.S. McKee, Research Engineer — 9/9/96 Date

Approved: B.M. Durst, Task Manager
Design and Systems Engineering — 9 Sept. 1996 Date

Approved: J.L. Ethridge, Project Manager — Sept 9, 1996 Date

DESCRIPTION OF THE TRITIUM-PRODUCING BURNABLE ABSORBER ROD FOR THE CLWR LEAD TEST ASSEMBLY

ABSTRACT

This document provides an unclassified description of the Commercial Light Water Reactor (CLWR) tritium-producing burnable absorber rod (TBAR) to be irradiated in the Lead Test Assembly (LTA) for the Tritium Target Qualification Project (TTQP). This description provides information for coordination with contractors associated with the TTQP.

1.0 INTRODUCTION

The purpose of this document is to provide an unclassified description of the TBAR design for the LTA to be irradiated in a CLWR. This design is derived from the New Production Light Water Reactor (NP LWR) Target Rod [1] and has been established as the reference CLWR TBAR design for the LTA. The TBAR is intended to be similar in form and nuclear characteristics to a PWR burnable absorber rod. Materials, component specifications, performance features, and functional requirements are described in the Phase 1 Design Review Documents [2,3].

2.0 DESCRIPTION OF THE TBAR FOR THE LTA

The TBAR LTA is constructed of materials that have been chosen for their ability to perform successfully in in-reactor and ex-reactor test programs and for their compatibility with the other reactor internals, fuel assemblies, and the reactor coolant system. The TBAR LTA upper structure assembly is shown in Appendix 1 for a typical Babcock & Wilcox design used in a Westinghouse 17x17

fuel assembly. The actual LTA will utilize a standard Westinghouse design holding 32 TBAR's. The material within the absorber rods have been selected to reflect design characteristics suitable for the production of tritium. Quality standards for material selection, fabrication, and inspection will be specified to ensure that important functions are maintained.

Basically, the TBAR is of the getter-barrier type, similar in form and nuclear characteristics to a pressurized water reactor (PWR) burnable absorber rod. Lithium aluminate pellets are enriched with an appropriate density and composition of ^{6}Li atoms to produce tritium and to simulate the nuclear characteristics of a burnable absorber rod. The target rod for the CLWR production core will be designed to provide the capability for a full core production rate of tritium in a PWR type environment of at least 2 kg/y (unclassified goal) while releasing less than 20,000 Ci/y tritium to the reactor coolant. However, the primary goal of the LTA is to address institutional issues and the tritium production will be limited to 0.5 to 0.75 g of tritium per TBAR. The LTA is composed of 32 TBARs in burnable absorber rod locations. The LTA will be loaded with TBARs only and will not include other absorber rods. The design life of the TBAR is 550 equivalent full-power days (EFPD) of in-reactor operation.

An isometric section of a getter-barrier TBAR is shown in Figure 1 to illustrate the arrangement of the components. The TBAR design consists of concentric cylindrical subcomponents clad with Type 316 stainless steel (316SS). The 316 SS cladding provides structural strength to the TBAR. To prevent tritium from diffusing into the reactor coolant from the TBARs and hydrogen in the coolant from diffusing inward, the inner surface of the 316SS cladding is pack aluminized to a depth of several mils. The barrier coating must have sufficient adhesion and toughness, so as not to peel or blister during fabrication, handling, and in-reactor operations. Without this permeation-resistant barrier, hydrogen could saturate the NPZ getters, rendering them ineffective for capturing tritium.

To maintain a low partial pressure of tritium within the target rods, a getter tube composed of nickel-plated Zircaloy-4 (NPZ) surrounds the $LiAlO_2$. The getter is enclosed within the cladding. The nickel coating on the NPZ getter maintains the effectiveness for tritium absorption by preventing the formation of ZrO_2 on the surface. Tritium produced in the $LiAlO_2$ pellets is released and reacts with the NPZ getter to form solid zirconium tritide within the getter. The pressure of tritium in equilibrium with the NPZ getters at operating temperatures is low; thus, the driving force for tritium permeation through the cladding is also low. As indicated in Figure 2, an NPZ getter disk is located at the bottom of the TBAR and another in the plenum at the bottom of the compression spring located at the top of the TBAR. These two getter disks limit tritium leakage through the uncoated welds and through the top and bottom end plugs.

Because some tritium is released from the $LiAlO_2$ in the form of T_2O, a Zircaloy-4 liner is placed inside the annular $LiAlO_2$ pellets to reduce T_2O by forming an oxide on the surface of the Zircaloy-4 liner and by releasing tritium so that it can be absorbed by NPZ getter or the liner. The liner also provides mechanical support to prevent axial relocation of the $LiAlO_2$ pellet material in the event any becomes fragmented.

The tritium is produced in a stack of NPZ getter subassemblies (pencils) containing the $LiAlO_2$ pellets. The getter subassemblies permit free exchange of gas within the target rod, but limit the axial movement of $LiAlO_2$ pellet material in the event any becomes fragmented. The TBAR is designed to use the same end plugs and to be the same length and diameter of the PWR burnable absorber rods they replace.

An NPZ getter tube surrounds the compression spring at the top of the pellet column to provide additional gettering material and surface area, thus reducing the partial pressure of tritium at the top of the target rod. The compression spring is fabricated from stainless steel and is similar to

springs used for PWR fuel and burnable absorber rods. The primary function of the plenum spring is to provide an axial force to restrain the stack of getter subassemblies during handling and shipping operations, while allowing for thermal axial growth of the getter subassemblies in the reactor. For closure of the target rods, end fittings (similar to those used in burnable absorber rods) are welded to each end of the cladding tube.

3.0 REFERENCES

1. Weber, J.W. 1991. NP LWR Target Rod Design Description. WHC-SC-WNP-DB-002, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

2. Durst, B.M. December 1995. Tritium Target Qualification Program Phase 1 Design Review Plan, PNNL-TTQP-001 (CRD), Tritium Target Qualification Project, Pacific Northwest National Laboratory, Richland, Washington.

3. Durst, B.M and E.R. Gilbert. January 1996. Supplementary Information Phase 1 Design Review Plan, PNNL-TTQP-002 (CRD), Tritium Target Qualification Project, Pacific Northwest National Laboratory, Richland, Washington.

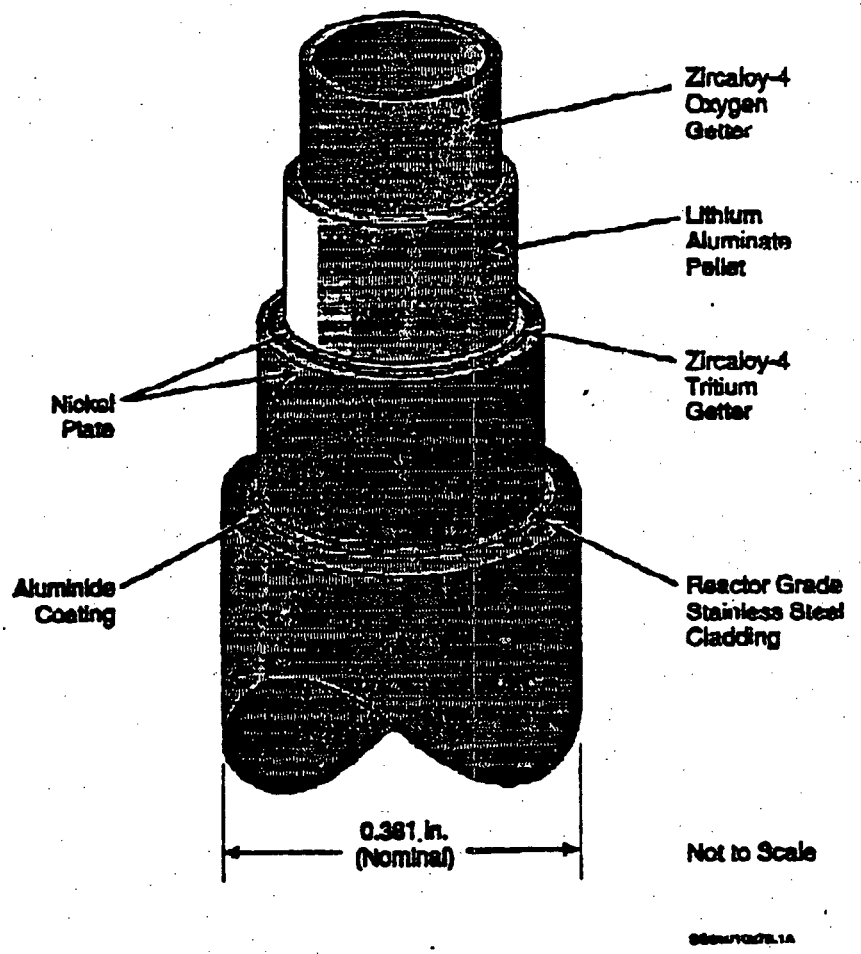
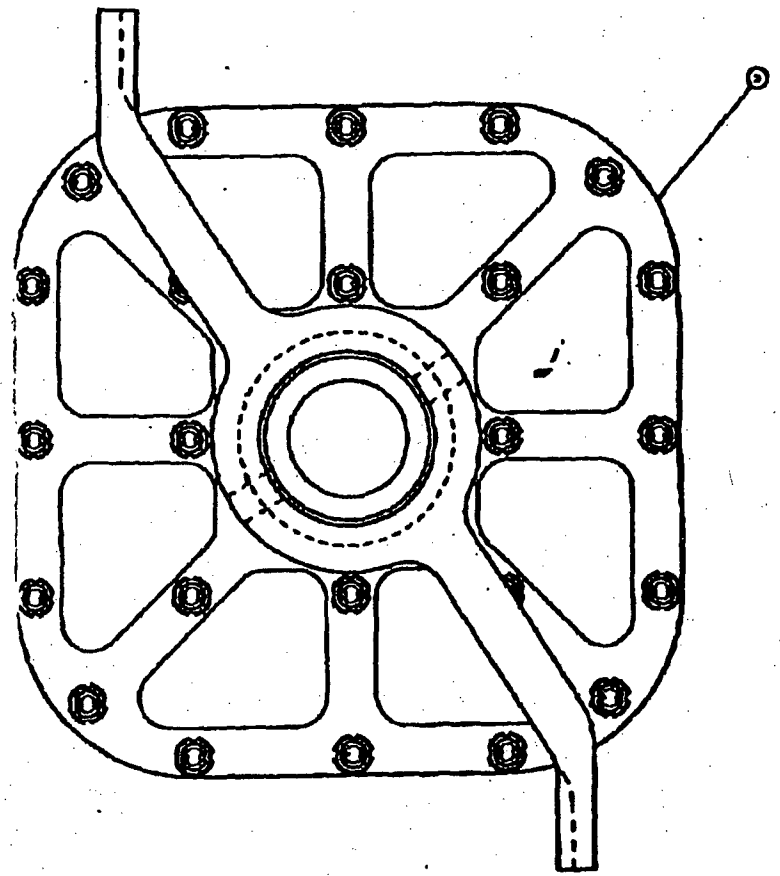
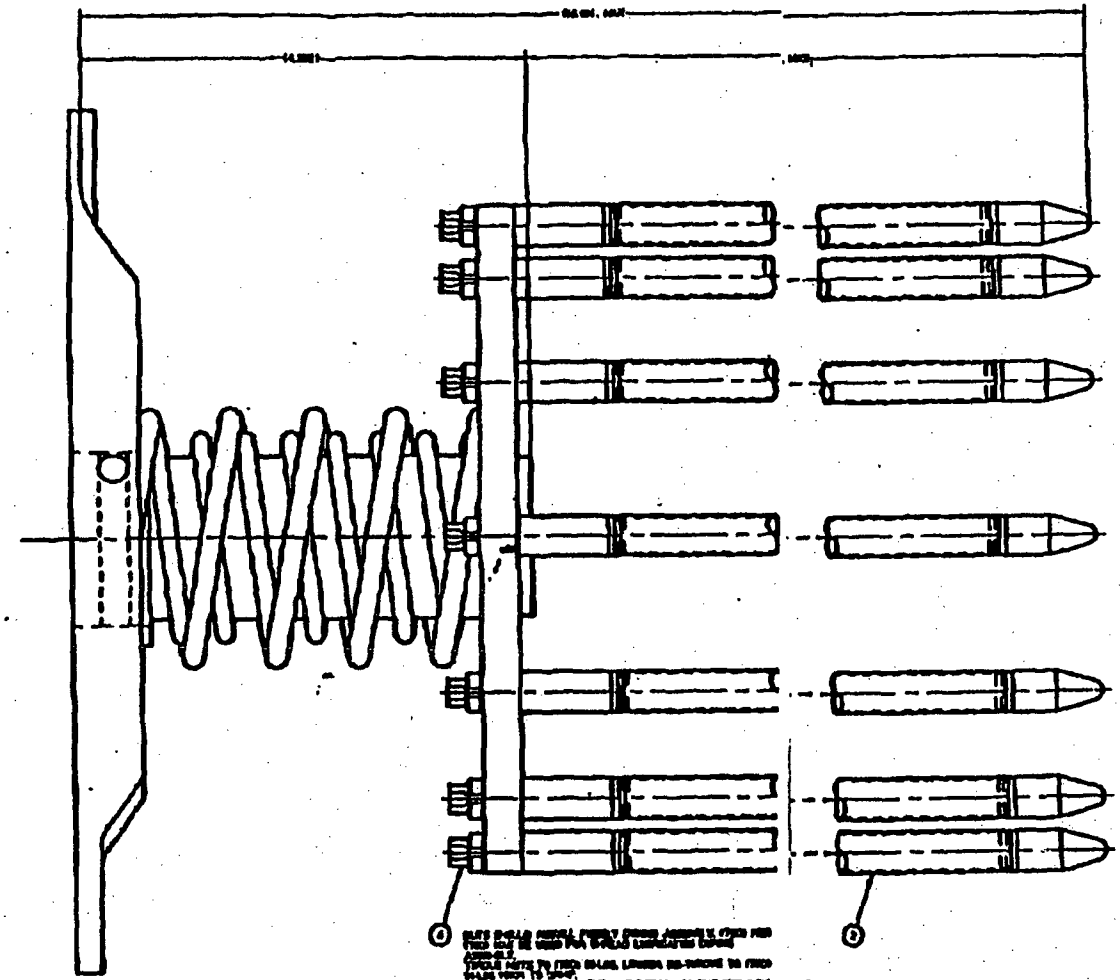


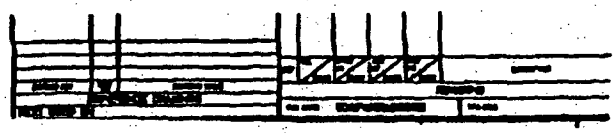
Figure 1. Isometric Section of a Tritium Producing Burnable Absorber Rod

Figu





1 ASSEMBLY



U. S. DEPARTMENT OF ENERGY

LWR TARGET LEAD TEST ASSEMBLY

TTR-95-002

Appendix B

Biological Review of the Tritium Target Lead Test Assembly, 300 Area

January 20, 1997

C. A. Brandt
K6-84
376-5345

Ms. Julie K. Turner
U.S. Department of Energy
Richland Operations Office
P. O. Box 550, MSIN K8-50
Richland, WA 99352

Dear Ms. Turner:

BIOLOGICAL REVIEW OF TRITIUM TARGET/LEAD TEST ASSEMBLY, 325 BLDG., 300 AREA, #97-300-010

Project Description:

- This biological review applies to that portion of the subject project that includes modifications to the 325 Building.

Survey Objectives:

- To determine the occurrence in the project area of plant and animal species protected under the Endangered Species Act (ESA), candidates for such protection, and species listed as threatened, endangered, candidate, sensitive, or monitor by the state of Washington, and species protected under the Migratory Bird Treaty Act.

- To evaluate the potential impacts of disturbance on priority habitats and protected plant and animal species identified in the survey.

Survey Methods:

- A field survey of the project area was conducted by T. Henrahan and R. Burrows on May 21, 1996. The Braun-Blanquet cover-abundance scale (Bonham 1989) was used to determine percent cover of dominant vegetation.

- Priority habitats and species of concern are documented as such in the following: Washington Department of Fish and Wildlife (1994,1995), U. S. Fish and Wildlife Service (1985,1992,1994) and Washington State Department of Natural Resources (19[illegible]).

Survey Results:

- The vicinity of the project area has been previously disturbed. Vegetation is characteristic of disturbed areas, consisting primarily of packed gravel and pavement with sparse amounts of cheatgrass (*Bromus tectorum*) and Russian thistle (*Salsola kali*).

- No migratory birds were observed nesting in the vicinity of the project area.

Conclusions:

- This biological survey is effective until April 15, 1997. Should the project described above commence after this date, a new ecological review will be required.
- No plant or animal species protected under the ESA, candidates for such protection, or species listed by the Washington state government were observed in the vicinity of the project location.
- No adverse impacts to species or habitats of concern are expected to occur from the proposed action.

Sincerely,

T. J. Lamont for

CA Brandt, Ph.D.
Project Manager
Ecological Compliance Assessment

CAB:tph

REFERENCES

Bonham, Charles D. 1989. Measurements for Terrestrial Vegetation, published by John Wiley & Sons, Inc. pp. 127-128.

U. S. Fish and Wildlife Service. 1985. Revised List of Migratory Birds; Final Rule. 50 FR 13708 (April 5, 1985).

U. S. Department of Interior, U. S. Fish and Wildlife Service. 1992. Endangered and Threatened Wildlife and Plants. 50 CFR 17.11 and 17.12. (August 29, 1992).

U. S. Fish and Wildlife Service. 1994. Endangered and Threatened Wildlife and Plants, Animal Candidate Review for Listing as Endangered or Threatened Species, Proposed Rule, 50 CFR 17. (November 15, 1994).

Washington Department of Fish and Wildlife. 1994. Species of Special Concern in Washington. (April 1994).

Washington Department of Fish and Wildlife. 1995. Priority Habitats and Species. 24 pp.

Washington Department of Natural Resources. 1994. Endangered, Threatened & Sensitive Vascular Plants of Washington. (January 1994).

Appendix C

Consequences of Tritium Releases During Post-Irradiation Examination of Tritium-Producing Burnable Absorber Rods (TPBARs)

Post Irradiation Examination (PIE) of the TPBARS would take place at Hanford, and neutron radiography would be conducted at a facility to be determined. For the purposes of this analysis, neutron radiography is assumed to occur at the ANL-W facility, near Idaho Falls, Idaho.

PIE of the TPBARs would take place at the PNNL Applied Chemistry Laboratory, designated the 325 building, which is located in the Hanford Site 300 Area. These activities may result in releases of tritium, as well as very small quantities of particulate activation products, to the environment. Routine releases could result from destructive examination of the TPBARs, extraction of tritium to determine production levels and retention efficiency, and permeability tests of the TPBAR cladding material. Accidental releases might result from damage to a TPBAR during handling, malfunctions of facility emission control equipment during PIE activities, or external events such as a fire or earthquake. The consequences of both routine emissions and potential accident scenarios have been evaluated for PIE activities, as described in the following sections.

C.1 Methods for Evaluation of Potential Consequences of PIE Activities

Radiation dose estimates were calculated using the CAP88-PC software package (Parks 1992) for routine emissions, and the GENII software system (Napier et al 1988) for acute (short-term) releases. Both codes implement a straight-line Gaussian plume model for atmospheric dispersion, and the food chain models are similar to those of NRC (1977) for ingestion dose estimates. The GENII software incorporates a seasonal model for ingestion calculations following an acute release that accounts for the types and quantities of food products growing during each season, as well as the delay time between radionuclide deposition and harvest. The atmospheric dispersion and air concentrations for chronic releases are based on annual average atmospheric conditions, and acute releases assume conditions that would not be exceeded more than 5% of the time. The dosimetry models in both codes are consistent with recommendations of the International Commission on Radiological Protection (ICRP) in its publications 26 (ICRP 1979) and 30 (ICRP 1979-1988). Other assumptions are based on recommended parameters for the Hanford Site in Schreckhise et al (1993).

The dose resulting from release of tritium to the environment would depend on its chemical form. The inhalation dose from oxidized tritium (as HTO or T_2O) is about 14,000 times higher than for tritium in elemental form (as HT or T_2). Elemental tritium is also assumed to make no contribution to doses received via the food chain (ingestion) pathways (DOE 1988). The dosimetry models in both the CAP88-PC and GENII codes assume that tritium is released to the environment in the oxidized form, and therefore are conservative for releases that involve elemental tritium. For this analysis, tritium released in elemental form is assumed to oxidize slowly in the environment. Based on experimental results, Brown et al. (1990) estimate the long-

term dose from elemental tritium releases to be about 1% of that for the oxidized form. Therefore, releases that occur as elemental tritium are multiplied by a factor of 0.01 to convert them to an equivalent release of tritium oxide for use with the environmental dosimetry software.

Health effects estimates are based on recommendations of the ICRP (1991) in its publication 60. The consequences in terms of latent cancer fatalities are estimated to be 4×10^{-4} per person-rem (4×10^{-2} per person-Sv) for adult workers and 5×10^{-4} per person-rem (5×10^{-2} per person-Sv) for the general population. The corresponding total incidence of detrimental health effects, including both fatal and nonfatal cancers and severe hereditary effects, is estimated to be 5.6×10^{-4} per person-rem (5.6×10^{-2} per person-Sv) for workers and 7.3×10^{-4} per person-rem (7.3×10^{-2} per person-Sv) for the general population. The higher rates for the general population account for the presence of more sensitive individuals, such as children, compared with the relatively homogeneous population of healthy adults in the work force. These estimates apply to radiation exposures at relatively low doses and dose rates (see ICRP 1991).

The ICRP estimates are based on radiation exposures to populations at higher doses and dose rates, and by different pathways, than those normally encountered in the environment. As a result, the health effects coefficients are presented in terms of collective dose to a relatively large population. Collective dose is defined as the sum of doses to all individuals in the population, who may exhibit a wide range of susceptibility to radiation-induced health effects. The health effects coefficients are therefore associated with substantial uncertainty when applied to dose estimates for individuals whose sensitivity may differ from the population average. However, the assumptions used to develop the health effects coefficients are sufficiently conservative that they would be "unlikely to underestimate the risks" (ICRP 1991).

C.2 Consequences of Routine PIE Activities

Non-destructive evaluation (NDE) of the TPBARs and neutron radiography would not involve breaching the cladding under normal conditions. Therefore, the NDE would not be expected to result in air emissions other than those typically associated with operation of the facility.

The remaining PIE of the irradiated TPBARs and associated tests would consist of 3 major activities: 1) sectioning the rods to evaluate changes to their internal structure, 2) extraction of tritium from the rods to determine production rates and retention characteristics, and 3) permeability testing of the TPBAR cladding material using tritium obtained from a commercial source. The radionuclide releases from each of these activities are estimated as follows:

1) Sectioning of TPBARs - Each TPBAR has an active target length of approximately 142" and a bounding tritium inventory of 12,000 Ci. All tritium in the cut cross-section is presumed to be volatilized during the sectioning procedure. Assuming that the average distance between cuts is about 3.75", and the width of each cut is 0.015", the estimated tritium release from sectioning each TPBAR is calculated as follows:

H-3 Release = (total length of TPBAR ÷ distance between cuts) x (cut width) x

(TPBAR H-3 inventory per unit length)
=(142" ÷ 3.75") x (0.015") x (12,000 Ci / 142")
= 48 Ci/TPBAR.

All of the tritium that would be volatilized during sectioning is assumed to be released via the building's heating, ventilation and air conditioning (HVAC) system. Small quantities of neutron activation products in the TPBAR cladding would also be converted to particulate form during this operation, but the facility emission controls would limit their releases to such small quantities that they would have no consequence when compared with the tritium releases.

2) Tritium Extraction and Analysis - An estimated upper bound for emissions from the tritium extraction and analysis process were approximately 0.1% of the total inventory via the mass spectrometer and 1% via the emission control system (either a bubbler or molecular sieve trap). The potential emissions from extracting tritium from one TPBAR are as estimated follows:

H-3 Release = (TPBAR tritium inventory) x (release fraction)
= (12,000 Ci) x (0.01 + 0.001)
= 130 Ci/TPBAR.

3) Cladding Permeability Tests - An upper bound estimate for tritium emissions from the cladding permeability tests is 10% of the total inventory volatilized from the commercial tritium source, which contains approximately 2000 Ci. The remaining tritium was assumed to be recovered and contained within the source following the test. The tritium emissions from this activity were therefore estimated as:

H-3 Release = (Source tritium inventory) x (release fraction)
= (2000 Ci) x (0.10)
= 200 Ci.

The consequences of routine tritium emissions were calculated using the CAP88-PC computer software and site-specific wind data from the Hanford Site 300 Area (Schreckhise et al 1993). The meteorological database represents the average of hourly data collected over the 9-year period from 1983 through 1991 at the 300 Area meteorological tower. Calculations were performed for a unit (1-Ci) release of tritium from the 325 building stack using normal ventilation parameters for stack EP-325-01-S. The effective stack height was set at 35 m, the exit velocity at 13 m/s, and the diameter at 2.44 m. Dose estimates are presented in Table C.1 for releases from all routine PIE activities. These results assume tritium is released in oxidized form, which provides a bounding estimate of the consequences. However, the tritium extraction process includes an oxidation step prior to trapping the gases in a bubbler or molecular sieve, so this assumption is not overly conservative for the specific processes considered in this assessment.

Table C.1 Consequences of Routine Tritium Emissions from Post-Irradiation Examination of TPBARs at the Hanford Site 325 Building

Consequences of Tritium Emissions from PIE Activities		
PIE Activity and Estimated Tritium Release	Dose (mrem) to the Maximally Exposed Offsite Resident (2 km E)	Dose (person-rem) to the population within 50 mi (80 km)
1-Ci tritium release	5.53×10^{-5}	2.4×10^{-4}
PIE Activities		
Sectioning of 1 TPBAR (48 Ci)	2.6×10^{-3}	1.2×10^{-2}
Tritium Extraction from 1 TPBAR (130 Ci)	7.3×10^{-3}	3.1×10^{-2}
Cladding Permeability Tests (200 Ci)	1.1×10^{-2}	4.8×10^{-2}

C.3 Consequences of Accidents During PIE Activities

The consequences of potential accidents during PIE of the TPBARs were evaluated for a spectrum of events having different severities and expected frequencies. A detailed safety analysis of the PIE activities would be performed before work commences; however, the scenarios evaluated for this assessment are representative of the types of events that are typically considered in safety assessments. Three accidents were evaluated for PIE activities, including: 1) breach of a single TPBAR during handling, 2) a localized fire involving the maximum quantity of tritium "at risk" during PIE, and 3) a seismic event and fire, which could involve all 32 TPBARs. A bounding accident during transport of the TPBARs between facilities was also evaluated. Accidents during PIE at Hanford are expected to bound those for similar types of events during neutron radiography because the facilities at ANL-W are farther from the nearest offsite receptors than those at Hanford (greater than 8 km vs 0.58 km). In addition, the localized fire scenario would not apply to NDE activities because the TPBARs would remain intact and would therefore not be considered at risk for this type of accident.

C.3.1 Rod Breach Scenario.

The rod breach or similar scenario could release the gaseous (i.e., unbound) tritium content of a single TPBAR. This event is expected to occur with a frequency between 1×10^{-2} and 1.0 per year (or one event in 1 to 100 years). Following irradiation, most of the tritium in the TPBARs is expected to be bound to the getter and other internal components. Based on experimental results of Johnson et al (1976), less than 30% of the TPBAR tritium inventory was assumed to be in a gaseous state, which would consist almost entirely of elemental tritium. Less than 0.5% of the total TPBAR tritium inventory would be expected to exist as gaseous tritium oxide. (Johnson et al 1976) If 1% of the free elemental tritium is assumed to oxidize in the environment following release (see section C.1), the total equivalent release as tritium oxide from a damaged TPBAR is calculated to be:

H-3 Release = (TPBAR inventory) x [(free oxide fraction) + (free elemental fraction) x

(fraction oxidized in environment)]
= (12,000 Ci) x [0.005 + (0.3 x 0.01)]
= 96 Ci.

The scenario for this event assumes that the tritium release is not mitigated by emission control devices.

C.3.2 Localized Fire.
A localized fire during PIE is assumed to involve release of all tritium considered to be at risk at any time in the 325 Building laboratories. The quantity at risk is assumed to be the total inventory of TPBARs that are undergoing tests at any given time. TPBARs that are intact and remain in their sealed storage containers within the hot cells are not considered to be at risk for this event. The quantity of tritium assumed to be at risk for this event is 70,000 Ci, which represents the content of 6-8 TPBARs. Because the event includes an external mechanism for releasing tritium bound in the TPBAR components and oxidizing it, the entire at-risk inventory is assumed to be released as tritium oxide. The estimated frequency of a localized fire is less than 0.10, or 1 in 10 years, and the time required to complete the activity is less than 6 months.

C.3.3 Seismic Event with Fire.
The bounding accident for PIE involves an external event such as a severe earthquake and fire that could damage all 32 of the TPBARs simultaneously. The anticipated frequency of accidents in this category is between 1×10^{-6} and 1×10^{-4} per year (or one event in 10,000 to 1 million years). The release scenario for this accident assumes that the building is breached, allowing the entire tritium inventory of all 32 TPBARs (385,000 Ci) to exit through an opening below the roof level with the HVAC system out of operation. Because this event includes a fire, the tritium was assumed to be oxidized prior to release from the building.

C.3.4 Consequences of a Bounding Accident During Transportation
The consequences of a bounding accident during transport of the TPBARs between Hanford and ANL-W were also evaluated. A maximum credible accident during transportation is assumed to breach the shipping container and damage all 32 TPBARs, releasing the free tritium inventory. The quantity of tritium oxide released is therefore equivalent to 32 times that estimated for the single rod breach in section C.3.1, or about 3100 Ci. The assumptions associated with this accident are discussed in detail in Appendix D, section D.4.2.

C.4 Summary of Accident Consequences
The dose to an individual located near the 325 Building was evaluated for each accident scenario described in Section C.3, and the results are presented in Table C.2. Atmospheric dispersion estimates and GENII results for a release of 1 Ci of tritium from the 325 Building are included in Table C-2. The dose calculations for releases from the facility use atmospheric dispersion estimates (E/Q values) for a ground-level release including a building wake dispersion model. The dose per Ci tritium released in the bounding transportation accident was estimated from the corresponding value for facility accidents, adjusting for the higher air concentration at each

receptor location following an open-area ground level release as follows:

Dose (mrem) per Ci Release (Transportation accidents) = mrem/Ci for facility accidents x (E/Q for open-area ground level release ÷ E/Q for release from facility)

100-m receptor: $= 3.6 \times 10^{-2} \times (3.4 \times 10^{-2} \div 1.2 \times 10^{-3})$
$= 1.0 \times 10^{0}$

580-m receptor: $= 4.2 \times 10^{-3} \times (1.7 \times 10^{-3} \div 1.4 \times 10^{-4})$
$= 5.1 \times 10^{-2}$

The dose for each accident scenario was then calculated by multiplying the dose per Ci tritium released by the estimated release for each type of event.

Table C.2 Consequences of Acute Tritium Releases at or near the Hanford Site 325 Building

Accident Releases - 325 Bldg. H-3 Release (as tritium oxide)	Onsite Dose, mrem 100m ESE E/Q = 1.2×10^{-3} s/m^3	Offsite Dose, mrem 580m ESE E/Q = 1.4×10^{-4} s/m^3	Collective Dose to Offsite population, person-rem
1 Ci	3.6×10^{-2}	4.2×10^{-3}	1.5×10^{-2}
TPBAR Breach (96 Ci)	3.5×10^{0}	4.0×10^{-1}	1.4×10^{0}
Localized Fire (70,000 Ci)	2.5×10^{3}	2.9×10^{2}	1.1×10^{3}
Earthquake + Fire (385,000 Ci)	1.4×10^{4}	1.6×10^{3}	5.8×10^{3}
Transportation Accidents Ground-level H-3 Release (as tritium oxide)	**Onsite Dose, mrem 100 m ESE E/Q = 3.4×10^{-2} s/m^3**	**Offsite Dose, mrem 580 m ESE E/Q = 1.7×10^{-3} s/m^3**	**Not Applicable**
1 Ci	1.0×10^{0}	5.1×10^{-2}	
3100 Ci	3.1×10^{3}	1.6×10^{2}	

C.5 References

Brown, R. M., G. L. Ogram, and F.S. Spencer. 1990. "Oxidation and Dispersion of HT in the Environment: The August 1986 Field Experiment at Chalk River," *Health Phys.* 58(2):171-181.

International Commission on Radiological Protection (ICRP). 1977. *Recommendations of the International Commission on Radiological Protection.* ICRP Publication 26, Annals of the ICRP, Vol. 1, No. 3, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection (ICRP). 1979-1988. *Limits for Intakes of Radionuclides by Workers.* ICRP Publication 30, Parts 1-4 (and supplements), *Annals of the ICRP* Vol. 2 (No. 3/4), Vol.4 (No. 3/4), Vol. 6 No. 2/3), Vol. 8 (No. 4), and Vol. 19 (No.4), Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection (ICRP). 1991. *1990 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 60, *Annals of the ICRP* Vol. 21 (No. 1-3), Pergamon Press, Oxford.

Johnson, A. B. Jr., T. J. Kabele, and W. E. Gurwell. 1976. *Tritium Production from Ceramic Targets: A Summary of the Hanford Coproduct Program.* BNWL-2097. Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., D. L. Strenge, R. A. Peloquin, and J. V. Ramsdell. 1988. *GENII -The Hanford Environmental Radiation Dosimetry Software System.* PNL-6584, Vol. 1 -Conceptual Representation, Vol. 2 - Users' Manual, Vol. 3 - Code Maintenance Manual. Pacific Northwest Laboratory, Richland, Washington.

Parks, B. S. 1992. *User's Guide for CAP88-PC. Version 1.0.* 402-B-92-001. Office of Radiation Programs, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Schreckhise, R. G., K. Rhoads, J. S. Davis, B. A. Napier, and J. V. Ramsdell. 1993. *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters.* PNL-3777, Rev. 2. Pacific Northwest Laboratory, Richland Washington.

U.S. Department of Energy (DOE). 1988. *Internal Dose Conversion Factors for Calculation of Dose to the Public.* DOE/EH-0071, DOE Assistant Secretary for Environment, Safety, and Health, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I.* Regulatory Guide 1.109, NRC Office of Standards Development, Washington, D.C.

APPENDIX D

TRANSPORTATION IMPACT ANALYSIS

This appendix evaluates the impacts of both incident-free (routine) transport of radioactive materials in which the shipments reach their destinations without incident and the impacts of accidents involving the shipments. The consequences of the maximum credible transportation accident are also calculated. The approaches and data used to calculate these impacts are presented, as well as the shipping scenarios and characteristics of the radioactive shipments that are important to determining the radiological impacts. Nonradiological impacts are also calculated.

Section D.1 provides a description of the shipping scenarios and the characteristics of the shipments analyzed in this Appendix. Descriptions of the approach and computer codes used in this analysis are presented in Section D.2. Section D.3 presents the results of the transportation impact calculations.

D.1 SHIPPING SCENARIOS AND SHIPMENT CHARACTERISTICS

This section presents the shipping scenarios and shipment characteristics for each of the shipments required for the transport of unirradiated and irradiated tritium-producing burnable absorber rods (TPBARs). The information presented includes container and shipment capacities, shipment inventories, numbers of shipments, and route information.

The radionuclide inventories used in the analyses are presented in Table D.1. The data in the table represent the maximum bounding inventories of each radionuclide. The bounding inventories were used in analyzing both incident-free and accident impacts.

This analysis was based on the following assumptions:

- All overland transportation would be by truck.
- The 32 TPBARS would be shipped in one package to the Westinghouse fuel fabrication facility located in Columbia, South Carolina. This shipment would consist of nonradioactive materials only.
- One shipment containing two packages (two integrated fuel assemblies per package) would be used to ship the assembled fuel to the Watts Bar Nuclear Power Plant (WBNP), located near Chattanooga, Tennessee. This shipment would utilize a commercial carrier approved for low specific activity material shipments.
- Two to four shipments, each containing one or two TPBAR-LTAs, would be used to ship the irradiated TPBARs from the WBNP to the Hanford Site near Richland, Washington. All shipments would utilize an NRC-licensed Type B cask on exclusive use routes, and the number of shipments would depend on the capacity of the specific cask used. For exclusive use shipments, highway route controlled quantities are shipped on interstate highways or state-designated alternative routes (49CFR171-177). This was assumed for the shipments of the irradiated TPBARS due to the radionuclide inventories and sensitive nature of the shipments (i.e., tritium).
- Following disassembly of the TPBAR-LTAs at Hanford, all 32 TPBARs would be transported in a single shipment to ANL-W, near Idaho Falls, ID, for nondestructive evaluation (NDE). These

shipments would also utilize an NRC-licensed Type B cask on exclusive use routes. Upon completion of the NDE, all 32 TPBARs would be returned to Hanford for post-irradiation examination (PIE).

When PIE activities are completed, all 32 TPBARs and associated laboratory waste are assumed to be disposed of at the Hanford Site low level waste burial grounds in the 200 Areas. After the TPBAR-LTAs are disassembled, the hardware other than the TPBARs (designated non-target bearing components, or NTBCs) were assumed to be packaged and transported to the burial grounds in 4 shipments using a DOE-approved shipping container. Spent TPBARs and associated laboratory wastes are assumed to be transported in one additional shipment.

Table D.1 Radionuclide Inventory

Radionuclide	Quantity per TPBAR[a] (Ci)	Quantity per assembly (Ci)	Quantity per shipping cask[b] (Ci)	NTBC[c]: Quantity per solid waste package (Ci)	Targets[d]: Quantity per package (Ci)
H-3	1.13E+04	9.28E+04	1.81E+05	0	3.62E+05
Cr-51	5.64E+00	1.35E+02	2.71E+02	9.02E+01	1.80E+02
Mn-54	1.41E+01	3.38E+02	6.77E+02	2.26E+02	4.51E+02
Fe-55	9.21E+01	2.21E+03	4.42E+03	1.47E+03	2.95E+03
Fe-59	6.46E-01	1.55E+01	3.10E+01	1.03E+01	2.07E+01
Co-58	1.33E+01	3.19E+02	6.38E+02	2.13E+02	4.26E+02
Co-60	3.03E+01	7.27E+02	1.45E+03	4.85E+02	9.70E+02
Ni-63	3.51E+00	8.42E+01	1.68E+02	5.62E+01	1.12E+02
Zr-95	4.51E+00	1.08E+02	2.16E+02	7.22E+01	1.44E+02
Nb-95	8.89E+00	2.13E+02	4.27E+02	1.42E+02	2.84E+02
Mo-99	7.18E-18	1.07E-16	3.41E-16	1.14E-16	2.27E-16

(a) Taken from TTQP-1-050, Conservative estimate for 180-day discharge
(b) Ci per shipping cask assuming 2 assemblies per cask
(c) NTBC - non-target-bearing components, Ci per waste package assuming 1 assembly per waste package
(d) Ci per package assuming 32 target rods per shipment to HFEF or solid waste

D.1.1 Transportation Route Information

The transportation routes assumed for this analysis are shown in Table D.2. The information shown in Table D.2 includes the number of shipments required, origin, and destination facilities.

Table D.2. Transportation Routing Information

Material Transported	No. of Shipments	Origin	Destination
Unirradiated TPBAR assemblies	1[a]	PNNL, Hanford, Washington	WBNP, Chattanooga, Tennessee
Irradiated TPBAR assemblies	2 - 4[b]	WBNP, Chattanooga, Tennessee	PNNL, Hanford, Washington
Irradiated TPBARs	1[b]	PNNL, Hanford, Washington	HFEF, Idaho Falls, Idaho
Irradiated TPBARs	1[b]	HFEF, Idaho Falls, Idaho	PNNL, Hanford, Washington
Irradiated TPBARs	1[c]	PNNL, Hanford, Washington	Solid Waste, Hanford, Washington
Non-target bearing components	4[c]	PNNL, Hanford, Washington	Solid Waste, Hanford, Washington
Return shipment of empty cask	1 - 3[a]	PNNL, Hanford, Washington	WBNP, Chattanooga, Tennessee

(a) Commercial routes used for analysis
(b) HM-164 routes used for analysis
(c) Onsite roadways

The transportation route information used in this analysis is shown in Table D.3. The information shown in Table D.3 includes the shipping distances and population densities. These data are used to calculate transportation impacts and were developed using the HIGHWAY 3.3 (Johnson et al. 1993) computer code for truck shipments or were estimated using site maps. The population density data for shipments on the Hanford Site were developed using site maps and suburban population densities to represent occupied facilities and rural population densities for all other areas adjacent to the transport route.

Table D.3. Summary of Transportation Analysis Information

Material Transported		No. of Shipments	Shipment distance (km one-way)	Population Density, people/km^2 [a]		
Origin	Destination			Rural	Suburban	Urban
Unirradiated TPBAR assemblies[b]						
PNNL	Westinghouse, Columbia, S.C.	1	4282.3	7.0 (86.2)	333.3 (12.7)	2071.8 (1.1)
Westinghouse, Columbia, S.C.	WBNP	1	515.0	14.0 (71.2)	292.6 (27.9)	1917.5 (0.8)
Irradiated TPBAR assemblies[c]						
WBNP	PNNL	2 - 4	4045.8	6.2 (87.5)	349.2 (11.3)	2174.7 (1.2)
Irradiated TPBARs						
PNNL [c]	HFEF	1	967.2	5.8 (91.6)	382.4 (7.9)	1984.0 (0.6)
HFEF [c]	PNNL	1	967.2	5.8 (91.6)	382.4 (7.9)	1984.0 (0.6)
PNNL[d]	Solid Waste	1	43.2	2.4 (97.1)	89.8 (2.9)	NA
Non-target bearing components						
PNNL[d]	Solid Waste	4	43.2	2.4 (97.1)	89.8 (2.9)	NA
Empty shipping cask[b]						
PNNL	WBNP	1 - 3	4282.3	7.0 (88.3)	333.3 (10.6)	2071.8 (1.1)

(a) Values shown in parenthesis indicate percentage of total route in each population zone.
(b) Commercial routes used for analysis
(c) HM-164 routes used for analysis
(d) Hanford Site roadways

D.2 ROUTINE AND ACCIDENT IMPACT ANALYSIS METHODS AND MODELS

This section describes the methods used to estimate consequences of normal and accidental exposure of individuals or populations to radioactive materials. The RADTRAN 4 computer codes (Neuhauser and Kanipe 1992) were used to calculate the transportation impacts, and the GENII software package (Napier et al. 1988) was used to estimate the consequences to the maximum individuals.

The output from computer codes, as total effective dose equivalent (TEDE or dose) to the affected receptors, was then used to express the consequences in terms of potential latent cancer fatalities (LCF). Recommendations of the International Commission on Radiological Protection (ICRP 1991) for low dose, low dose rate radiological exposures were used to convert dose as TEDE to LCF. The conversion factor applied to adult workers (i.e., Hanford Site workers) was 4×10^{-4} LCF/rem TEDE; and the conversion factor for the general population was 5×10^{-4} LCF/rem TEDE. The general population was assumed to have a higher rate of cancer induction for a given radiation dose than healthy adult workers because of the presence of more sensitive individuals (e.g., children) in the general population.

Nonradiological incident-free and accident impacts were also evaluated. Nonradiological incident-free impacts consist of fatalities from fugitive emissions or pollutants emitted from the vehicles. Nonradiological accident impacts are the fatalities resulting from potential vehicular accidents involving the shipments. Neither of these two categories of impacts is related to the radiological characteristics of the cargo. Hand calculations were performed using unit-risk factors (fatalities per km of travel) to derive estimates of the nonradiological impacts. The nonradiological impacts were calculated by multiplying the unit risk factors by the total shipping distances for all of the shipments in each shipping option. Nonradiological unit risk factors for incident-free transport were taken from Neuhauser and Kanipe (1992).

D.2.1 RADTRAN 4 Computer Code

The RADTRAN 4 computer code (Neuhauser and Kanipe 1992) was used to perform the analyses of the radiological impacts of routine transport and the integrated population risks of accidents during transport of the irradiated TPBAR assemblies, TPBARs, and NTBCs. RADTRAN was developed by Sandia National Laboratories (SNL) to calculate the risks associated with the transportation of radioactive materials. The original code was written by SNL in 1977 in association with the preparation of NUREG-0170, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes* (NRC 1977). The code has since been refined and expanded and is currently maintained by SNL under contract with DOE.

The RADTRAN 4 computer code is organized into the following seven models (Neuhauser and Kanipe 1992):

- material model
- transportation model
- population distribution model
- health effects model
- accident severity and package release model
- meteorological dispersion model
- economic model.

The code uses the first three models to calculate the potential population dose from normal, incident-free transportation and the first six models to calculate the risk to the population from user-defined accident scenarios. The economic model is not used in this study.

D.2.1.1 Material Model

The material model defines the source as either a point source or as a line source. For exposure distances less than twice the package dimension, the source is conservatively assumed to be a line source. For all other cases, the source is modeled as a point source that emits radiation equally in all directions.

The material model also contains a library of 59 isotopes, each of which has 11 defining parameters used to calculate dose. The user can add isotopes not in the RADTRAN library by creating a data table in the input file consisting of eleven parameters.

D.2.1.2 Transportation Model

The transportation model allows the user to input descriptions of the transportation route. A transportation route may be divided into links or segments of the journey, with information for each link on population density, mode of travel (e.g., trailer truck), accident rate, vehicle speed, road type, vehicle density, and length. Alternatively, the transportation route also can be described by aggregate route data for rural, urban, and suburban areas. For this analysis, the aggregate route method was used for each potential origin-destination combination.

D.2.1.3 Health Effects Model

The health effects model in RADTRAN 4 is outdated and is replaced by hand calculations. The health effects are determined by multiplying the RADTRAN4 population dose (person-rem) by a conversion factor.

D.2.1.4 Accident Severity and Package Release Model

Accident analysis in RADTRAN 4 is performed using the accident severity and package release model. The user can define up to 20 severity categories for three population densities (urban, suburban, and rural), each increasing in magnitude. Eight severity categories for SNF containers that are related to fire, puncture, crush, and immersion environments are defined in NUREG-0170 (NRC 1977). Various other studies have been performed for small packages (Clarke et al. 1976) and large packages (Dennis et al. 1978) that also can be used to generate severity categories. The accident scenarios are further defined by allowing the user to input release fractions and aerosol and respirable fractions for each severity category. These fractions are also a function of the physical-chemical properties of the materials being transported.

D.2.1.5 Meteorological Dispersion Model

RADTRAN 4 allows the user to choose two different methods for modeling the atmospheric transport of radionuclides after a potential accident: Pasquill atmospheric-stability category data or averaged time-integrated concentrations. In this analysis, the dispersion of radionuclides after a potential accident is modeled by the use of time-integrated concentration values in downwind areas compiled from national averages by SNL.

D.2.1.6 Incident-Free Transport

The models described above are used by RADTRAN 4 to determine dose from incident-free transportation or risk from potential accidents. The public and worker doses calculated by RADTRAN 4 for incident-free transportation are dependent on the type of material being transported and the transportation index (TI) of the package or packages. The TI is defined in 49 CFR 173.403(bb) as the highest package dose rate in millirem per hour at a distance of 1 m from the external surface of the package. Dose consequences are also dependent on the size of the package, which as indicated in the material model description, will determine whether the package is modeled as a point source or a line source for close-proximity exposures.

D.2.1.7 Analysis of Potential Accidents

The accident analysis performed in RADTRAN 4 calculates population doses for each accident severity category using six exposure pathway models: inhalation, resuspension, groundshine, cloudshine, ingestion, and direct exposure. This RADTRAN 4 analysis assumes that any contaminated area is either mitigated or public access is controlled so the dose via the ingestion pathway equals zero. The consequences calculated for each severity category are multiplied by the appropriate frequencies for accidents in each category and summed to give a total point estimate of risk for a radiological accident.

D.2.2 GENII Description

GENII (Napier et al. 1988), which is also referred to as the Hanford Environmental Dosimetry Software System, was developed by the Pacific Northwest National Laboratory to analyze radiological releases to the environment. GENII is composed of seven linked computer programs and their associated data libraries, including user interface programs, internal and external dose factor generators, and the environmental dosimetry programs.

GENII is capable of:

- Calculating doses resulting from acute or chronic releases, including options for annual dose, committed dose, and accumulated dose
- Calculating doses from various exposure pathways evaluated, including those through direct exposure via water, soil, and air, as well as inhalation and ingestion pathways
- Acute and chronic elevated and ground level releases to air
- Acute and chronic releases to water
- Initial contamination of soil or surfaces
- Radionuclide decay.

The pathways considered in this analysis include inhalation, submersion, and external exposures due to ground contamination.

D.3 RESULTS OF INCIDENT-FREE TRANSPORTATION IMPACT ANALYSIS

This section discusses the radiological and non-radiological impacts to the truck crew and the public during incident-free or routine transportation activities. The key input parameters for the RADTRAN 4 computer code that were used to perform the incident-free transportation impact calculations are provided in Table D.4. Separate subsections are provided below for the results of the radiological and nonradiological impact calculations.

D.3.1 Radiological Impacts of Incident-Free Transportation

The radiological doses to the truck crew, onsite worker, and the public from transportation activities were calculated using RADTRAN 4 (see Section D.2). RADTRAN 4 uses a combination of meteorological, demographic, health physics, transportation, packaging, and material factors to analyze the radiological exposures from incident-free transport activities. The doses to the truck crew and the public were calculated on a per-shipment basis and for the entire campaign.

Table D.4 Incident-Free and Accident Analyses Input Parameters[a]

Parameter	Value
Fraction of travel time per population zone	See Table D.3[b]
Radiation dose rate (mrem/hr) at 1m: Type B shipping cask solid waste container	1,000 [c] 200[d]
Number of crewmen	2
Distance from source to crew, meters	10
Stop time per kilometer, hours per kilometer	0.011

Persons exposed while stopped	50
Average exposure distance while stopped, meters	20
Number of people per vehicle	2
Traffic count in rural zone, one-way vehicles per hour	470
Traffic count in suburban zone, one-way vehicles per hour	780
Traffic count in urban zone, one-way vehicles per hour	2,800
Total shipping distance, kilometers	See Table D.3[b]
Population densities by population zone	See Table D.3[b]

(a) RADTRAN 4 default values except where indicated
(b) Values are shipment dependent
© Regulatory maximum for a Type B package (10CFR71), RADTRAN 4 automatically adjusts for maximum allowable in crew compartment
(d) Hanford Site waste acceptance criteria

No radiological impacts are associated with transporting the unirradiated TPBARs to the Westinghouse fuel assembly facility or with transporting the assembled fuel to WBNP. It is also assumed that there are no radiological impacts associated with transporting the empty shipping cask from PNNL to WBNP for reloading. Therefore, the potential routine radiological impacts have been estimated for shipments from WBNP to PNNL, PNNL to HFEF, from HFEF to PNNL, and from PNNL to the Hanford Site solid waste facility.

The potential radiological impacts, based on the radionuclide inventories shown in Table D.1, have been calculated using the RADTRAN 4 computer code (Neuhauser and Kanipe 1994) and the assumptions provided in Tables D.3 and D.4. The potential radiological impacts involve in-transit doses to the public or, where appropriate, Hanford Site workers from radiation emitted from the shipping cask and doses to the transport workers in the vicinity of the shipment during cask-handling activities, e.g., loading or unloading the cask on or off the truck trailer. In-transit doses have been estimated for the truck drivers; the general public, including people at truck stops or those living or working adjacent to the transport route; and nearby travelers (moving in the same and opposite directions). The results of the analysis are shown in Table D.5.

Table D.5. Radiological Impacts of Routine or Incident-Free Transportation

Material Transported		Radiological Impacts (person-rem)		Health Effects (LCFs)
Origin	Destination	Truck Crew	Public	Public
Irradiated TPBAR assemblies				
WBNP	PNNL			
	2 shipments	0.40	1.5	None (7.5E-04)
	4 shipments	0.80	3.0	None (1.5E-03)

Irradiated TPBARs				
PNNL	HFEF	0.046	0.18	None (9.0E-05)
HFEF	PNNL	0.046	0.18	None (9.0E-05)
PNNL	Solid Waste	0.0020	0.0024	None (9.6E-07)
Non-target bearing components				
PNNL	Solid Waste	0.0080	0.0094	None (3.8E-06)

The total collective doses to the crew and members of the public for all shipments are 0.50 person-rem and 1.9 person-rem, respectively if 2 shipments are made between WBNP and PNNL; the corresponding estimates for 4 shipments would be 0.9 person-rem to the crew and 3.4 person-rem to the public (see Table D.5). To place these impacts in perspective, the estimated dose the public and Hanford Site workers might receive can be compared with the natural background dose they receive. The natural background dose was calculated for the exposed population along the route for one shipment from WBNP to PNNL. The exposed population was determined to be unshielded individuals within 30 m on both sides of the route. Thus, the total area involved is the product of the total shipping distance times 60 m. The number of persons in this area along the route was determined by multiplying the total affected area by the sum of the products of the travel fractions and population densities in rural, suburban and urban zones (see Table D.3), as shown below.

Total shipping distance = 2514 km
Exposure area, A = (2514 km)(0.06 km) = 151 km^2

Total exposed population = A [(travel fraction)(population density)]

= 151 km^2 [(0.875)(6.2)+(0.113)(349.2)+(0.012)(2174.7)]

= 10,700 persons

According to the National Council on Radiation Protection (NCRP 1987), the average annual natural background exposure in the United States is 300 mrem per year per person. The resulting average annual radiation dose to the exposed population (i.e., 10,700 persons) for the shipment from WBNP to PNNL is estimated to be 3,200 person-rem per year or 0.37 person-rem per hour. Based on the HIGHWAY 3.3 computer runs, the shipment from WBNP to PNNL will take approximately 2.25 days or 54 hours; therefore, the estimated dose from natural background radiation for a 54- hour period is 20 person-rem to the exposed population—greater than 13 times the estimated dose to the public or 1.5 person-rem per shipment (see Table D.5).

D.3.2 Non-Radiological Impacts of Incident-Free Transportation Activities

Impacts to the public from non-radiological causes were also evaluated. These impacts included fatalities resulting from fugitive emissions or pollutants emitted from the vehicles during normal transportation. Based on Rao et al. (1982), the types of pollutants that could impact the public are sulfur oxides (SO_x), particulates, nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and photochemical oxidants (O_x). Of these pollutants, Rao et al. (1982) determined that the majority of the health effects are due to SO_x and the particulates. Rao et al. (1982) developed unit risk factors (fatalities per kilometer) for truck shipments traveling in urban population zones. The unit risk factor is 1.0E-07 fatalities/km for truck shipments.

The nonradiological incident-free impacts were calculated based on the travel distances shown in Table D.3. The results are shown in Table D.6. No nonradiological impacts are associated with this activity. That is, the total estimated number of fatalities is less than 4.2E-05.

Table D.6. Nonradiological Impacts of Routine or Incident-Free Transportation

Material Transported		Nonradiological Impacts of fugitive emissions (fatalities)	
Origin	Destination		
Unirradiated TPBAR assemblies			
PNNL	WBNP	None	(5.9E-06)
Irradiated TPBAR assemblies			
WBNP	PNNL 2 shipments 4 shipments	 None None	 (1.1E-05) (2.2E-05)
Irradiated TPBARs			
PNNL	HFEF	None	(5.3E-07)
HFEF	PNNL	None	(5.3E-07)
PNNL	Solid Waste	NA[a]	
Non-target bearing components			
PNNL	Solid Waste	NA[a]	
Empty shipping cask for reloading			
PNNL	WBNP 1 shipment 3 shipments	 None None	 (4.2E-06) (1.3E-05)

(a) Travel is restricted to Hanford Site roadways; therefore, unit risk factor is not applicable.

D.4 ANALYSIS OF TRANSPORTATION ACCIDENTS

This section discusses the potential radiological and non-radiological impacts of transportation accidents for each part of the transportation route discussed in Section D.1. Radiological accident impacts to the collective population (public) were calculated using the RADTRAN 4 computer code (Neuhauser and Kanipe 1992). The radiological impacts to the maximum onsite and offsite individuals, were calculated using GENII (Napier 1988).

D.4.1 Radiological Impacts to the Public from Transportation Accidents

This section describes the analyses performed to assess radiological impacts to the public and the maximum individuals from transportation accidents.

The transportation impacts are expressed as maximum individual doses or as integrated population risks. To determine the integrated population risks, the expected consequences of an accident were multiplied by the accident frequency, summed over all possible accidents, and then integrated over the entire shipping campaign. The potential impacts or consequences to the population from transportation accidents were expressed in terms of radiological dose and latent cancer fatalities.

Accident impacts can result from breaches in the shipping cask or damage to the cask shielding; however, the frequencies of occurrence of transportation accidents that would release significant quantities of radioactive material are relatively small. The shipping casks are designed to withstand specified transportation accident conditions (i.e., the shipping casks for all the materials shipped in this analysis were assumed to meet the Type B packaging requirements specified in 49 CFR 173 and 10 CFR 71); therefore, only a relatively small fraction of accidents involve conditions that are severe enough to result in a release of radioactive materials.

If the material were released to the environment, it would be dispersed and diluted by weather action, and a small amount would be deposited on the ground through plume depletion. Access to the area adjacent to the transportation accident would be controlled by emergency response personnel until the area could be remediated and the radiation monitoring personnel had declared the area safe.

The RADTRAN 4 computer code was used to calculate the radiological risk of transportation accidents involving radioactive material shipments. The RADTRAN 4 methodology was summarized previously. For further details, refer to the discussions presented by *RADTRAN III* (Madsen et al. 1986) and *RADTRAN 4: Volume 2 -- Technical Manual* (Neuhauser and Kanipe 1992).

The RADTRAN 4 computer code calculates potential accident transportation risk impacts using five major categories of input data : 1) accident frequency, 2) release quantities, 3) atmospheric dispersion parameters, 4) population distribution parameters, and 5) human uptake and dosimetry models. Accident frequency and release quantities are discussed below; the remaining parameters were discussed in Section D.2.1.

To calculate the frequency of a severe accident, an overall accident rate (accidents per truck-km) is multiplied by the conditional probability that an accident would involve mechanical and/or thermal conditions that are severe enough to result in container failure and subsequent release of radioactive material.

For this analysis, the six shipment-specific severity categories and conditional probabilities identified in DOE (1996) were used to model cask failure. The conditional probability for a given severity category is

defined as the fraction of accidents that would fall into that severity category if an accident were to occur. Severity category 1 was defined as encompassing all accidents within the Type B package envelope that would not be severe enough to result in failure of the shipping cask (i.e., accidents with zero release). The higher categories (2-6) were defined to include more severe accidents that might lead to a release of radioactive material. The conditional probabilities of the various severity categories that were used in this analysis are shown in Table D.7.

Table D.7. Severity Category Conditional Probabilities (DOE 1995)

Mode/ Truck	Conditional Probability by Severity Category					
	1	2	3	4	5	6
Rural	0.462	0.302	0.176	0.0403	0.0183	6.84E-04
Suburban	0.436	0.285	0.221	0.0506	8.38E-03	7.31E-05
Urban	0.583	0.382	0.0278	6.36E-3	8.88E-04	1.22E-05

Release fractions are used to determine the quantity of radioactive material released to the environment as a result of an accident. The quantity of material released is a function of the severity of the accident (i.e., thermal and mechanical conditions produced in the accident), the response of the shipping container to these conditions, and the physical and chemical properties of the material being shipped. However, not all of the material released as a result of the accident is respirable and results in impacts to an individual. A fraction of the material released can be suspended in a plume and inhaled by an individual. The release fractions used in this analysis are shown in Table D.8. The fraction of the material released and suspended in plume (Aerosol) that can be inhaled by an individual (Respirable) is shown in Table D.9.

Table D.8. Release Fraction by Material and Severity Category

TPBAR Assembly Component	Release Fraction by Severity Category					
	1	2	3	4	5	6
H-3[a]	0	0.0099	0.033	0.39	0.33	0.63
NTBC[a]	0	3.0E-10	1.0E-09	1.0E-08	1.0E-08	1.0E-07
(a) Taken from DOE (1995), for aluminum and metallic spent nuclear fuel						

Table D.9. Aerosol and Respirable Fractions by Material and Severity Category

TPBAR assembly component	Aerosol and respirable fractions by severity category[a]					
	1	2	3	4	5	6
H-3[b]	A=0 R=0	A=1 R=1	A=1 R=1	A=1 R=1	A=1 R=1	A=1 R=1

NTBC[b]	A=0 R=0	A=0.01 R=0.05	A=0.01 R=0.05	A=0.01 R=0.05	A=0.01 R=0.05	A=0.01 R=0.05

(a) A = fraction that is aerosol, R = fraction that is respirable
(b) Taken from Neuhauser et al. (1992), H-3 characterized as a gas, and NTBC characterized as loose chunks.

The input data used to calculate the radiological dose to the public (i.e., population densities, travel times, and distances) were the same as the inputs used to calculate the incident-free dose to the population and are shown in Tables D.3 and D.4. The radiological inventory used in the accident analysis was shown in Table D.1. The accident frequency used in the analysis was based on a review of local or state-specific accident data (Saricks and Kvitek 1994). The Hanford Site accident data (or rates expressed as accidents/km) used in this analysis were taken from Bergsman et al. (1995) and are recommended for the Hanford Site. The accident rate used for truck shipments is 8.86E-08 accidents/km (5.50E-08 accidents/mi).

Table D.10 presents the expected consequences for each transportation mode by waste type and destination. As shown in Table D.10, there are no impacts to the public (i.e., LCFs are less than 3.3E-04).

Table D.10. Radiological Impacts from Transportation Accidents

Material Transported		Radiological Impacts (person-rem)	Health Effects (LCFs)
Origin	Destination	Public	Public
Irradiated TPBAR assemblies			
WBNP	PNNL 2 shipments 4 shipments	 0.35 0.59	 None (1.8E-04) None (3.0E-04)
Irradiated TPBARs			
PNNL	HFEF	0.030	None (1.5E-05)
HFEF	PNNL	0.030	None (1.5E-05)
PNNL	Solid Waste	0.00016	None (6.4E-08)
Non-target bearing components			
PNNL	Solid Waste	1.0E-11	None (4.0E-15)

D.4.2 Radiological Impacts to Maximum-Exposed Individuals

The consequences of a maximum credible accident to an individual were evaluated for shipments between the Hanford Site and ANL-W. Of the shipments evaluated, this leg would produce the greatest potential

consequences because all 32 irradiated TPBARs could be involved. The receptor is assumed to be located at a distance of 100 m from the release if the accident occurs outside the boundaries of a DOE facility, or at the site boundary if the accident occurs onsite. Radiological doses were calculated for maximally exposed individuals near the PNNL 325 Building, either 100 m from the release point (the onsite individual), or at a distance of 580 m (the site boundary). For this bounding analysis, the maximum individuals were assumed to be located east-southeast of the release, which is the direction in which maximum consequences are obtained. These receptors were also presumed to bound the consequences of accidents that might take place within the INEEL site boundary or at offsite locations. The radionuclide inventory used in this analysis is shown in Table D.1. However, because tritium accounts for greater than 99% of the dose, only tritium releases are discussed in detail.

The bounding accident evaluated for transportation involves an impact severe enough to breach the shipping container and damage the TPBARs. Only free gaseous tritium within the TPBARs is assumed to be released in this event. Consistent with the evaluation for facility accidents (see Appendix C, Section C.3.1), the free tritium inventory in a single TPBAR amounts to an equivalent release of 96 Ci as tritium oxide. Therefore, if all 32 TPBARs were damaged, the maximum release of tritium oxide would amount to about 3100 Ci. The radiological impacts of this release to the maximum individuals were calculated using GENII (Napier et al. 1988), and the results are presented in Table D.11 (see also Appendix C, Table C.2).

The estimated frequency of this accident is less than 2×10^{-5} based on a round-trip transport distance of 1200 mi between ANL-W and Hanford (Table D.3), an accident rate of 2.3×10^{-7}/mi, and a conditional frequency of less than 6×10^{-2} for accidents of severity category 4 or greater (Table D.7). Accidents of lesser severity would release substantially less than the total free tritium inventory in the TPBARs (Table D.8), whereas accidents involving sufficiently high thermal and mechanical stress to release 100% of the tritium would be considered incredible (i.e., they have an expected frequency less than 1×10^{-7}).

Table D.11. Dose to Maximally Exposed Individuals

Maximum Individual	Distance from Release	Total Effective Dose Equivalent (mrem)
Public/Onsite	100 m	3.1×10^{3}
Offsite	580 m	1.6×10^{2}

D.4.3 Non-Radiological Impacts due to Transportation Accidents

This section describes the analyses performed to assess non-radiological impacts to the public and Hanford Site workers. The non-radiological impacts associated with the transportation of the tritium lead test assemblies are assumed to be comparable to the impacts associated with general transportation activities in the United States. To calculate non-radiological impacts or fatalities, a unit risk factor (i.e. fatalities per km or fatalities per mi, developed for specific population zones or density) is multiplied by the total

shipment distance (i.e., total distance per campaign). The fatalities are due to vehicular impacts with solid objects, rollovers, or collisions. Therefore, unit risk factors are required for crew members and the public, i.e., individuals on or immediately adjacent to roadways.

The unit risk factors applied to determine non-radiological impacts to the public (i.e., persons not on the Hanford Site) are taken from Saricks and Kvitek (1994). These factors are developed for specific population densities and are expressed as fatalities per km traveled. The unit risk factor used in this analysis for Hanford Site shipments, taken from Daling and Harris (1994), was 5.3E-08 fatalities/km for the public.

Results are obtained for each alternative by multiplying the unit risk factors by the appropriate total shipping distances for each alternative. It has been assumed that an accident that results in public or Hanford Site worker fatalities will also be fatal to the truck crew. The results of this analysis are shown in Table D.12 for all transportation modes, waste types, and destinations.

Table D.12. Non-Radiological Impacts due to Transportation Accidents

Material Transported		Non-radiological Impacts (fatalities)
Origin	Destination	
Unirradiated TPBAR assemblies		
PNNL	WBNP	None (9.0E-05)
Irradiated TPBAR assemblies		
WBNP	PNNL 2 shipments 4 shipments	 None (1.4E-04) None (2.8E-04)
Irradiated TPBARs		
PNNL	HFEF	None (1.6E-05)
HFEF	PNNL	None (1.6E-05)
PNNL	Solid Waste	None (1.9E-06)
Non-target bearing components		
PNNL	Solid Waste	None (9.2E-06)
Empty shipping cask for reloading		
PNNL	WBNP 1 shipment 3 shipments	 None (6.4E-05) None (1.9E-04)

D.5 References

10 CFR 71. 1993. U.S. Nuclear Regulatory Commission, "Packaging and Transportation of Radioactive Material." U.S. Code of Federal Regulations.

49 CFR 173. 1993. U.S. Department of Transportation, "Shippers - General Requirements for Shipments and Packages." U.S. Code of Federal Regulations.

Bergsman, K.E, T.B Bergman, D.W. Bergmann, G.E. Costley, M.T. Jansky, M. Kummerer, R.L. McCormack, M.J. Monthey, A.N. Praga, I.K. Ullah, W.L. Willis, and A.G. Hosler. 1995. *K Basin Environmental Impact Statement Technical Input.* WHC-SD-SNF-TI-013, Rev. 0. Westinghouse Hanford Company, Richland, Washington.

Clarke, R. K., J. T. Foley, W. F. Hartman, and D. W. Larson, 1976, *Severities of Transportation Accidents, Volume 1 - Summary.* SLA-74-001, Sandia National Laboratories, Albuquerque, New Mexico.

Daling, P. M. and M. S. Harris, 1994, *Transportation Impact Analysis for Shipment of Irradiated N-Reactor Fuel and Associated Materials*, PNL-10249, Pacific Northwest Laboratory, Richland, Washington.

Dennis, A. W., J. T. Foley, W. F. Hartman, and D. W. Larson, 1978, *Severities of Transportation Accidents Involving Large Packages.* SAND77-0001, Sandia National Laboratories, Albuquerque, New Mexico.

International Commission on Radiological Protection (ICRP). 1991. *1990 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 60, Pergamon Press, Oxford.

Johnson, P. E., D. S. Joy, D. B. Clarke, and J. M. Jacobi. 1993. *HIGHWAY 3.3, An Enhanced Highway Routing Model: Program Description, Methodology, and Revised User's Manual.* ORNL/TM-12124. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Madsen, M. M., J. M. Taylor, R. M. Ostmeyer, and P. C. Reardon. 1986. *RADTRAN III.* SAND84-0036. Sandia National Laboratories, Albuquerque, New Mexico.

Napier, B. A., D. L. Strenge, R. A. Peloquin, and J. V. Ramsdell. 1988. *GENII -The Hanford Environmental Radiation Dosimetry Software System.* PNL-6584, Vol. 1 -Conceptual Representation, Vol. 2 - Users' Manual, Vol. 3 - Code Maintenance Manual. Pacific Northwest Laboratory, Richland, Washington.

Neuhauser, K. S. and F. L. Kanipe. 1992. *RADTRAN 4: Volume 3 -- User Guide.* SAND89-2370. Sandia National Laboratories, Albuquerque, New Mexico.

Rao, R.K., E. L. Wilmot, and R. E. Luna. 1982. *Non-Radiological Impacts of Transporting Radioactive Material.* SAND81-1703. Sandia National Laboratories, Albuquerque, New Mexico.

Saricks, C. and T. Kvitek. 1994. *Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight.* ANL/ESD/TM-68. Argonne National Laboratory, Argonne, Illinois.

U.S. Department of Energy (DOE). 1995. *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environment Impact Statement.* DOE/EIS-0203-F. U.S. Department of Energy, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes.* NUREG-0170. Washington D.C.

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600
(360) 407-6000 • TDD Only (Hearing Impaired) (360) 407-6006

June 25, 1997

Mr. Paul F.X. Dunigan Jr.
U.S. Dept. of Energy
PO Box 550
Richland WA 99352

Dear Mr. Dunigan:

Thank you for the opportunity to comment on the draft environmental assessment for Lead Test Assembly Irradiation and Analysis for the Watts Bar Nuclear Plant, Tennessee; and Hanford Site, Richland, Washington (DOE/EA-1210). We have reviewed the document and have the following comments.

Post irradiation examination and nondestructive evaluation activities conducted at Hanford's 325 facility should be planned and executed in a manner which fully supports required cleanup and compliance work and associated schedules under the Hanford Federal Facility Agreement and Consent Order.

Documentation should be forwarded to appropriate Ecology project managers for any wastes generated for storage, treatment, or disposal at Hanford facilities, containing identification, characterization, and plans for management.

If you have any questions, please call Mr. Roger Stanley with our Nuclear Waste program at (360) 407-7108.

Sincerely,

Barbara J. Ritchie

Barbara J. Ritchie
Environmental Review Section

BJR:ri
97-3847

cc: Ron Effland, Kennewick
Roger Stanley, Nuc Waste
Geoff Tallent, Nuc Waste

RECEIVED
JUL 01 1997
DOE-RL/RLCC

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

JUL 21 1997

97-STP-479

Ms. Barbara Ritchie
Environmental Review Section
State of Washington
Department of Ecology
P. O. Box 47600
Olympia, Washington 98504-7600

Dear Ms. Ritchie:

RESPONSE TO COMMENTS ON THE DRAFT ENVIRONMENTAL ASSESSMENT FOR THE LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS

The U.S. Department of Energy, Richland Operations Office received your letter, dated June 25, 1997, providing comments on the draft environmental assessment for the Lead Test Assembly Irradiation and Analysis for the Watts Bar Nuclear Plant, Tennessee; and Hanford Site, Richland, Washington (DOE/EA-1210). Thank you for your interest in this project and for the comments provided in your letter.

In response to your comments, post irradiation examination and nondestructive evaluation activities conducted at the 325 Building will be planned and executed in a manner which fully supports required cleanup and compliance work and associated schedules under the Hanford Federal Facility Agreement and Consent Order.

In addition, documentation will be forwarded to appropriate Ecology project managers for any wastes generated for storage, treatment, or disposal at Hanford facilities in accordance with existing procedures.

If you have any questions, please contact me on 376-6667 or Julie Turner, NEPA Document Manager, on 372-4015.

Sincerely,

Annabelle Rodriguez
for Paul F. X. Dunigan, Jr.
NEPA Compliance Officer

STP:JKT

cc: C. M. Borgstrom, EH-42
S. M. Sohinki, DP-62

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DOE OVERSIGHT DIVISION
761 EMORY VALLEY ROAD
OAK RIDGE, TENNESSEE 37830-7072

June 27, 1997

Paul F. X. Dunigan, Jr., NEPA Compliance Ofl
US Department of Energy
Richland Operations Office
PO Box 550
Richland Washington 99352

Dear Mr. Dunigan

Document Review -- Draft Environmental Assessment: "Lead Test Assembly Irradiation and Analysis Watts Bar Nuclear Plant, Tennessee and Hanford Site, Richland, Washington," DOE/EA-1210, June 1997

The Tennessee Department of Environment and Conservation, DOE Oversight Division (TDEC/DOE-O) has received the above Draft Environmental Assessment (EA). The Subject EA was reviewed in accordance with the requirements of the National Environmental Policy Act (NEPA) and associated implementing regulations 40 CFR 1500 1508 and 10 CFR 1021 as implemented.

If you have any questions regarding the Division's review, please contact Dale Rector at (423) 481-0995.

Sincerely

Earl C. Leming
Director

cc: Dodd Galbreath, Tennessee Environmental Policy Office
Mike Mobley, Division of Radiological Health
Susan Gawarecki, Oak Ridge Reservation Local Oversight Committee
Mary Bryan, Oak Ridge Site Specific Advisory Board
James C. Hall, Manager DOE ORO

em394.99

RECEIVED
JUL 07 1997
DOE-RL/RLCC

Tennessee Department of Environment and Conservation/DOE Oversight Division

Comments on Draft Environmental Assessment
DOE/EA-1210, June 1997,
Lead Test Assembly Irradiation and Analysis Watts Bar Nuclear Plant,
Tennessee and Hanford Site, Richland, Washington

GENERAL COMMENTS

- It should be clearly stated that the same design, configuration, and number of tritium-producing burnable absorber rod lead test assemblies (TPBAR-LTAs) will be used during tritium testing as would be used during regular production or the differences explained.
- All wastes generated, including but not limited to radionuclides, should be identified.

It is exhilarating to see the Department of Energy identify a very practical and "common sense" solution to a complex problem. The initial ideas to construct a completely new reactor or an accelerator to produce tritium for defense purposes seemed conceptually weak from a technological, political, environmental, and public opinion perspective. This proposed approach incorporates existing materials and assets and allows an engineered solution to the problem of tritium production for both national defense and industrial applications.

SPECIFIC COMMENTS

Page 1-1, last paragraph.
"A combination of the Commercial Light Water Reactor (CLWR) and accelerator alternatives (one option to serve as the primary tritium source with the other serving as the backup source) was selected in the Tritium Supply and Recycling Programmatic Environmental Impact Statement (TSR PEIS) Record of Decision (60 FR 63877-63891)."

DOE seems to be determined to include an accelerator as at least a secondary or backup tritium source. To be a practical backup, the accelerator must exist. If, one does not exist one can only assume one will be built and available as a backup. Tennessee's original comments (May 12, 1995, letter to Stephen M. Sohinki, US DOE) had assumed that if, a Light Water Reactor (LWR) was used, an accelerator would not be built at environmental and taxpayer expense. Simply select different LWRs (within the TVA system, if necessary) as secondaries in case of unexpected outages at the primary.

Section 2.2.2, Page 2-4
Would irradiation of the lithium produce increased pressures within the TPBAR-LTA assembly as lithium was converted to tritium? If so, would that pressure increase be negligible?

Section 2.2.3, Page 2-4
What types and activities of neutron activated materials will be produced within the TPBAR-LTA during and after irradiation? Please list the individual isotopes and activities that would be expected.

Section 2.2.4, Page 2-4
Does the Oak Ridge Reservation have a neutron radiography facility that would be suitable for the post irradiation examination? Would Oak Ridge be an interim stop for TPBAR materials bound for Hanford?

Page 2-3, paragraph 3
What have previously mentioned DOE tests shown about the potential of TPBARs cladding to fail and cause large leaks, such as into the reactor pool and primary coolant? Are the same manufacturing quality control checks done as for typical burnable borosilicate absorber rods, control rods, and fuel rods which are typically manufactured in the private sector? Is the frequency of cladding failure similar? What are the specific differences in cladding construction and materials, if any?

Page 2-5, paragraph 2
"All of the TPBARs may then be punctured to collect and analyze gases that accumulated during irradiation, and the penetrations would be resealed prior to storage or further handling."

What have, mentioned, previous DOE tests shown about gas characteristics in the TPBARs and pressure differentials between internal and external zones? Have tests already been done under similar neutron fluxes and burns? This information would be valuable in order to evaluate hazards before the TPBARs are irradiated and shipped to Hanford. The State of Tennessee is responsible for emergency management for the Watts Bar Nuclear Plant (WBN) vicinity and requests the information for emergency preparedness.

Pages 5-1, 5-3, D-18, & D-19
"Erickson et al 1997" is referenced in section 5.1.1.2 on page 5-1, section 5.2 on page 5-3 and in section 5.4.2 on page 5-5; however, that reference is not included in the list of references on pages D-18 & D-19.

Section D-1, Page D-1
Are the radionuclide levels identified in Table D-1 representative of the levels expected after irradiation or are they theorized maximums?

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

JUL 21 '97

97-STP-507

Mr. Earl C. Leming, Director
DOE Oversight Division
Department of Environment and Conservation
761 Emory Valley Road
Oak Ridge, Tennessee 37830-7072

Dear Mr. Leming:

RESPONSE TO COMMENTS ON DRAFT ENVIRONMENTAL ASSESSMENT DOE/EA-1210: LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS, WATTS BAR NUCLEAR PLANT, TENNESSEE AND HANFORD SITE, RICHLAND WASHINGTON

The Richland Operations Office has received your comments, dated June 27, 1997, on the subject draft Environmental Assessment (EA). Thank you for your interest in the environmental impacts of this project and for your comments. Responses to the comments are enclosed.

If you have any questions please contact Julie Turner, NEPA Document Manager, on (509) 372-4015 or myself on (509) 376-6667.

Sincerely,

Paul F. X. Dunigan, Jr.
NEPA Compliance Officer

STP:JKT

Enclosure

cc w/encl:
C. M. Borgstrom, EH-42
S. M. Sohinki, DP-62

DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE
RESPONSES TO COMMENTS FROM
STATE OF TENNESSEE, DEPARTMENT OF ENVIRONMENT AND CONSERVATION
ON THE DRAFT ENVIRONMENTAL ASSESSMENT
LEAD TEST ASSEMBLY IRRADIATION AND ANALYSIS

General Comments:

It should be stated that the same design, configuration and number of TPBARS used during the test will be used during regular production.

It is not necessarily true that the same number, design or configuration of TPBARs used for the LTA test would also be used during regular production. The results from the LTA test, along with the design of the reactor eventually selected for production and the quantity of tritium required, will determine the eventual production configuration.

All waste generated, should be identified.

Sections 2.2.5 and 5.3 of the EA identify, both qualitatively and quantitatively, the expected types and volumes of waste generated during each phase of the proposed action. Wastes generated by routine operations at the reactor, which would not be impacted by the proposed action, were not specifically called out but are discussed in NRC (1995).

Specific Comments:

1. *Section 2.2.2, Page 2-4 - Would irradiation of the lithium produce increased pressures within the TPBAR-LTA assembly as the lithium was converted to tritium? If so, would that pressure increase be negligible?*

Generation of tritium and helium during irradiation would increase the pressure within the TPBARs. However, they are designed to maintain their integrity under conditions expected during shipping, handling, and reactor Condition I - IV events, with the exception of a (large break loss of coolant accident). An evaluation of expected performance of the TPBARs under the conditions at the Watts Bar Nuclear Plant (WBN) is described in a separate report (Erickson et al 1997). The TPBAR maximum internal design pressure is 3000 psia and the external design pressure is 2500 psia. The actual internal pressures in the TPBARs during and after the irradiation cycle are anticipated to be much lower than the design criteria (14.7 to 1755 psia).

2. *Section 2.2.3, Page 2-4 - What types and activities of neutron activated materials will be produced within the TPBAR-LTA during and after irradiation? Please list the individual isotopes and activities that would be expected.*

The TPBAR radionuclide inventory at various times after completion of the irradiation cycle was evaluated in a separate document (TTQP-1-050).

Based on that assessment, bounding inventories in the TPBARs and LTA hardware were assumed for purposes of the analysis in the environmental assessment (EA). The bounding TPBAR and hardware radionuclide inventories are summarized in Appendix D, Table D.1 of the EA.

3. *Section 2.2.4, Page 2-4 - Does the Oak Ridge Reservation have a neutron radiography facility that would be suitable for the post irradiation examination? Would Oak Ridge be an interim stop for TPBAR materials bound for Hanford?*

It is our understanding that the neutron radiography facility at ANL-W is the only operational DOE facility capable of handling the TPBARs. Use of facilities at ORR for this activity is unlikely for the reasons described in Section 3.2 of the EA; therefore, ORR would not be a potential stop during transport of the TPBARs from WBN to Hanford.

4. *Page 2-3, paragraph 3 - What have previously mentioned DOE tests shown about the potential of TPBARs cladding to fail and cause large leaks, such as into the reactor pool and primary coolant? Are the same manufacturing quality control checks done as for typical burnable borosilicate absorber rods, control rods, and fuel rods which are typically manufactured in the private sector? What are the specific differences in cladding construction and materials, if any?*

Erickson et al (1997) describes the results of previous DOE tests as related to the expected safety and operational performance of the TPBARs at WBN. The potential for, and consequences of, a TPBAR failure are described in Erickson et al (1997) and in section 5.4.2 of the EA. Such an event would result in a small (less than 2%) increase in the offsite consequences compared to those from WBN routine operations, and would not cause the facility to exceed any regulatory standards.

The TPBARs are designed and manufactured to the same safety and quality standards as the commercially produced Westinghouse PWR burnable absorber rods. A quality assurance audit of the process used to manufacture the TPBARs was conducted to ensure that NRC nuclear safety requirements were being implemented. Substitution of TPBARs for a small number of the standard absorber rods is not expected to affect performance of the reactor or its safety systems under normal or off-normal operating conditions (see also response to specific comment #1). More detailed descriptions of the TPBAR design are provided in Erickson et al (1997) and in TTQP-1-015, which is included as Appendix A to the EA.

5. *Page 2-5, paragraph 2 - What have, mentioned, previous DOE tests shown about gas characteristics in the TPBARs and pressure differentials between internal and external zones? Have tests already been done under similar neutron fluxes and burns? This information would be valuable in order to evaluate hazards before the TPBARs are irradiated and shipped to Hanford. The State of Tennessee is responsible for emergency management for the Watts Bar Nuclear Plant (WBN) vicinity and requests the information for emergency preparedness.*

The expected performance of the TPBARs under operating conditions at WBN are described in Erickson et al (1997), based on previous tests at DOE facilities (see also response to specific comment #1 regarding the expected pressure within the TPBARs). No potential effects on WBN plant or safety system operation were identified, and tritium that might be released from the TPBARs under off-normal conditions would contribute only minimally to the consequences of accidents evaluated in the WBN FSAR. Detailed performance data for tritium retention in the TPBAR components are classified; however, a bounding estimate of the tritium release and consequences from a severe transportation accident are described in the EA, sections 5.5.2.1 and D.4.2.

6. *Pages 5-1, 5-3, D-18, and D-19 - "Erickson et al 1997" is referenced in section 5.1.1.2 on page 5-1, section 5.2 on page 5-3, and in section 5.4.2 on page 5-5; however, that reference is not included in the list of references on pages D-18 and D-19.*

The reference is listed in section 8.0, page 8-1, which is the reference list for the main text of the EA. Pages D-18 and D-19 contain only the references for Appendix D, in which the Erickson document was not cited.

7. *Section D-1, page D-1 - Are the radionuclide levels identified in Table D-1 representative of the levels expected after irradiation or are they theorized maximums?*

The radionuclide inventories in Table D.1 represent the bounding design inventories for the TPBARs following irradiation (see section D.1, paragraph 2, and TTQP-1-050). The best estimate inventories are similar to the bounding estimates for most radionuclides; however, for a few isotopes they may be up to 60% lower than the bounding design inventories.

References:

Erickson, LW, A. Lopez, E.F. Love, B.E. Schmitt, E.R. Gilbert, R.L. Van Witbeck, 1997. *Report on the Evaluation of the Tritium Producing Burnable Absorber Rod Lead Test Assembly*. PNNL-11419, Rev. 1. Pacific Northwest National Laboratory, Richland, Washington.

U.S. Nuclear Regulatory Commission (NRC). 1995. *Final Environmental Statement Related to the Operation of Watts Bar Nuclear Plant, Units 1 and 2.* NUREG-0498, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, D.C.

Tritium Target Qualification Project (TTQP). 1996. *Description of the Tritium-producing Burnable Absorber Rod for the CLWR Lead Test Assembly.* TTQP-1-015. Prepared by Mohr and Associates, Richland, Washington for Pacific Northwest National Laboratory, Richland, Washington.