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TENNESSEE VALLEY AUTHORITY

Office of Natural Resources and Economic Development
Division of Air and Water Resources

RESULTS OF PLANKTON STUDIES CONDUCTED IN 1986 AND 1987 AS PART OF THE OPERATIONAL AQUATIC MONITORING PROGRAM AT SEQUOYAH NUCLEAR PLANT, CHICKAMAUGA RESERVOIR

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EXECUTIVE SUMMARY

TVA conducted plankton studies in 1986 and 1987 to further examine causes of reduced plankton densities observed in Chickamauga Reservoir under low reservoir flows and two-unit operation at Sequoyah Nuclear Plant (SQN). Studies in 1986 were conducted with both SQN units shutdown, low reservoir flows, and water pumped through the condenser cooling water (CCW) system (in May) and no water pumped through the CCW (in August). In May, phytoplankton densities were not reduced downstream of SQN; zooplankton densities were reduced. In August neither were reduced. Results of 1986 studies indicated that phytoplankton densities would not be reduced unless reservoir flows were low and SQN was dissipating heat in the CCW causing the heated water discharged through the diffusers to rise to the surface thereby mixing deeper strata water (low in phytoplankton) with upper strata water (rich in phytoplankton). Reduction of zooplankton densities in absence of dissipation of heat in the CCW indicated a relationship between reduced densities and physical effects from entrainment through the CCW.

Studies in 1987 were aimed at evaluating effects of entrainment through the CCW in absence of heat dissipation. Reservoir flows in 1987 were representative of more normal conditions than those experienced in 1986. Phytoplankton densities in the diffuser discharge pond were not reduced relative to densities in the intake

on either the July or August 1987 study dates. Similarly, comparison of phytoplankton densities in the reservoir downstream of SQN with those upstream showed no reductions. Zooplankton densities were lower at the diffuser discharge pond on both sample dates, indicating a possible relationship to physical effects from entrainment through the CCW. Zooplankton densities in the reservoir downstream of SQN were not reduced compared to upstream, indicating reservoir flows were sufficiently high to prevent manifestation of lowered densities in the reservoir.

SQN effects on plankton under two-unit operation and normal reservoir flows have yet to be fully evaluated. Coincidental occurrence of these conditions has not existed during previous study periods. Recommendations provided in earlier reports to investigate these conditions should be followed when SQN resumes operation.

INTRODUCTION

This report provides results of plankton investigations conducted in 1986 and 1987 as part of the Sequoyah Nuclear Plant (SQN) aquatic monitoring program on Chickamauga Reservoir. The monitoring program was initially designed to identify major changes in water quality and biological communities of Chickamauga Reservoir resulting from operation of SQN. Results of monitoring conducted in 1980-84 (reported in TVA, 1982, 1983, 1984, and 1985) identified few significant changes in Chickamauga Reservoir considered to be related to operation of SQN. Based on absence of plant-induced effects and fulfillment of the minimum period required by the NPDES permit, some components of the program were recommended to be terminated and others recommended to be continued (some with specific alterations).

Plankton investigations were recommended for continuation with specific changes because SQN appeared to have an influence on phytoplankton and zooplankton during low reservoir flows and two-unit operation. Coincidental occurrence of two-unit operation and more normal flows was not encountered during the 1980-84 study period to sufficiently evaluate effects of SQN during those conditions. Hence, recommendations for studies in 1985 and thereafter were primarily aimed at evaluating two-unit operation and more normal flows.

Reservoir flows in 1985 were low due to drought conditions throughout the Tennessee Valley. Results of plankton investigations conducted in 1985 supported previous results in that SQN apparently caused reduced densities of phytoplankton and zooplankton downstream of SQN under low flow conditions (TVA, 1986). Results of the 1985 investigations were used to select specific conditions of reservoir flow and SQN operation necessary to fully evaluate SQN influence on plankton as described in table 1. Plankton investigations would not be conducted in the future unless those conditions developed.

Both units at SQN were shut down in August 1985. If recommendations were to be strictly adhered to, plankton investigations would not be conducted until SQN operation resumed. However, the drought in the Tennessee Valley continued into 1986 resulting in low reservoir flows. Also, water continued to be pumped through the condenser cooling water (CCW) and the essential raw cooling water (ERCW) systems for part of the year and only the ERCW during other times (the ERCW represents a negligible flow relative to the CCW flow). This set of conditions provided a unique opportunity to study plankton dynamics in Chickamauga Reservoir under low reservoir flows with SQN pumping water through the CCW (conducted in May) and with no flow through the CCW (conducted in August). Results of investigations conducted in May and August 1986 are reported here for the first time.

SQN continued to be shutdown through 1987. Again, if recommendations were strictly adhered to, plankton investigations would not have been conducted. However, results of the special studies conducted in 1986 indicated there would be value in conducting in-plant studies to evaluate condenser passage effects on plankton densities. Results of the "in-plant" studies conducted in 1987 are reported here.

1986 INVESTIGATIONS

Objective

Investigations in 1986 were conducted to determine if reduced plankton densities observed in previous years under conditions of low reservoir flows and SQN dissipating heat to the CCW would still be observed if (1) reservoir flows were low and SQN pumped water through the CCW and ERCW with no addition of heat in the CCW and (2) reservoir flows were low and SQN pumped water only through the ERCW (a negligible volume relative to the CCW). These conditions were examined in May and August, respectively.

Methods

Sample collection procedures, laboratory handling and processing procedures, and data analytical procedures were essentially the same as those used for 1985 studies and described in detail in TVA (1986).

Full-stratum zooplankton tows and stratified phytoplankton and water quality samples (0.3, 1.0, 3.0, and 5.0 m depths) were collected on May 20 and August 27, 1986, from five locations on Chickamauga Reservoir (figure 1). Phytoplankton community measurements (in duplicate) included at each location were organism enumeration, phytopigment concentration, and primary production rates. Water quality parameters included nutrients, alkalinity, and turbidity. *In situ* full stratum measurements of dissolved oxygen (DO), pH, temperature, and conductivity were made during sample collection at all locations. Duplicate zooplankton samples were examined for organism identification and enumeration.

Samples for chlorophyll fluorescence measurements were collected on May 20 and August 28, 1986, from surface and one meter depths and then at two-meter intervals to the bottom. The samples were collected from midchannel at TRMs 478.2, 482.0, 483.4, and 484.5.

Results and Discussion

All data as well as results of statistical procedures used to analyze those data are provided in the appendices. Appendix A contains water quality data; appendix B contains phytoplankton data; appendix C contains zooplankton data.

Environmental conditions in Chickamauga Reservoir during May and August 1986 were quite different from typical years in that the Tennessee Valley was in a second consecutive drought year. Reservoir flows were substantially below normal (8,100 cfs in May and 13,500 cfs in August) and residence times in the reservoir were much longer than usual (figures 2 and 3).

Plant operating conditions were also different in 1986 than in previous years of operational monitoring. Both units at SQN were shut down in August 1985 and did not resume operation in 1986. During May the CCW was pumping about half capacity which, coupled with low river flows, resulted in a substantial proportion (11 percent) of the river flow being entrained. During August, the CCW was not pumping any water and only nominal quantities were withdrawn for other purposes.

This combination of factors allowed evaluation of plankton dynamics in Chickamauga Reservoir under low-flow conditions with the CCW operating but without heat from unit generation (May) and without the CCW operating (August). Because reduced plankton densities had been observed during previous low-flow periods when potential for plant effect was high, studies in 1986 provided insight on those operational characteristics likely important in causing observed reductions.

During May the phytoplankton community exhibited natural successional changes from upstream to downstream. Chlorophytes decreased from upstream to downstream, while the reverse was true for chrysophytes and cyanophytes resulting in an overall increase in total cell density (figure 4). It appears that pumping water through the CCW had little influence on the phytoplankton. This could be expected because chlorophyll fluorescence data and dissolved oxygen data showed that phytoplankton were concentrated in upper strata and water entrained into the CCW was withdrawn from near bottom with little influence on upper strata.

The zooplankton community exhibited reduced densities at the diffuser station in May compared to control stations 1.1 and 7.1 miles upstream (figure 5). The reduction was apparent in several taxa although the two dominant forms (*Diaphanosoma leuchtenbergianum* and copepod nauplii) were affected the most. These lowered densities may have been a plant effect, i.e., destruction of organisms during passage through the

CCW. Another possibility is that there may be a sampling artifact related to the unusual hydraulics caused by the underwater dam and the mixing action created by the diffusers. Samples could be collected from the intake basin and diffuser pond to help determine if the reduction occurs during passage through the CCW.

During August neither the phytoplankton nor zooplankton data yielded any pattern that would indicate a relationship to presence/operation of SQN (figures 4 and 5). The reduced zooplankton densities typically observed at the diffuser station under low-flow conditions were not observed in August (low river flow but no flow through the CCW).

Studies conducted in 1986 indicate that pumping water through the CCW without addition of heat has little effect on the phytoplankton. Heat added in the CCW during electrical generation gives buoyancy to water discharged through the diffusers. When reservoir flows are sufficiently low, it appears that the heated water rises to the surface and mixes bottom water (low in phytoplankton) with upper strata water (rich in phytoplankton), thereby causing an apparent reduction in density in upper strata.

Recommendations

Recommendations provided in previous TVA reports and approved by the Tennessee Department of Health and Environment (with specific changes) should be followed when SQN resumes operation once the conditions set forth (table 1) develop. In the meantime while SQN units are not generating (no addition of heat) and water is being pumped through the CCW, plankton samples should be collected from the intake near the pumping station and from the diffuser pond to help determine if densities are reduced from passage through the CCW. Samples should also be taken from TRM 484.5 and TRM 483.4 to determine if decreased densities are apparent at those locations at the time of collection.

1987 INVESTIGATIONS

Objective

Investigations in 1987 were conducted to determine if reductions observed in plankton densities (especially zooplankton) during previous low flow study periods were related to passage through the CCW.

Methods

Sample collection procedures, laboratory handling and processing procedures, and data analytical procedures were basically the same as in previous SQN studies (except as noted below) and have been detailed elsewhere (TVA, 1986). Studies in 1987 were conducted on two occasions, July 27 and August 31.

Sample collection sites differed substantially in 1987 from previous studies (figure 6). Samples were collected from near the CCW intake pumping station and near the diffuser pond discharge to examine differences resulting from passage through the plant. Samples were also collected from the cooling tower return channel near the overflow to the diffuser pond. Samples from this site were not compared directly to either the intake or discharge samples because water sampled was not in the flow path between the intake and diffuser pond under the operating scheme on both days of sample collection. When SQN is on helper mode cooling, this location is in the flow path between the intake and diffuser pond. These locations are referenced as in-plant collection sites.

All in-plant samples were collected at mid-depth of the respective sample site--5.0 m at the intake, 3.5 m in the diffuser pond, and 0.5 m in the return channel. Duplicate zooplankton enumeration samples were collected with a 50L Schindler trap from each site while duplicate phytoplankton enumeration and phytopigment samples were collected with standard gear. A single sample for chlorophyll fluorescence was collected at each of these sites also.

Two reservoir sample sites were also included--TRM 484.5 (in midchannel near the SQN skimmer wall) and TRM 483.4 (in midchannel downstream of the diffuser). These two sites were included to determine how changes caused by passage through the plant (if they occurred) were reflected at the two reservoir sites used in previous studies as the "intake" and "discharge" sites. The same types of community measurements were included at the reservoir sites with the addition of carbon assimilation rates. Full water column zooplankton tows were made with a plankton net and phytoplankton samples were collected at several depths.

In situ measurements of dissolved oxygen (DO), pH, temperature, and conductivity were made during sample collection at all sample stations except the cooling tower return channel. In addition, water samples for metals and residual chlorine were collected each survey in the diffuser pond and at 1.5 m at TRMs 484.5 and 483.4 as requested in a January 9 letter from the Tennessee Department of Health and Environment. The metals sample was analyzed for cadmium, boron, lead, aluminum, and nickel.

Statistical tests were not used to examine differences between "in-plant" stations and "reservoir" sites because of differences in sample collection procedures required by differences in habitat at in-plant and reservoir areas. The main points of interest were the intake/discharge data relationships and the upstream/downstream reservoir data relationship.

Results and Discussion

All data as well as results of statistical procedures used to analyze those data are provided in appendices. Appendix D contains water quality data, appendix E contains phytoplankton data, and appendix F contains zooplankton data.

Environmental conditions in July and August 1987 were representative of more normal conditions than those which existed in 1985 and 1986 (figures 7 and 8). Reservoir flows were 30,300 ft^3/s (858 m^3/s) on July 27 and 23,100 ft^3/s (654 m^3/s) on August 31 which compare to long-term average flows of 29,700 and 31,500 ft^3/s (841 and 892 m^3/s) for July and August, respectively.

SQN remained shut down throughout 1987. Raw water demand was approximately 900 ft^3/s (25m^3/s) on both sample dates which computes to about a three percent hydraulic entrainment rate in July and four percent in August. Changes in the plankton community attributable to operation of SQN have not been observed in previous study periods with entrainment rates this low.

Water quality data indicated generally stratified conditions (temperature and DO) on July 27 and well-mixed conditions on August 31.

The lowest DO (3.9 mg/L) observed for either study period occurred near bottom at TRM 484.5 on July 27 and the highest level (9.6 mg/L) near surface at TRM 483.4 on the same date. Supersaturated DOs and elevated pH levels in upper strata at both TRM 484.5 and 483.4 on July 27 indicate substantial algal photosynthetic activity. These conditions did not exist on August 31, nor were they apparent at the inplant sites on either study date.

Concentrations of selected metals in water are in table 2 along with their respective criteria for protection of aquatic life. The only instance where a criterion was exceeded was for lead in the diffuser pond on July 27 when the 4.0 μg/L measured slightly exceeded the chronic criterion level of 3.2 μg/L. Comparisons between an instantaneous measurement and a criterion based on a 4-day average must be made conservatively and used only as an indication of potential effects. Because the measured level was much below the acute level (84 μg/L), it is unlikely that toxic effects would have resulted with a calculated maximum exposure period (retention time in diffuser pond) of 2.5 hours.

Chlorine residuals were $\leq$0.1 mg/L (the minimum detection limit) at all sites tested. Sites tested were the 5-foot depth at TRMs 484.5 and 483.4 and the diffuser pond on both sample dates.

All phytoplankton measurements on both July 27 and August 31 revealed few differences between intake and diffuser pond samples (total densities are illustrated in figure 9). These results indicate no discernible impact from passage through the plant under the conditions which existed.

Likewise, phytoplankton cell densities (figure 9) and chlorophyll a concentration at the two reservoir sites were similar. This would be expected because the relatively low volume of unheated discharge water would not be expected to reach upper strata where most algal activity occurs. Surprisingly, carbon assimilation rates were higher at TRM 483.4 than at TRM 484.5 on both occasions. This would indicate better conditions at TRM 483.4 but there is nothing in available information which could help explain this difference.

Phytoplankton cell densities and chlorophyll a concentrations were much lower at in-plant sites than reservoir sites in July but not August. This was likely due to stratified conditions in July which allowed water from deeper strata, low in phytoplankton, to be pulled under the skimmer wall into the intake basin, while in August well-mixed conditions caused the phytoplankton to be more evenly distributed in the water column.

Zooplankton densities were lower at the diffuser pond site than at the intake site on both study dates (figure 10), although reductions were much greater in July (88 percent lower) than in August (42 percent lower). In July these reductions occurred in essentially all taxa; whereas, in August most rotifer taxa were greatly reduced but cladoceran and copepod taxa were negligibly affected. These large reductions would not be expected based on entrainment studies at TVA fossil-fired plants (TVA, 1978).

Zooplankton densities at the reservoir station downstream of the diffuser were actually higher than those at the station near the intake on both sample dates; opposite the trend observed at the in-plant stations (figure 10). Losses observed at in-plant stations would not necessarily be observed at the reservoir station because the plant was entraining such a small proportion (three - four percent) of the river flow.

Results of 1987 studies coupled with knowledge gained from previous studies provide insight on the relationship between SQN and observed differences in the plankton community. A summary of previous study conditions and conclusions drawn from plankton data are in table 3. Table 3 indicates that the phytoplankton community would not be substantially affected unless SQN entrained at least 10 percent of the river flow and had a heated effluent which apparently causes the water discharged through the diffusers to rise to the surface thereby mixing deeper strata water (low in phytoplankton) with upper strata water (rich in phytoplankton). It appears zooplankton may be affected anytime water is being pumped through the plant, but this effect is not detectable in the reservoir unless a relatively large proportion (10 percent or greater) of the river flow (or zooplankton if different from the hydraulic proportion) is entrained. It should be noted in table 3 that on some occasions SQN entrained approximately 10 percent of the river flow and effects on phytoplankton and zooplankton were not observed.

Recommendations

Recommendations provided in previous TVA reports and approved by the Tennessee Department of Health and Environment (with specific changes) should be followed when SQN resumes operation once the conditions set forth (table 1) develop. These recommendations were developed to evaluate effects of SQN on plankton under "normal" reservoir flows and maximum SQN operation. This information is necessary to adequately evaluate effects of SQN on plankton.

Table 1. Conditions Under Which Samples Will Be Collected to Determine If Two-Unit Operation of Sequoyah Nuclear Plant Causes Effects of Plankton at Other Than Low River Flows

Season*	Level of Operation	Flow (cfs)	Required Period†
Spring	two-unit	19,000	2-3
Spring	two-unit	28,300	1-2
Summer	two-unit	12,000	6-7
Summer	two-unit	29,700	1-2
Summer	two-unit	37,500	1-2

*Spring = May; Summer = July 15 - August 15.
†Number of days required where specified conditions of plant operation and reservoir flow must exist before plankton studies would be conducted.

Table 2. Levels of Metals in Water at Each Collection Site in 1987 Plankton Studies at Sequoyah Nuclear Plant (all units g/L unless otherwise noted).

	Water Quality Criteria		July 27			August 31		
	Chronic	Acute	TRM 484.5	TRM 483.4	Diffuser Pond	TRM 484.5	TRM 483.4	Diffuser Pond
Boron	*	*	<50	<50	<50	<50	<50	<50
Cadmium	1.1†	3.9†	0.1	0.1	0.3	<0.1	<0.1	<0.1
Lead	3.2†	82†	<1	1	4	2	<1	1
Nickel	160	1,400	2	1	4	2	2	2
Aluminum	150‡	950‡	<50	60	110	<50	<50	<50

*Not developed for protection of aquatic life.
†At water hardness 100 mg/L.
‡Levels provided in draft criteria document dated February 18, 1986.

Table 3. Subjective Evaluation of Potential for Plant Impacts on Plankton During Each Operational Monitoring Period and Conclusion Drawer for Evaluation of Plankton Data Associated with Aquatic Monitoring Program for Sequoyah Nuclear Plant

Sample Period	Plant Load	Flows			Potential for Impact	Conclusion*	
		River	Intake	%		Phytoplankton	Zooplankton
1981							
Winter†	0	20,000	900	5	None-Low	Not Different-1	Not Different-1
Spring	500-1,100	10,000	900	9	Low	Different-2	Not Different-1
Summer†	0	30,000	1,200	4	None-Low	Different-2	Different-3
Fall	1,000	20,000	1,200	6	Low	Not Different-1	Different-3
1982							
Winter	800	60,000	1,100	2	None-Low	Not Different-1	Not Different-1
Spring	2,200	9,000	2,500	28	High	Different-4	Different-4
Summer	2,200	44,000	2,500	5	Moderate	Different-3	Different-3
Fall†	0	40,000	1,100	3	None to Low	Not Different-1	Not Different-1
1983							
Winter	2,200	50,000	2,500	5	Moderate	Different-3	Not Different-1
Spring‡	2,200	25,000	2,500	10	High	Not Different-1	Different-4
Summer	1,100	40,000	1,200	3	Low	Different-3	Different-2
Fall	1,100	25,000	2,000	8	Low-Moderate	Different-3	Different-3
1984							
Winter	1,100	21,100	2,100	10	Moderate	Not Different-1	Not Different-1
Spring‡	1,100	43,000	1,500	4	Low	Different-3	Different-3
Summer‡	1,100	44,200	2,200	5	Low	Different-3	Different-3
Fall‡	1,100	27,600	1,300	5	Low	Different-3	Not Different-1
1985							
Winter	2,200	29,600	2,500	8	Moderate	Different-3	Different-3
Spring	1,100	8,100	2,100	26	High	Different-5	Different-5
July	1,100-2,200	23,200	2,500	10	High	Different-5	Different-5
Fall	-	-	-	-			

Table 3. (Continued)

Sample Period	Plant Load	Flows: River	Flows: Intake	Flows: %	Potential for Impact	Conclusion*: Phytoplankton	Conclusion*: Zooplankton
1986							
Spring†	0	8,100	875	11	Low	Not Different-1	Different-3
Summer†	0	13,500	50	<1	None-Low	Not Different-1	Not Different-1
1987							
July†	0	30,300	875	3	None-Low	Not Different-1	Not Different-1
August†	0	23,100	875	4	None-Low	Not Different-1	Not Different-1

*Categories for conclusions (summarized from previous operational monitoring reports):

1. No effect--no station differences observed; SQN had no effect.

2. Unrelated to SQN--observed differences among stations were judged to be unrelated to operation of SQN (SQN neither initiated nor accentuated differences); hence, concluded no effect.

3. Not SQN induced--observed differences among stations were not caused or initiated by operation of SQN, but plant operation may have accentuated community changes which had started upstream of SQN; differences included in this category were considered inconsequential.

4. Partially SQN related--observed differences were related to some extent but not totally to operation of SQN.

5. Differences among stations were apparently caused by operation of SQN.

†Potential of impact resulting only from entrainment through the plant.

‡Community densities quite low, probably too low to provide meaningful evaluation of plant effects.

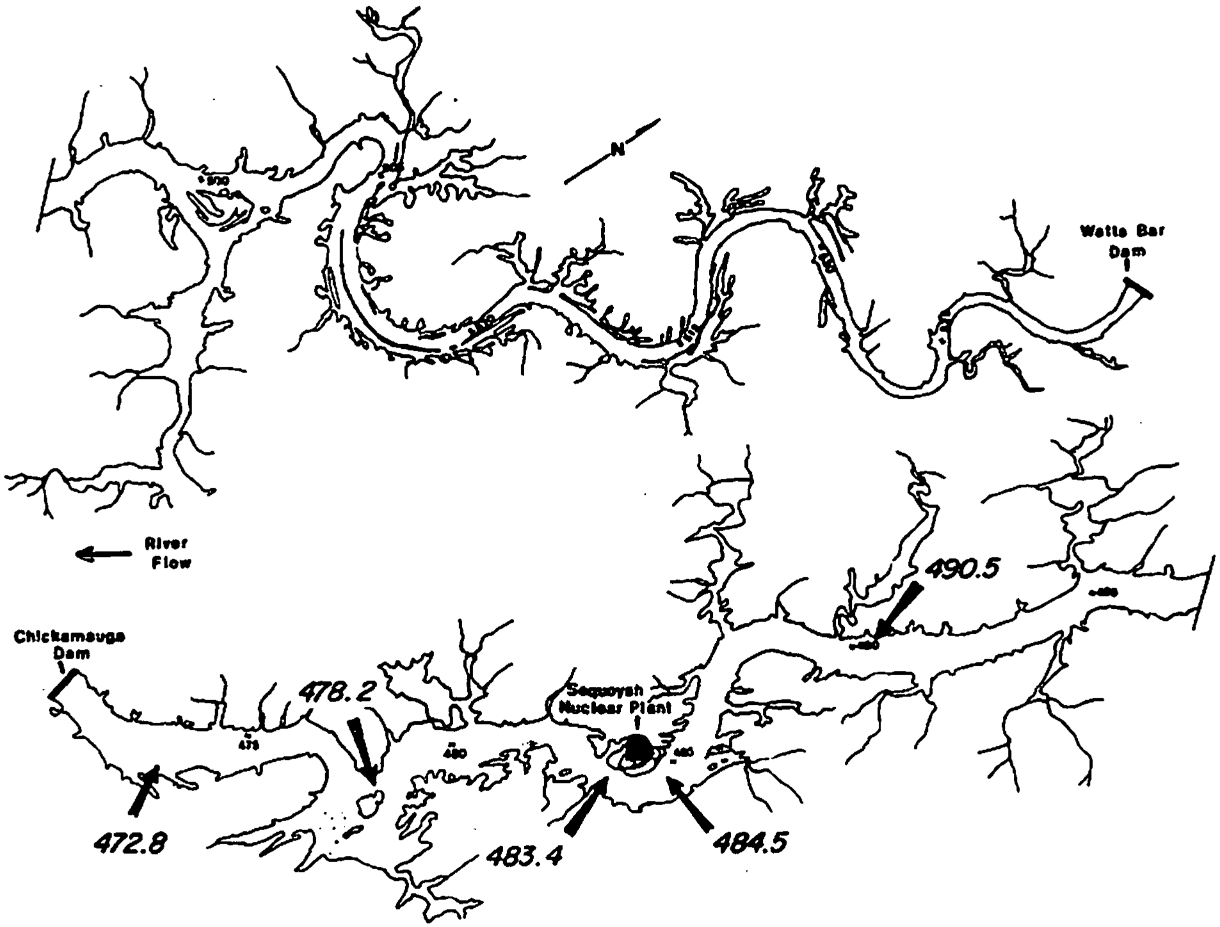


Figure 1. Location of Water Quality, Phytoplankton, and Zooplankton Sample Stations for Operation Monitoring, Sequoyah Nuclear Plant, Chickamauga Reservoir.

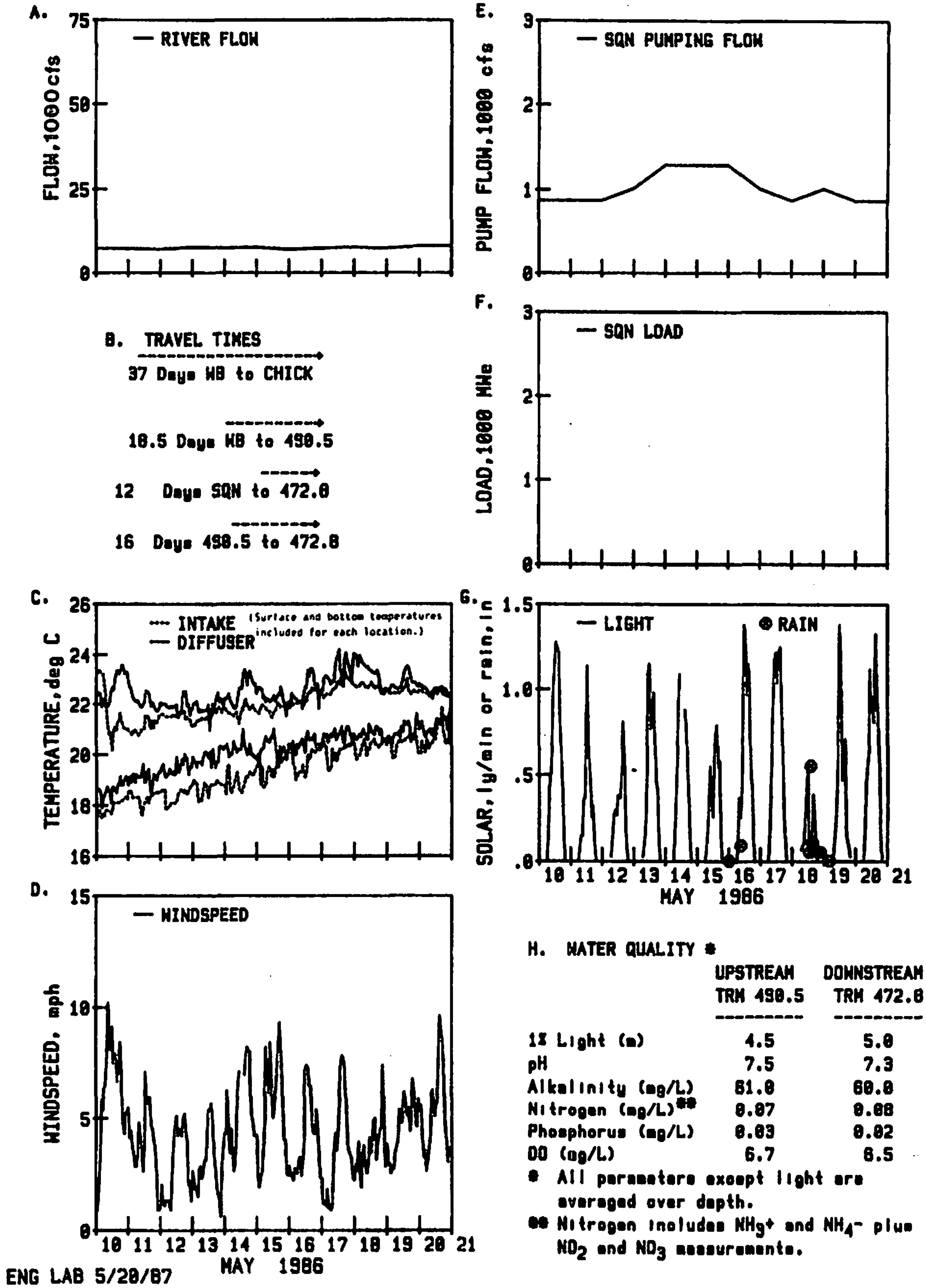
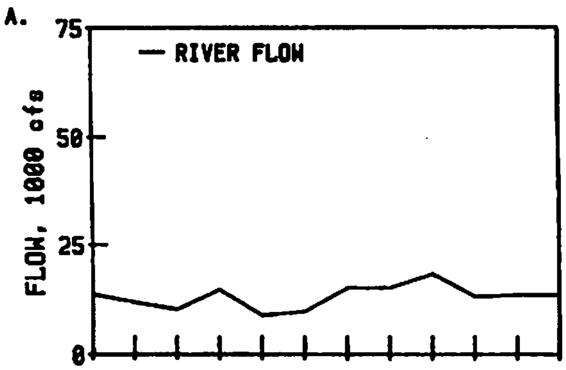
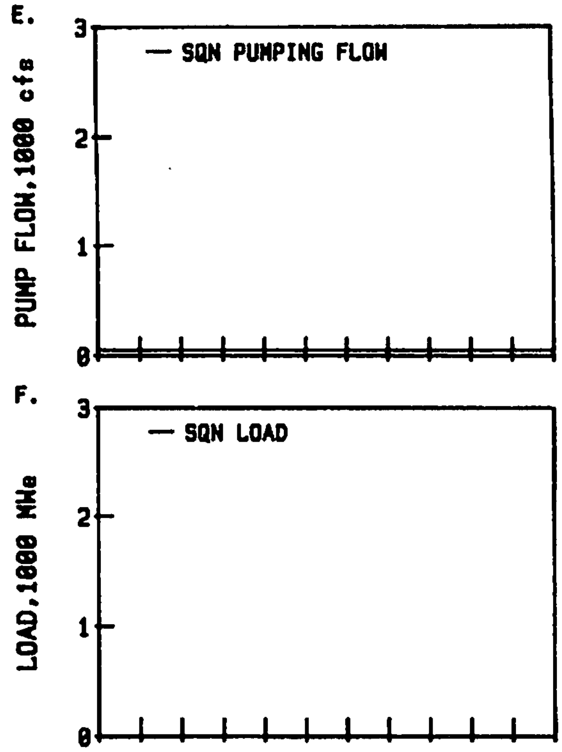


Figure 2. Conditions Prior to Plankton Sampling on May 20, 1986, for Monitoring Associated with Sequoyah Nuclear Plant, Chickamauga Reservoir.





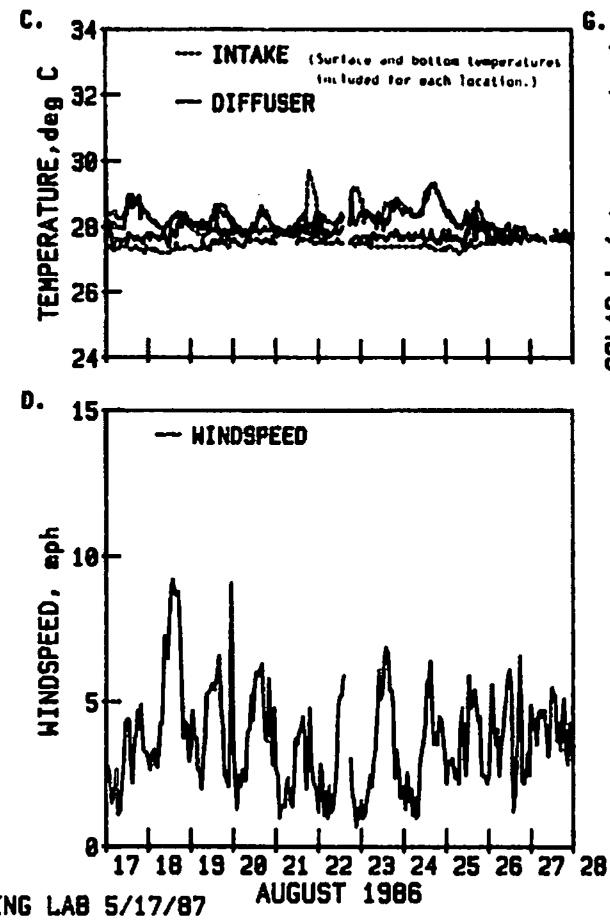
B. TRAVEL TIMES

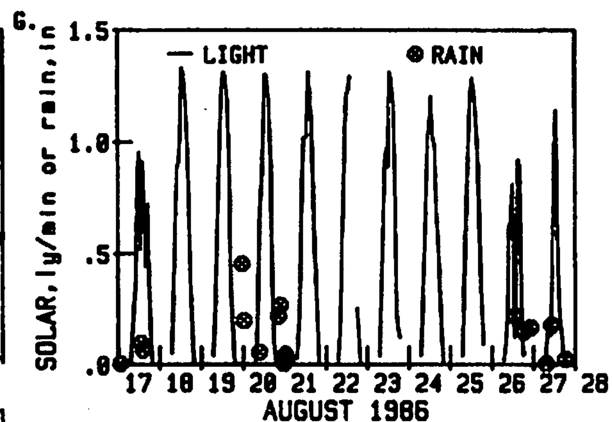
22 Days WB to CHICK

11 Days WB to 490.5

7 Days SQN to 472.0

10 Days 490.5 to 472.0





H. WATER QUALITY *

	UPSTREAM TRM 490.5	DOWNSTREAM TRM 472.0
1% Light (m)	4.5	6.5
pH	7.4	7.4
Alkalinity (mg/L)	67.0	68.0
Nitrogen (mg/L)**	0.15	0.13
Phosphorus (mg/L)	0.04	0.04
DO (mg/L)	4.3	4.4

* All parameters except light are averaged over depth.

** Nitrogen includes NH_3^+ and NH_4^- plus NO_2 and NO_3 measurements.

Figure 3. Conditions Prior to Plankton Sampling on August 27, 1986, for Monitoring Associated with Sequoyah Nuclear Plant, Chickamauga Reservoir.

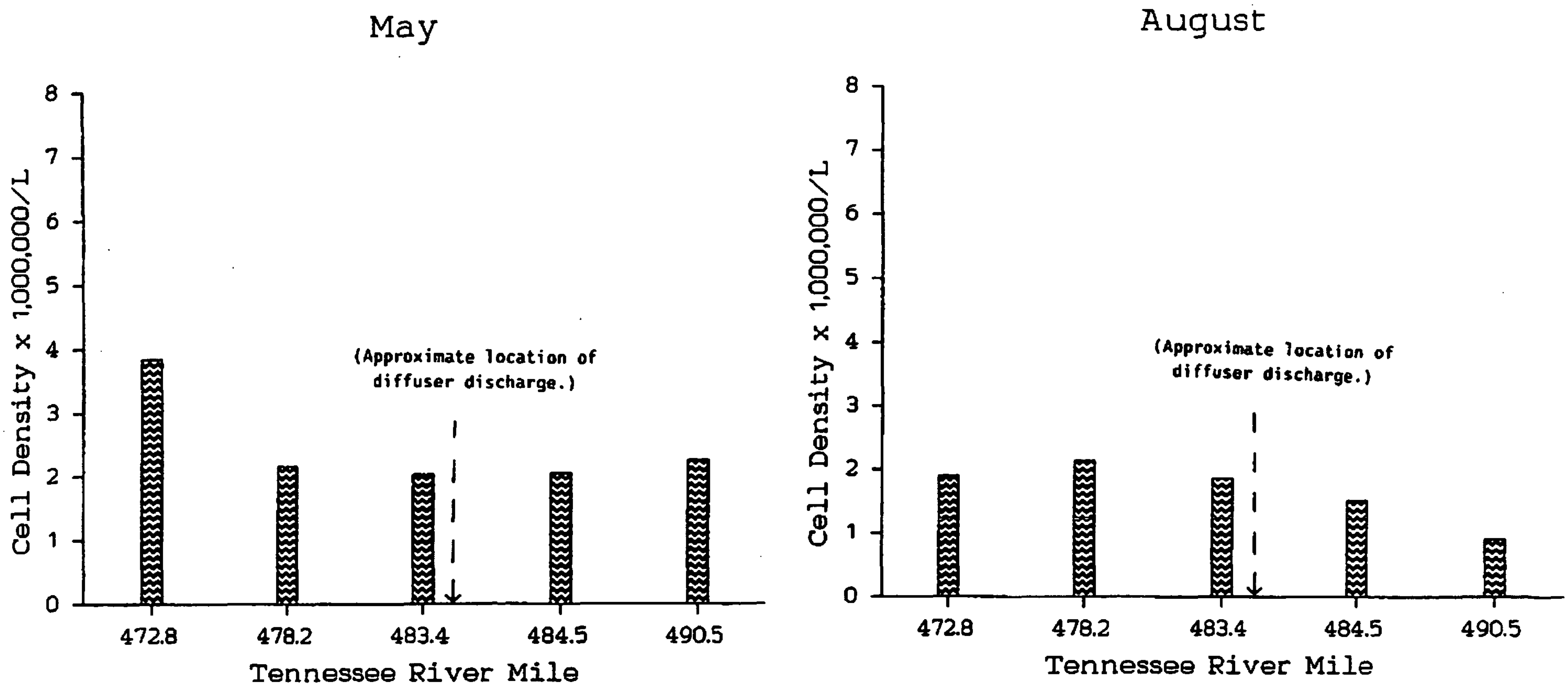


Figure 4. Mean Total Photoplankton Cell Density at Each Collection Site on Chickamauga Reservoir in May and August 1986 Associated with Aquatic Monitoring Program for Sequoyah Nuclear Plant.

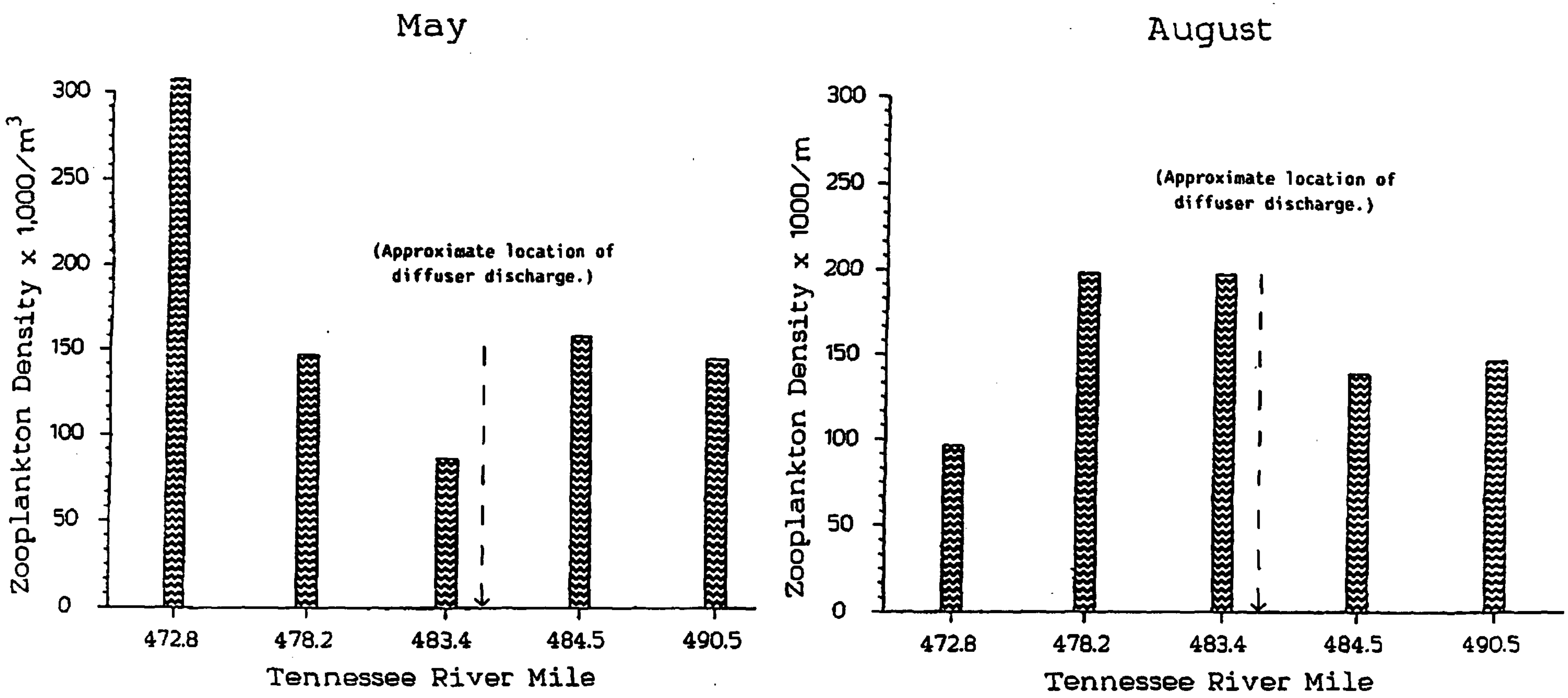


Figure 5. Mean Total Zooplankton Density at Each Collection Site on Chickamauga Reservoir in May and August 1986 Associated with Aquatic Monitoring Program for Sequoyah Nuclear Plant.

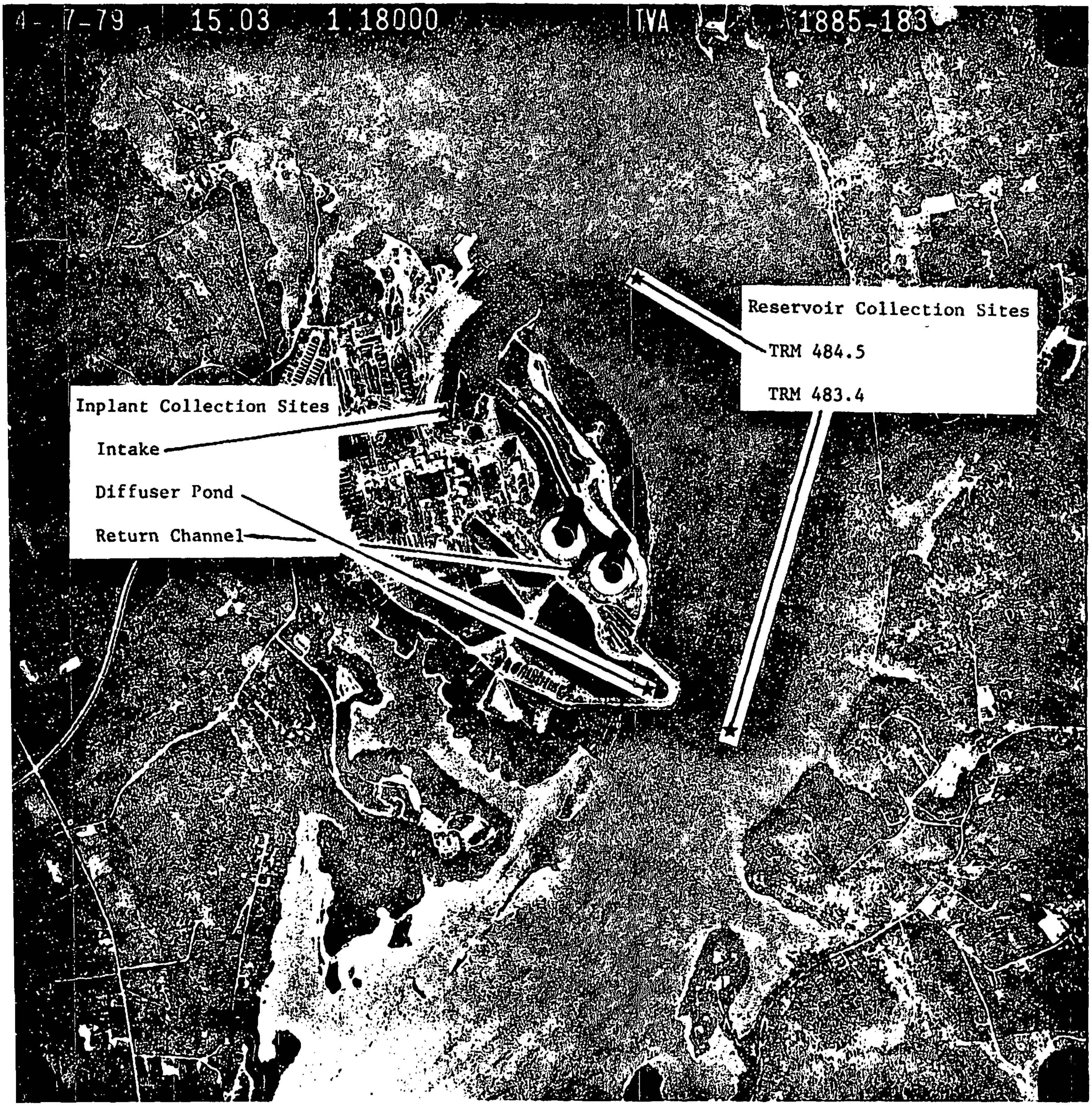
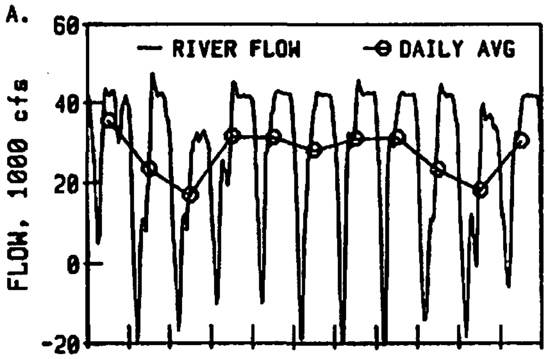
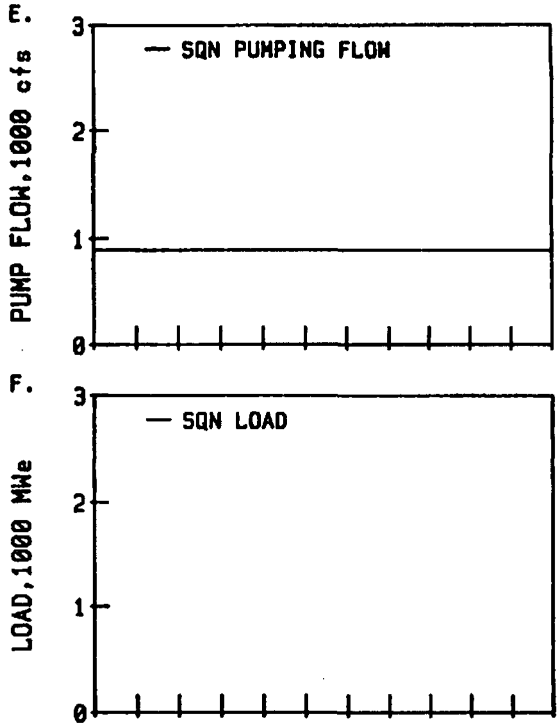


Figure 6. Location of In-Plant and Reservoir Collection Sites Included in Plankton Studies in July and August 1987 Associated with Aquatic Monitoring Program for Sequoyah Nuclear Plant.





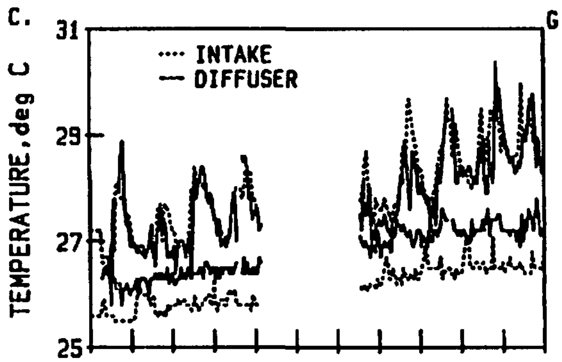
B. TRAVEL TIMES

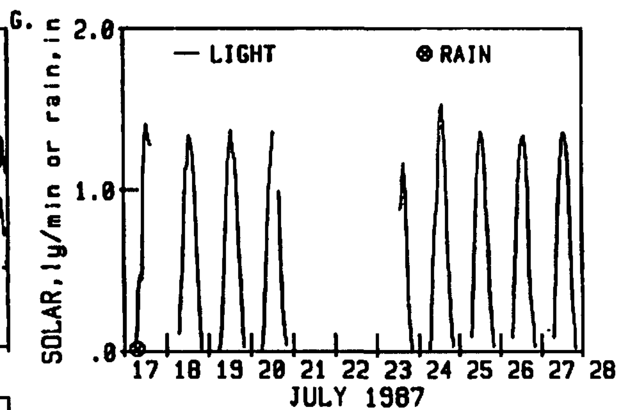
12 Days WB to CHICK

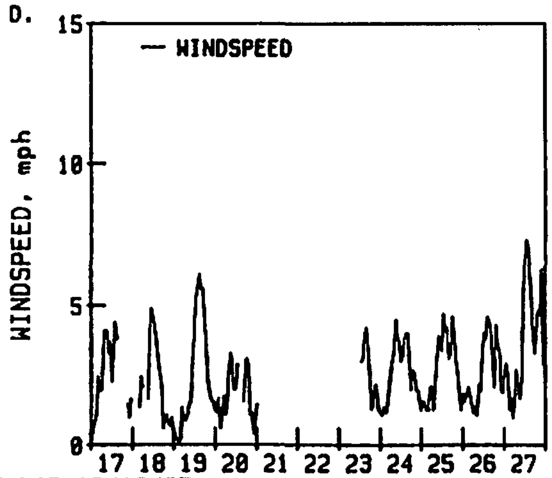
4.3 Days WB to 496.5

4.3 Days SQN to 471.1

7.4 Days 496.5 to 471.1







ENG LAB 12/10/87

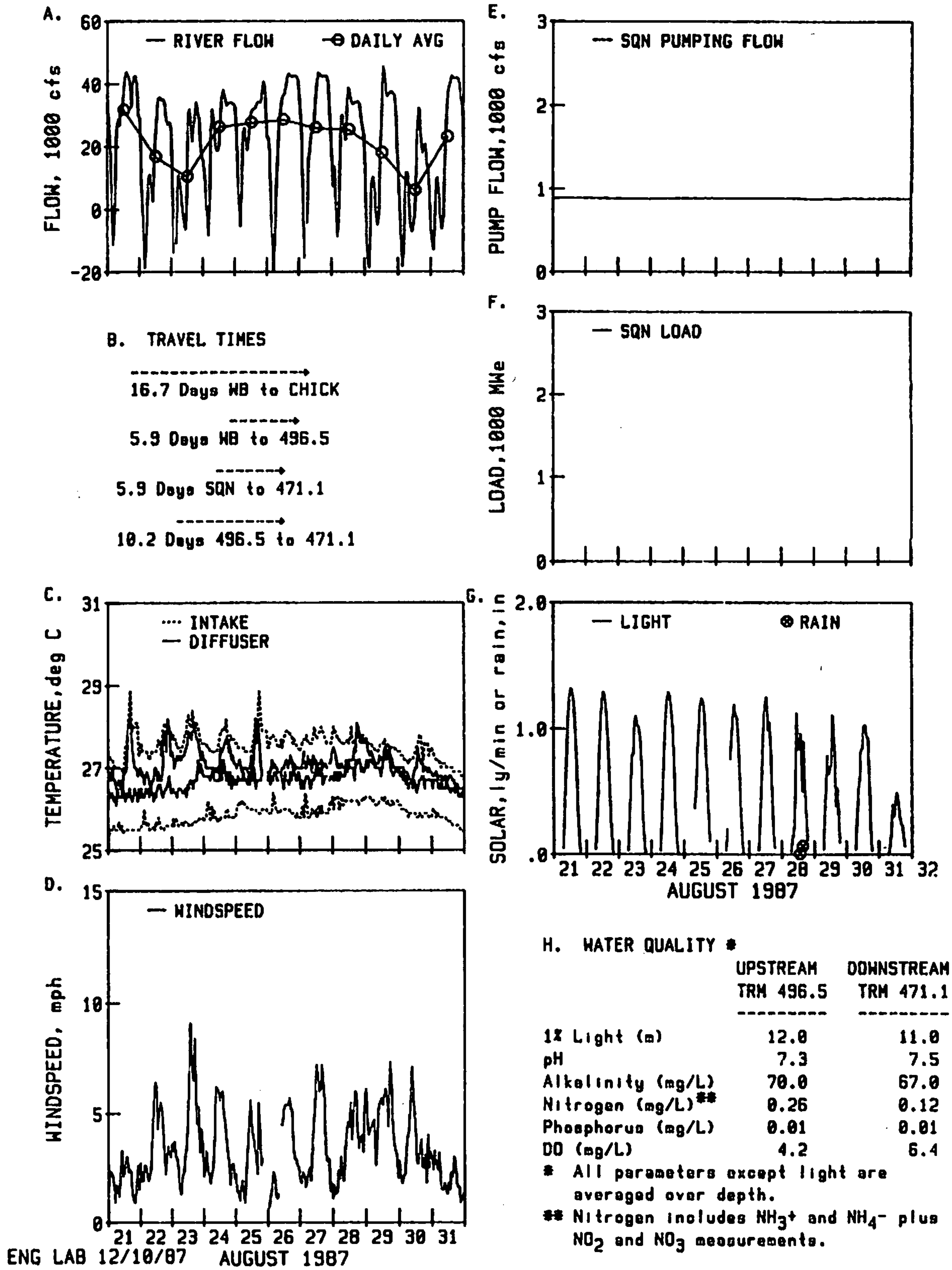
H. WATER QUALITY *

	UPSTREAM TRM 496.5	DOWNSTREAM TRM 471.1
1% Light (m)	12.0	NA
pH	7.5	7.5
Alkalinity (mg/L)	65.0	61.0
Nitrogen (mg/L)**	0.25	0.17
Phosphorus (mg/L)	0.01	0.01
DO (mg/L)	5.0	6.0

* All parameters except light are averaged over depth.

** Nitrogen includes NH_3^+ and NH_4^- plus NO_2 and NO_3 measurements.

Figure 7. Conditions Prior to Plankton Sampling on July 17, 1987, for Monitoring Associated with Sequoyah Nuclear Plant, Chickamauga Reservoir.



	UPSTREAM TRM 496.5	DOWNSTREAM TRM 471.1
1% Light (m)	12.0	11.0
pH	7.3	7.5
Alkalinity (mg/L)	70.0	67.0
Nitrogen (mg/L)**	0.26	0.12
Phosphorus (mg/L)	0.01	0.01
DO (mg/L)	4.2	6.4

* All parameters except light are averaged over depth.

** Nitrogen includes NH_3^+ and NH_4^- plus NO_2 and NO_3 measurements.

Figure 8. Conditions Prior to Plankton Sampling on August 31, 1987, for Monitoring Associated with Sequoyah Nuclear Plant, Chickamauga Reservoir.

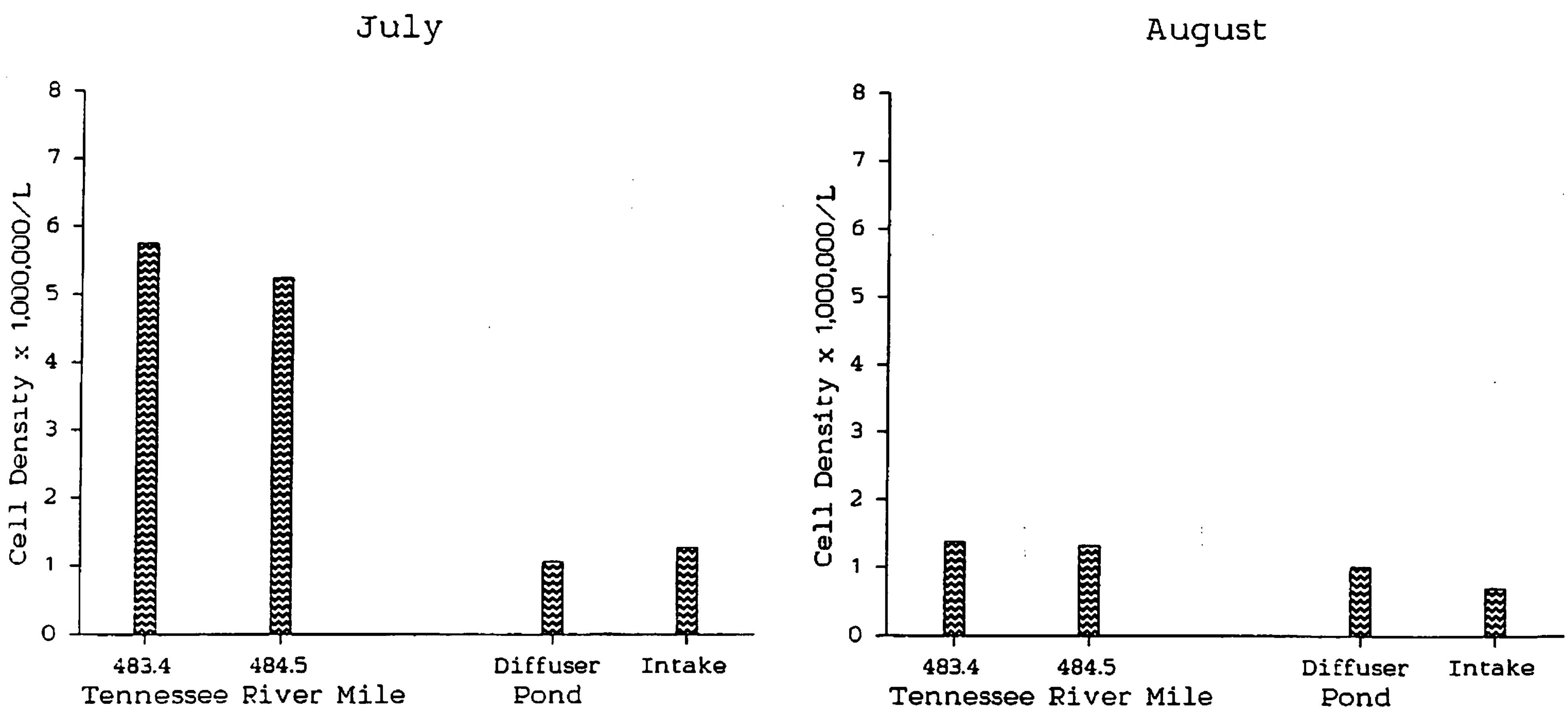


Figure 9. Mean Total Phytoplankton Cell Density at Each Collection Site in July and August 1987 Associated with Aquatic Monitoring Program for Sequoyah Nuclear Plant.

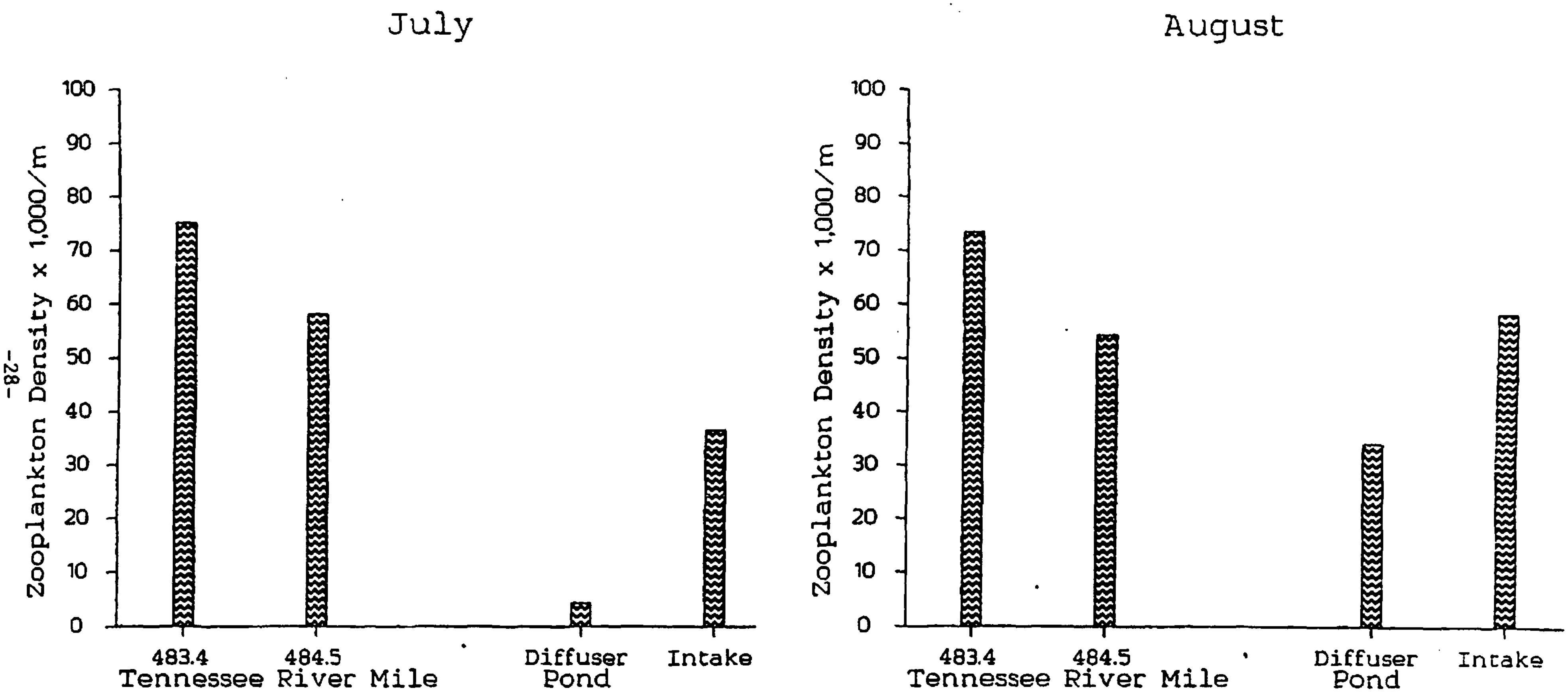


Figure 10. Mean Total Zooplankton Density at Each Collection Site in July and August 1987 Associated with Aquatic Monitoring for Sequoyah Nuclear Plant.

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APPENDIX A

WATER QUALITY DATA ON
MAY 20 AND AUGUST 27, 1986

STATION - 475302 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 478.19

DATE	TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	84258 SERIES CODE ALPHA
860520	0520	1	0.01	0.01<	2.9	12.400	1.000<	1.050<	1.25<	860718	4.8	A<<<
860520	0522	3	0.02	0.01<	2.4	10.650	1.000<	1.000<	1.55<	860718	5.2	AL
860520	0524	5								860718		
860520	0526	10	0.01	0.01<	2.9	12.150	1.000<	1.000<	1.00<	860718	5.1	AJRR
860520	0528	16	0.01	0.01<	2.9	11.750	1.000<	1.050<	1.90<	860718	5.0	A&
860520	0530	26								860718		
860520	0532	39								860718		
860520	0534	46								860718		
860520	0536	52								860718		
860827	0825	1	0.03	0.01	4.2	7.650	1.000<	1.000<	2.05	870212	3.9	A dW
860827	0826	2								860919		
860827	0827	3	0.03	0.01	4.1	7.450	[illegible]50<	2.100<	3.80	870212	3.9	A dW
860827	0829	5								860919		
860827	0831	10	0.03	0.01	4.9	7.500	[illegible]<	1.000<	2.80	870212	4.7	A.
860827	0833	16	0.04	0.01	4.7	7.600	1.[illegible]	1.000<	1.95<	870212	3.3	A <<
860827	0835	26								860919		
860827	0837	39								860919		
860827	0839	46								860919		
860827	0840	56								860919		
860520												
NUMBER		19	8	8	8	8	8	8	8	19	8	19
MAXIMUM		56	0.04	0.01	4.9	12.400	1.950<	2.100<	3.80	870212	5.2	[illegible]
MINIMUM		1	0.01	0.01<	2.4	7.450	1.000<	1.000<	1.00<	860718	3.8	[illegible]
SUM		402	0.18	0.08	28.8	77.350	8.950	9.200	16.30	16392324	36.4	[illegible]
SUM SQ.		15252	0.00	0.00	110.4	784.302	10.602	11.615	36.66	1.41E+13	168.0	[illegible]
MEAN		21	0.02	0.01	3.6	9.669	1.119	1.150	2.04	862780	4.5	[illegible]
VARIANCE		375	0.00	0.00	1.0	5.161	0.113	0.148	0.81	15597568	0.3	[illegible]
STD.DEV.		19	0.01	0.00	1.0	2.272	0.336	0.385	0.90	3949	0.6	[illegible]
STD.ERR.		4	0.00	0.00	0.3	0.803	0.119	0.136	0.32	906	0.2	[illegible]
COEF VAR		92	51.78	0.13	27.2	23.496	30.023	33.437	44.09	0	12.9	[illegible]
LOG MEAN		11	0.02	0.01	3.5	9.436	1.087	1.111	1.85	862760	4.5	[illegible]
860827												

STATION - 475302 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 478.19

DATE	TIME	00003 DEPTH FEET	00002 HSAMPLOC % FROM RT BANK	00008 LAB IDENT. NUMBER	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	33098 VSAMPLOC DEPTH METERS	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L	00630 NO2&NO3 N-TOTAL MG/L
860520	0920	1	74	33029	22.2	195	0.3	7.54	7.3	62	0.16	0.34	0.37
860520	0922	3	74	33030	22.4	195	1.0	7.24	7.3	61	0.18	0.35	0.03
860520	0924	5	74		22.4	195	1.5	7.16	7.4				
860520	0926	10	74	33031	22.4	195	3.0	7.04	7.3	61	0.19	0.34	0.07
860520	0928	16	74	33032	22.4	195	5.0	6.89	7.2	61	0.21	0.34	0.07
860520	0930	26	74		22.1	195	8.0	6.03	7.1				
860520	0932	39	74		21.8	195	12.0	3.66	6.8				
860520	0934	46	74		20.0	156	14.0	2.42	6.8				
860520	0936	52	74		19.4	197	16.0	1.61	6.7				
860827	0825	1	74	37690	27.8	215	0.3	5.18	7.6	70	0.29	0.32	0.10
860827	0826	2	74				0.5						
860827	0827	3	74	37691	27.8	216	1.0	5.01	7.6	68	0.27	0.31	0.09
860827	0829	5	74		27.8	216	1.5	5.10	7.5				
860827	0831	10	74	37692	27.9	216	3.0	4.98	7.6	71	0.29	0.31	0.15
860827	0833	16	74	37693	27.8	216	5.0	[illegible]92	7.6	66	0.23	0.32	0.29
860827	0835	26	74		27.8	216	8.0	5.[illegible]0	7.6				
860827	0837	39	74		27.8	225	12.0	5.03	7.6				
860827	0839	46	74		27.9	220	14.0	5.02	7.5				
860827	0840	56	74		27.9	218	17.0	4.94	7.5				

860520												
NUMBER	19			18	18	19	18	18	8	8	8	8
MAXIMUM	56			27.9	225	17.0	7.54	7.6	71	0.29	0.35	0.15
MINIMUM	1			19.4	195	0.3	1.61	6.7	61	0.16	0.31	0.07
SUM	402			444.7	3716	123.1	94.84	132.1	520	1.81	2.23	0.66
SUM SQ.	15252			11172.3	769454	1427.9	543.32	971.3	33928	0.43	0.31	0.06
MEAN	21			24.7	206	6.5	5.27	7.3	65	0.23	0.33	0.08
VARIANCE	375			10.9	136	35.0	2.57	0.1	19	0.00	0.00	0.00
STD.DEV.	19			3.3	12	5.9	1.60	0.3	4	0.05	0.02	0.01
STD.ERR.	4			0.8	3	1.4	0.38	0.1	2	0.02	0.01	0.00
COEF VAR	92			13.4	6	91.3	30.40	4.2	7	21.77	54.01	14.12
LOG MEAN	11			24.5	206	3.4	4.96	7.3	65	0.22	0.32	0.09

860827

STATION - 475265 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 490.47

DATE TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	84058 SERIES CODE ALPHA
860827 1020	33								860919		
860520											
NUMBER	16	8	8	8	8	9	8	8	16	8	16
MAXIMUM	33	0.04	0.02	3.7	24.950	1.500<	1.150<	2.65	870212	8.5	0.00
MINIMUM	1	0.03	0.01<	2.6	4.600	1.000<	1.000<	1.00<	860718	4.2	0.00
SUM	211	0.28	0.09	25.7	96.200	8.000	8.200	11.45	13782920	49.5	0.00
SUM SQ.	4733	0.01	0.00	83.3	1681.824	8.060	8.425	19.44	1.19E+13	326.0	0.00
MEAN	13	0.03	0.01	3.2	12.025	1.000	1.025	1.43	861433	6.2	0.00
VARIANCE	130	0.00	0.00	0.1	75.003	0.000	0.003	0.44	5522500	2.8	0.00
STD.DEV.	11	0.01	0.00	0.3	8.660	0.060	0.053	0.66	2350	1.7	0.00
STD.ERR.	3	0.00	0.00	0.1	3.062	0.000	0.019	0.23	588	0.6	0.00
COEF VAR	86	15.27	31.43	10.2	72.020	0.000	5.215	46.16	0	27.1	0.00
LOG MEAN	8	0.03	0.01	3.2	9.510	1.500	1.024	1.33	861425	6.0	0.00
860827											

STATION - 475265 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 490.47

DATE	TIME	00003 DEPTH FEET	00002 HSAMPLOC % FROM RT BANK	00008 LAB IDENT. NUMBER	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00098 VSAMPLOC DEPTH METERS	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L	00630 NO2&NO3 N-TOTAL MG/L
860520	1115	1	85	33021	22.7	198	0.3	8.48	7.7	62	0.34	0.02	0.03
860520	1117	3	85	33022	22.9	198	1.0	8.05	7.7	61	0.38	0.02	0.04
860520	1119	5	85		22.9	198	1.5	7.64	7.7				
860520	1121	10	85	33023	22.9	198	3.0	7.47	7.6	61	0.31	0.03	0.04
860520	1123	16	85	33024	22.7	202	5.0	6.80	7.5	60	0.27	0.05	0.06
860520	1125	23	85		21.0	196	7.0	4.55	7.5				
860520	1127	30	85		20.9	196	9.0	4.13	7.1				
860827	1006	1	85	37682	27.5	223	0.3	4.56	7.4	68	0.23	0.05	0.11
860827	1007	2	85				0.5						
860827	1008	3	85	37683	27.6	222	1.0	4.36	7.4	66	0.21	0.04	0.13
860827	1010	5	85		27.6	222	1.5	4.29	7.3				
860827	1012	10	85	37684	27.6	223	3.0	4.35	7.4	66	0.28	0.05	0.11
860827	1014	16	85	37685	27.6	223	5.0	4.27	7.4	67	0.34	0.04	0.10
860827	1016	23	85		27.6	223	7.0	4.25	7.4				
860827	1018	30	85		27.6	223	9.0	4.24	7.4				
860827	1020	33	85		27.6	223	10.0	4.18	7.4				
860520													
NUMBER		16			15	15	16	15	15	8	8	9	8
MAXIMUM		33			27.6	223	10.0	8.48	7.7	68	0.38	0.05	0.11
MINIMUM		1			20.9	196	0.3	4.13	7.1	60	0.21	0.02	0.03
SUM		211			376.7	3168	64.1	81.62	111.8	511	2.36	0.33	0.59
SUM SQ.		4733			9570.2	671394	434.9	483.76	834.1	32711	0.72	0.01	0.05
MEAN		13			25.1	211	4.0	5.44	7.5	64	0.29	0.04	0.07
VARIANCE		130			7.9	165	11.9	2.83	0.0	10	0.00	0.00	0.00
STD.DEV.		11			2.8	13	3.4	1.68	0.2	3	0.06	0.01	0.03
STD.ERR.		3			0.7	3	0.9	0.43	0.0	1	0.02	0.00	0.01
COEF VAR		86			11.2	6	86.0	30.92	2.1	5	19.77	34.18	46.94
LOG MEAN		8			25.0	211	2.4	5.23	7.5	64	0.29	0.04	0.07
860827													

DATE	TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTO	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	84059 SERIES CODE ALPHA
860520	1115	1	0.04	0.01<	3.0	24.950	1.000<	1.150<	1.00<	860718	8.2	AC
860520	1117	3	0.03	0.01	3.2	22.450	1.000<	1.000<	1.30<	860718	8.5	AH
860520	1115	5								860718		
860520	1121	10	0.03	0.01<	3.1	19.100	1.000<	1.050<	2.30	860718	7.2	A3
860520	1123	16	0.03	0.01<	2.6	9.200	1.000<	1.000<	2.65	860718	6.5	AY
860520	1125	23								860718		
860520	1127	30								860718		
860827	1006	1	0.04	0.02	3.3	4.800	1.000<	1.000<	1.20<	861029	5.5	AQ
860827	1007	2								860919		
860827	1008	3	0.03	0.01	3.4	4.930	1.000<	1.000<	1.00<	861029	5.1	AJ3R
860827	1010	5								860919		
860827	1012	10	0.04	0.01	3.4	5.900	1.000<	1.000<	1.00<	861029	4.3	AD<<
860827	1014	16	0.04	0.01	3.7	4.900	1.000<	1.000<	1.00<	870212	4.2	AC
860827	1016	23								860919		
860827	1018	30								860919		

STATION - 475304 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 483.40

DATE	TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	84053 SERIES CODE ALPHA
860520	0555	1	0.01	0.01<	2.8	15.900	1.000<	1.050	1.00<	860718	5.4	AOJW
860520	0556	1	0.03	0.01<	2.9					860718	5.8	A<<<D
860520	0557	3	0.01	0.01<	2.6	17.350	1.350<	1.500	1.00<	860718	5.7	AS
860520	0559	5								860718		
860520	1001	10	0.02	0.01<	4.2	17.500	1.000<	1.000<	1.75<	860718	5.7	AS
860520	1003	16	0.02	0.01<	3.4	15.750	1.000<	1.000<	2.70<	860718	6.1	A/RR
860520	1005	26								860718		
860520	1007	39								860718		
860520	1010	49								860718		
860827	0506	1	0.04	0.01	3.7	7.450	1.000<	1.000<	1.95<	870212	4.1	AARR
860827	0507	2								860919		
860827	0508	3	0.04	0.01	3.6	7.200	1.000<	1.000<	1.85	870212	4.4	AFJW
860827	0510	5								860919		
860827	0512	10	0.04	0.01	3.8	6.550	1.000<	1.000<	1.35<	870212	4.2	AC
860827	0514	16	0.04	0.01	4.0	7.550	1.000<	1.000<	1.50	870212	4.5	AH
860827	0516	26								860919		
860827	0518	39								860919		
860827	0520	49								860919		
860827	0522	52								860919		
860520												
NUMBER		19	9	9	9	8	8	8	8	19	9	19
MAXIMUM		52	0.04	0.01	4.2	17.500	1.350<	1.500	2.70	870212	6.1	0.00
MINIMUM		1	0.01	0.01<	2.6	6.550	1.000<	1.000<	1.00<	860718	4.1	0.00
SUM		353	0.25	0.09	31.0	95.250	8.350	8.550	13.10	16392824	45.9	0.00
SUM SQ.		12687	0.01	0.00	109.3	1315.392	8.822	9.352	23.65	1.41E+13	239.0	0.00
MEAN		19	0.03	0.01	3.4	11.906	1.044	1.069	1.64	862780	5.1	0.00
VARIANCE		340	0.00	0.00	0.3	25.903	0.015	0.031	0.31	15597568	0.6	0.00
STD.DEV.		18	0.01	0.00	0.6	5.090	0.124	0.175	0.56	3949	0.8	0.00
STD.ERR.		4	0.00	0.00	0.2	1.799	0.044	0.062	0.20	906	0.3	0.00
COEF VAR		99	46.86	0.13	16.3	42.747	11.856	16.387	34.23	0	15.4	0.00
LOG MEAN		9	0.02	0.01	3.4	10.917	1.035	1.058	1.56	862760	5.0	0.00
860827												

STATION - 475304 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 483.40

DATE	TIME	00003 DEPTH FEET	00002 HSAMPLOC % FROM RT BANK	00008 LAB IDENT. NUMBER	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00098 VSAMPLOC DEPTH METERS	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L	00630 NO2&NO3 N-TOTAL MG/L
860520	0955	1	17	33025	22.5	197	0.3	8.13	7.6	61	0.21	0.32	0.26
860520	0956	1	17	33042			0.30				0.16	0.32	0.26
860520	0957	3	17	33026	22.5	197	1.0	7.86	7.6	60	0.21	0.32	0.26
860520	0959	5	17		22.5	198	1.5	7.66	7.6				
860520	1001	10	17	33027	22.5	197	3.0	7.55	7.5	60	0.24	0.33	0.36
860520	1003	16	17	33028	22.3	198	5.0	6.04	7.3	60	0.24	0.33	0.27
860520	1005	26	17		21.8	197	8.0	[illegible]	7.2				
860520	1007	39	17		21.5	197	12.0		7.0				
860520	1010	49	17		21.3	197	15.0	[illegible]	6.9				
860827	0906	1	17	37696	27.7	215	0.3	4.	7.6	68	0.28	0.32	0.12
860827	0907	2	17				0.5						
860827	0908	3	17	37687	27.7	215	1.0	4.56	7.4	68	0.21	0.31	0.12
860827	0910	5	17		27.7	215	1.5	4.50	7.4				
860827	0912	10	17	37688	27.7	215	3.0	4.41	7.5	68	0.21	0.31	0.12
860827	0914	16	17	37689	27.7	216	5.0	4.41	7.5	69	0.24	0.31	0.12
860827	0916	26	17		27.7	216	8.0	4.43	7.5				
860827	0918	39	17		27.7	216	12.0	4.39	7.5				
860827	0920	49	17		27.7	216	15.0	4.39	7.5				
860827	0922	52	17		27.7	217	16.0	4.39	7.5				
860520													
NUMBER		19			17	17	19	17	17	8	9	9	9
MAXIMUM		52			27.7	217	16.0	8.13	7.6	69	0.28	0.33	0.12
MINIMUM		1			21.3	197	0.3	4.14	6.9	60	0.16	0.31	0.06
SUM		353			426.2	3519	108.4	92.04	126.2	514	2.00	0.17	0.79
SUM SQ.		12637			10819.1	729875	1197.0	532.30	937.6	33154	0.45	0.30	[illegible]
MEAN		19			25.1	207	5.7	5.41	7.4	64	0.22	0.32	[illegible]
VARIANCE		343			8.4	90	32.1	2.12	0.0	19	0.00	0.00	[illegible]
STD.DEV.		18			2.9	9	5.7	1.46	0.2	4	0.03	0.01	[illegible]
STD.ERR.		4			0.7	2	1.3	0.35	0.1	2	0.01	0.00	[illegible]
COEF VAR		99			11.5	5	99.4	26.92	2.8	7	14.89	41.39	[illegible]
LOG MEAN		9			24.9	207	2.3	5.25	7.4	64	0.22	0.32	[illegible]

860827

STATICN - 475300 CHICKAMAUGA RESERVOIR TENNE VER 472.90

DATE	TIME	00003 DEPTH FEET	00002 HSAMPLOC % FROM RT BANK	00008 LAB IDENT. NUMBER	00010 WATER TEMP CENT	CN FI MI J	00098 VSAMPLOC DEPTH METERS	00300 DO MG/L	00400 PH SU	.31 K .LD .G/L	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L	00630 NO2&NO3 N-TOTAL MG/L
860520	0845	1	85	33033	22.2		0.3	8.20		61	0.12	0.13	0.06
860520	0847	3	85	33034	22.3		1.0	8.00	..5	60	0.15	0.13	0.06
860520	0849	5	85		22.3		1.5	7.82	7.6				
860520	0851	10	85	33035	22.3		3.0	7.70	7.4	60	0.16	0.12	0.05
860520	0853	16	85	33036	22.4		5.0	7.45	7.3	59	0.14	0.02	0.05
860520	0855	26	85		21.9	19.	8.0	6.10	7.1				
860520	0857	39	85		20.6	196	.2.0	3.46	6.8				
860520	0859	49	85		19.9	196	0	3.39	6.8				
860827	0755	1	85	37694	27.8	216		4.60	7.5	70	0.35	0.11	0.12
860827	0756	1	85D	37702							0.35	0.11	0.13
860827	0756	2	85										
860827	0757	3	85	37695	27.8	216	1.	4.54	7.4	67	0.35	0.11	0.12
860827	0759	5	85		27.9	216	1.5	4.57	7.4				
860827	0801	10	85	37696	28.4	222	3.0	4.60	7.4	68	0.26	0.12	0.11
860827	0803	16	85	37697	27.9	217	5.0	4.58	7.4	67	0.23	0.12	0.12
860827	0805	26	85		27.9	216	8.0	.59	7.4				
860827	0807	52	85		27.8	219	16.0	28	7.1				

860520												
NUMBER	17			15	15	17		15	8	9	9	5
MAXIMUM	52			28.4	222	16.0	8.	7.7	70	0.35	0.13	0.19
MINIMUM	1			19.9	195	0.3	3.2	6.8	59	0.12	0.01	0.05
SUM	265			369.4	3084	81.4	82.88	109.9	512	2.11	0.17	0.82
SUM SQ.	8765			9246.8	635940	828.0	504.49	806.1	32904	0.57	0.09	0.08
MEAN	16			24.6	206	4.8	5.53	7.3	64	0.23	0.02	0.09
VARIANCE	290			10.7	134	27.4	3.32	0.1	19	0.01	0.00	0.00
STD.DEV.	17			3.3	12	5.2	1.82	0.3	4	0.10	0.01	0.03
STD.ERR.	4			0.8	3	1.3	0.47	0.1	2	0.03	0.00	0.01
COEF VAR	109			13.3	6	109.3	33.00	3.7	7	41.42	41.39	38.20
LOG MEAN	8			24.4	205	2.3	5.25	7.3	64	0.22	0.02	0.08

860827

DATE	TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WOF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	64059 SERIES CODE ALPHA
860520	0845	1	0.02	0.01<	2.5	12.900	1.000<	1.550	1.00<	860718	4.7	A.
860520	0847	3	0.02	0.01<	2.7	13.350	1.000<	1.150	1.35<	860718	4.8	A<<<
860520	0849	5								860718		
860520	0851	10	0.03	0.01<	2.6	18.150	1.000<	1.200	1.14<	860718	7.8	A8<<
860520	0853	16	0.02	0.01<	2.9	17.100	1.000<	1.300<	1.60<	860718	6.4	AWWW
860520	0855	26								860718		
860520	0857	39								860718		
860520	0859	49								860718		
860827	0755	1	0.05	0.01	4.6	4.500	1.000<	1.000<	1.45	870212	3.6	A RR
860827	0756	1	0.04	0.01	4.5					870212	6.5	AY D
860827	0756	2								861002		
860827	0757	3	0.03	0.02	4.0	5.050	1.000<	1.000<	1.45	870212	4.0	A
860827	0759	5								860919		
860827	0801	10	0.04	0.01	4.6	5.350	1.000<	1.000<	1.50	870212	4.7	A.

STATION - 475300 CHICKAMAUGA /OIR TENNESSEE RIVER 472.80

DATE	TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	'0680 '6 C L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	_18 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBICTY LAB NTU	84058 SERIES CODE ALPHA
860827	0803	16	0.04	0.01	.6	6.250	1.000<	1.000<	1.05<	870212	3.4	A dd
860827	0805	26								860919		
860827	0807	52								860919		
860520												
NUMBER		17	9	9		8	8	8	8	17	9	17
MAXIMUM		52	0.05	0.02	4.[illegible]	'9.150	1.000<	1.550	1.80	870212	7.8	[illegible]
MINIMUM		1	0.02	0.01<	2.5	.530	1.000<	1.000<	1.00<	860718	3.4	[illegible]
SUM		265	0.29	0.10	33.0	550	8.000	9.200	10.74	14690563	45.9	[illegible]
SUM SQ.		8765	0.01	0.00	129.4	1[illegible]12	8.000	10.955	14.92	1.27E+13	251.8	[illegible]
MEAN		16	0.03	0.01	3.7	[illegible]	1.000	1.150	1.34	863563	5.1	[illegible]
VARIANCE		290	0.00	0.00	0.9	32[illegible]	0.000	0.039	0.07	19640000	2.2	[illegible]
STD.DEV.		17	0.01	0.00	1.0	5.[illegible]	0.000	0.198	0.27	4432	1.5	[illegible]
STD.ERR.		4	0.00	0.00	0.3	2.00[illegible]	[illegible]000	0.070	0.09	1075	0.5	[illegible]
COEF VAR		109	33.92	30.00	26.3	55.002	[illegible]	17.235	19.93	1	29.2	[illegible]
LOG MEAN		8	0.03	0.01	3.5	8.935	1.[illegible]	1.136	1.32	863546	4.9	[illegible]
860827												

STATION - 475023 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 444.5

DATE	TIME	00003 DEPTH FEET	00002 HSAMPLOC % FROM RT BANK	00008 LAB IDENT. NUMBER	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00098 VSAMPLOC DEPTH METERS	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L	00630 NO2&NO3 N-TOTAL MG/L
860520	1030	1	85	33037	22.5	198	0.3	7.52	7.5	60	0.15	0.05	0.06
860520	1032	3	85	33038	22.6	198	1.0	7.28	7.5	60	0.15	0.05	0.06
860520	1034	5	85		22.6	198	1.5	7.21	7.5				
860520	1036	10	85	33039	22.5	198	3.0	7.22	7.4	60	0.24	0.05	0.06
860520	1038	16	85	33040	22.6	198	5.0	7.13	7.4	60	0.19	0.05	0.06
860520	1040	26	85		22.6	198	8.0	7.09	7.4				
860520	1042	39	85		22.3	197	12.0	6.41	7.3				
860520	1044	49	85		21.2	197	15.0	4.13	7.3				
860827	0530	1	85	37698	27.7	219	0.3	4.65	7.5	68	0.27	0.02	0.12
860827	0531	2	85				0.5						
860827	0532	3	85	37699	27.8	219	1.0	4.59	7.5	70	0.27	0.01	0.12
860827	0534	5	85		27.8	213	1.5	4.55	7.5				
860827	0536	10	85	37700	27.8	217	3.0	4.49	7.4	68	0.24	0.01	0.12
860827	0538	16	85	37701	27.8	218	5.0	4.47	7.4	67	0.23	0.02	0.12
860827	0540	26	85		27.8	218	8.0	4.46	7.4				
860827	0542	46	85		27.7	219	14.0	3.38	7.3				
860520													
NUMBER		16			15	15	16	15	15	8	8	8	8
MAXIMUM		49			27.8	219	15.0	7.52	7.5	70	0.27	0.05	0.12
MINIMUM		1			21.2	197	0.3	3.38	7.3	60	0.15	0.01	0.06
SUM		258			373.3	3108	79.1	94.58	111.3	513	1.74	0.25	0.72
SUM SQ.		8176			9401.0	645512	767.9	607.76	826.1	33037	0.39	0.01	0.07
MEAN		16			24.9	207	4.9	5.69	7.4	64	0.22	0.03	0.09
VARIANCE		264			7.9	110	25.1	2.20	0.0	20	0.00	0.00	0.00
STD.DEV.		16			2.8	10	5.0	1.48	0.1	4	0.05	0.02	0.03
STD.ERR.		4			0.7	3	1.3	0.38	0.0	2	0.02	0.01	0.01
COEF VAR		101			11.3	5	101.4	26.32	1.1	7	22.36	64.79	35.64
LOG MEAN		8			24.7	207	2.6	5.45	7.4	64	0.21	0.02	0.09
860827													

DATE	TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	84355 SERIES CODE ALPHA
860520	1030	1	0.03	0.01<	2.9	13.600	1.050<	1.050<	1.70	860718	5.8	A*<<
860520	1032	3	0.03	0.01	2.9	12.950	1.000<	1.050<	2.55<	860718	5.8	A*<<
860520	1034	5								860718		
860520	1036	10	0.04	0.01	2.9	13.750	3.900	4.350	5.60	860718	4.3	AD<<
860520	1038	16	0.04	0.01<	3.1	13.750	1.000<	1.000<	1.60<	860718	4.8	A<<<
860520	1040	26								860718		
860520	1042	39								860718		
860520	1044	49								860718		
860827	0530	1	0.05	0.03	5.2	7.600	1.000<	1.000<	1.00<	870212	4.2	AC
860827	0531	2								860919		
860827	0532	3	0.03	0.01	6.5	8.250	1.000<	1.000<	1.25<	870212	4.5	AH
860827	0534	5								860919		
860827	0536	10	0.04	0.01	5.1	6.400	1.000<	1.000<	1.70<	870212	4.6	AIRR
860827	0538	16	0.04	0.01	5.0	4.400	1.000<	1.000<	4.00	870212	6.2	AT
860827	0540	26								860919		

STATION - 475023 CHICKAMAUGA RESERVOIR TENNESSEE RIVER 484.5

DATE TIME	00003 DEPTH FEET	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	74041 WQF SAMPLE UPDATED	82079 TURBIDTY LAB NTU	84059 SERIES CODE ALPHA
860827 0542	46								860919		
860520											
NUMBER	16	8	8	8	8	8	8	8	16	8	16
MAXIMUM	49	0.05	0.03	6.9	13.750	3.900	4.350	5.80	870212	6.2	0.00
MINIMUM	1	0.03	0.01<	2.9	4.400	1.000<	1.000<	1.00<	860718	4.2	0.00
SUM	253	0.30	0.10	33.6	80.700	10.950	11.450	19.80	13810268	40.2	0.00
SUM SQ.	8175	0.01	0.00	155.1	916.930	22.312	26.127	67.72	1.19E+13	206.3	0.00
MEAN	16	0.04	0.01	4.2	10.087	1.367	1.431	2.47	863142	5.0	0.00
VARIANCE	268	0.00	0.00	2.0	14.696	1.046	1.391	2.67	17791000	0.6	0.00
STD.DEV.	16	0.01	0.01	1.4	3.833	1.023	1.180	1.64	4218	0.8	0.00
STD.ERR.	4	0.00	0.00	0.5	1.355	0.362	0.417	0.58	1054	0.3	0.00
COEF VAR	101	18.36	56.57	33.7	38.002	74.735	82.415	66.07	0	15.6	0.00
LOG MEAN	8	0.04	0.01	4.0	9.353	1.193	1.216	2.10	863127	5.0	0.00
860827											

APPENDIX B

PHYTOPLANKTON DATA AND RESULTS OF STATISTICAL TESTS MAY 20 AND AUGUST 27, 1986

Table B-1. *Percentage Composition of Phytoplankton Groups During Operational* Monitoring Periods (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Phytoplankton Group	Tennessee River Mile				
		472.8	478.2	483.4	484.5	490.5
May 1986	Chlorophyta	12	22	46	38	46
	Chrysophyta	47	43	28	20	19
	Cryptophyta	5	6	7	4	4
	Cyanophyta	35	28	19	38	30
	Euglenophyta	1	1	0	0	0
	Pyrrhophyta	0	0	0	0	0
Aug. 1986	Chlorophyta	28	31	34	38	33
	Chrysophyta	13	13	15	18	19
	Cryptophyta	2	2	2	2	3
	Cyanophyta	56	53	49	40	44
	Euglenophyta	1	0	0	1	1
	Pyrrhophyta	0	0	0	1	0

Table B-2. Individual Sample Totals, Means, Standard Deviations, and Coefficients of Variation for Total Phytoplankton and Group Cell Densities (No./L) During Operational Monitoring (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

May 86

	TRM* 472.8					TRM 478.2					TRM 483.4				
Depth (M)	Sample 1	Sample 2	Mean	STD†	CV‡	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
							Chlorophyta								
0.3	594392	669080	631736	52812	8	588168	563272	575720	17604	3	1023848	834016	928932	134231	14
1.0	532152	497920	515036	24206	5	395224	376552	385888	13203	3	1182560	834016	1008288	246458	24
3.0	413896	367216	390556	33008	8	451240	373440	412340	55013	13	946048	687752	816900	182643	22
5.0	357880	339208	348544	13203	4	634848	469912	552380	116627	21	1201232	743768	972500	323476	33
							Chrysophyta								
0.3	2607856	2334000	2470928	193645	8	1204344	1219904	1212124	11003	1	572608	488584	530596	59414	11
1.0	1888984	1938776	1913880	35208	2	949160	942936	946048	4401	0	644184	672192	658188	19805	3
3.0	1612016	1596456	1604236	11003	1	970944	778000	874472	136432	16	569496	482360	525928	61614	12
5.0	1269696	1310152	1289924	28607	2	697088	728208	712648	22005	3	553936	535264	544600	13203	2
							Cryptophyta								
0.3	164936	255184	210060	63815	30	177384	127592	152488	35208	23	208504	146264	177384	44010	25
1.0	171160	217840	194500	33008	17	80912	102696	91804	15404	17	143152	90248	116700	37409	32
3.0	158712	136928	147820	15404	10	140040	96472	118256	30807	26	146264	102696	124480	30807	25
5.0	208504	124480	166492	59414	36	108920	146264	127592	26406	21	136928	90248	113588	33008	29
							Cyanophyta								
0.3	2190848	1045632	1618240	809790	50	448128	709536	578832	184843	32	65352	49792	57572	11003	19
1.0	1319488	1692928	1506208	264062	18	491696	410784	451240	57213	13	292528	298752	295640	4401	1
3.0	1518656	995840	1257248	369687	29	697088	784224	740656	61614	8	382776	734432	558604	248658	45
5.0	902480	1058080	980280	110026	11	273856	1045632	659744	545728	83	563272	721984	642628	112226	17

Table B-2. (Continued)

May 86

Depth (M)	TRM* 472.8 Sample 1	Sample 2	Mean	STD†	CV‡	TRM 478.2 Sample 1	Sample 2	Mean	STD	CV	TRM 483.4 Sample 1	Sample 2	Mean	STD	CV
								Euglenophyta							
0.3	24896	43568	34232	13203	39	31120	18672	24896	8802	35	9336	6224	7780	2201	28
1.0	24896	18672	21784	4401	20	9336	6224	7780	2201	28	6224	6224	6224	0	0
3.0	24896	21784	23340	2201	9	15560	12448	14004	2201	16	15560	9336	12448	4401	35
5.0	9336	18672	14004	6602	47	6224	9336	7780	2201	28	15560	6224	10892	6602	61
								Pyrrhophyta							
0.3	0	0	0	0	.	0	0	0	0	.	9336	3112	6224	4401	71
1.0	3112	0	1556	2201	141	0	3112	1556	2201	141	3112	3112	3112	0	0
3.0	6224	3112	4668	2201	47	3112	12443	7780	6602	85	6224	3112	4668	2201	47
5.0	6224	0	3112	4401	141	0	3112	1556	2201	141	6224	3112	4668	2201	47
								Total							
0.3	5582928	4347464	4965196	873605	18	2449144	2638976	2544060	134231	5	1888984	1527992	1708488	255260	15
1.0	3939792	4366136	4152964	301471	7	1926328	1842304	1884316	59414	3	2271760	1904544	2088152	259661	12
3.0	3734400	3121336	3427868	433502	13	2277984	2057032	2167508	156237	7	2066368	2019688	2043028	33008	2
5.0	2754120	2850592	2802356	68216	2	1720936	2402464	2061700	481913	23	2477152	2100600	2288876	266262	12

Table B-2. (Continued)

	May 86									
	TRM 484.5					TRM 490.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
					Chlorophyta					
0.3	1048744	905592	977168	101224	10	1294592	1117208	1205900	125429	10
1.0	908704	594392	751548	222252	30	1223016	1005176	1114096	154036	14
3.0	784224	613064	698644	121028	17	1011400	970944	991172	28607	3
5.0	818456	494808	656632	228854	35	955384	672192	813788	200247	25
					Chrysophyta					
0.3	578832	507256	543044	50612	9	522816	441904	482360	57213	12
1.0	311200	323648	317424	8802	3	473024	407672	440348	46211	10
3.0	457464	407672	432568	35208	8	463688	448128	455908	11003	2
5.0	314312	332984	323648	13203	4	385888	348544	367216	26406	7
					Cryptophyta					
0.3	121368	80912	101140	28607	28	143152	102696	122924	28607	23
1.0	108920	65352	87136	30807	35	102696	84024	93360	13203	14
3.0	118256	80912	99584	26406	27	130704	102696	116700	19805	17
5.0	62240	84024	73132	15404	21	43568	59128	51348	11003	21
					Cyanophyta					
0.3	1092312	1020736	1056524	50612	5	146264	675304	410784	374088	91
1.0	725096	927376	826236	143034	17	641072	902480	771776	184843	24
3.0	762440	796672	779556	24206	3	743768	983392	863580	169440	20
5.0	273856	572608	423232	211250	50	927376	357880	642628	402694	63

Table B-2. (Continued)

	May 86									
	TRM 484.5					TRM 490.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
					Euglenophyta					
0.3	3112	9336	6224	4401	71	15560	12448	14004	2201	16
1.0	3112	3112	3112	0	0	6224	6224	6224	0	0
3.0	3112	6224	4668	2201	47	9336	9336	9336	0	0
5.0	3112	6224	4668	2201	47	9336	6224	7780	2201	28
					Pyrrhophyta					
0.3	0	3112	1556	2201	141	18672	15560	17116	2201	13
1.0	0	0	0	0	0	9336	9336	9336	0	0
3.0	0	0	0	0	0	3112	3112	3112	0	0
5.0	3112	0	1556	2201	141	9336	3112	6224	4401	71
					Total					
0.3	2844368	2526944	2685656	224453	8	2141056	2365120	2253088	158437	7
1.0	2057032	1913880	1985456	101224	5	2455368	2414912	2435140	28607	1
3.0	2125496	1904544	2015020	156237	8	2362008	2517608	2439808	110026	5
5.0	1475088	1490648	1482868	11003	1	2330888	1447080	1888984	624947	33

Table B-2. (Continued)

	Aug. 86														
	TRM 472.8					TRM 478.2					TRM 483.4				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	Sample STD	Sample CV	1	2	Mean	STD	CV
	Chlorophyta														
0.3	463688	504144	483916	28607	6	883808	718872	801340	116627	15	781112	681528	731320	70417	10
1.0	678416	563272	620844	81419	13	634848	603728	619288	22005	4	634848	538376	586612	68216	12
3.0	566384	563272	564828	2201	0	653520	560160	606840	66015	11	709536	581944	645740	90221	14
5.0	476136	482360	479248	4401	1	721984	563272	642628	112226	17	591280	460576	525928	92422	18
	Chrysophyta														
0.3	258296	230288	244292	19805	8	267632	239624	253628	19805	8	301864	264520	283192	26406	9
1.0	370328	286304	328316	59414	18	308088	258296	283192	35208	12	220952	211616	216284	6602	3
3.0	273856	214728	244292	41810	17	286304	233400	259852	37409	14	311200	304976	308088	4401	1
5.0	171160	149376	160268	15404	10	357880	270744	314312	61614	20	301864	242736	272300	41810	15
	Cryptophyta														
0.3	34232	46680	40456	8802	22	49792	59128	54460	6602	12	43568	59128	51348	11003	21
1.0	34232	40456	37344	4401	12	46680	34232	40456	8802	22	31120	49792	40456	13203	33
3.0	18672	34232	26452	11003	42	31120	40456	35788	6602	18	40456	52904	46680	8802	19
5.0	21784	31120	26452	6602	25	46680	34232	40456	8802	22	31120	21784	26452	6602	25
	Cyanophyta														
0.3	1888984	1129656	1509320	536926	36	1602680	1142104	1372392	325676	24	1294592	1095424	1195008	140833	12
1.0	1335048	1325712	1330380	6602	0	1755168	1201232	1478200	391692	26	1008288	905592	956940	72617	8
3.0	880696	753104	816900	90221	11	1017624	946048	981836	50612	5	871360	862024	866692	6602	1
5.0	634848	594392	614620	28607	5	824680	606840	715760	154036	22	653520	507256	580388	103424	18

Table B-2. (Continued)

	Aug. 86														
	TRM 472.8					TRM 478.2					TRM 483.4				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	Sample STD	Sample CV	1	2	Mean	STD	CV
	Euglenophyta														
0.3	6224	6224	6224	0	0	12448	12448	124480	0	12448	3112	7780	6602	85	
1.0	40456	24896	32676	11003	34	3112	9336	6224	4401	71	6224	6224	6224	0	0
3.0	3112	9336	6224	4401	71	9336	3112	6224	4401	71	18672	9336	14004	6602	47
5.0	3112	6224	4668	2201	47	6224	3112	4668	2201	47	6224	6224	6224	0	0
	Pyrrhophyta														
0.3	0	0	0	0	.	15560	6224	10892	6602	61	9336	3112	6224	4401	71
1.0	9336	6224	7780	2201	28	6224	3112	4668	2201	47	9336	3112	6224	4401	71
3.0	12448	9336	10892	2201	20	3112	3112	3112	0	0	15560	9336	12448	4401	35
5.0	0	3112	1556	2201	141	6224	6224	6224	0	0	15560	6224	10892	6602	61
	Total														
0.3	2651424	1916992	2284208	519322	23	2831920	2178400	2505160	462108	18	2442920	2106824	2274872	237656	10
1.0	2467816	2246864	2357340	156237	7	2754120	2109936	2432028	455507	19	1910768	1714712	1812740	138633	8
3.0	1755168	1584008	1669588	121028	7	2001016	1786288	1893652	151836	8	1966784	1820520	1893652	103424	5
5.0	1307040	1266584	1286812	28607	2	1963672	1484424	1724048	338880	20	1599568	1244800	1422184	250859	18

Table B-2. (Continued)

	Aug. 86									
	TRM 484.5					TRM 490.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
					Chlorophyta					
0.3	712648	600616	656632	79219	12	389000	360992	374996	19805	5
1.0	781112	591280	686196	134231	20	304976	233400	269188	50612	19
3.0	435680	392112	413896	30807	7	298752	295640	297196	2201	1
5.0	628624	417008	522816	149635	29	230288	233400	231844	2201	1
					Chrysophyta					
0.3	348544	255184	301864	66015	22	202280	214728	208504	8802	4
1.0	314312	270744	292528	30807	11	133816	124480	129148	6602	5
3.0	317424	242736	280080	52812	19	205392	196056	200724	6602	3
5.0	252072	227176	239624	17604	7	146264	164936	155600	13203	8
					Cryptophyta					
0.3	34232	28008	31120	4401	14	40456	34232	37344	4401	12
1.0	52904	28008	40456	17604	44	18672	34232	26452	11003	42
3.0	37344	21784	29564	11003	37	31120	18672	24896	8802	35
5.0	31120	24896	28008	4401	16	21784	18672	20228	2201	11
					Cyanophyta					
0.3	585056	613064	599060	19805	3	637960	535264	586612	72617	12
1.0	525928	522816	524372	2201	0	482360	339208	410784	101224	25
3.0	743768	637960	690864	74818	11	304976	267632	286304	26406	9
5.0	728208	513480	620844	151836	24	280080	270744	275412	6602	2

Table B-2. (Continued)

	Aug. 86									
	TRM 484.5					TRM 490.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
					Euglenophyta					
0.3	18672	9336	14004	6602	47	6224	6224	6224	0	0
1.0	21784	3112	12448	13203	106	3112	3112	3112	0	0
3.0	6224	6224	6224	0	0	3112	3112	3112	0	0
5.0	18672	12448	15560	4401	28	6224	9336	7780	2201	28
					Pyrrhophyta					
0.3	15560	9336	12448	4401	35	6224	3112	4668	2201	47
1.0	12448	9336	10892	2201	20	0	0	0	0	.
3.0	15560	6224	10892	6602	61	6224	3112	4668	2201	47
5.0	9336	6224	7780	2201	28	6224	3112	4668	2201	47
					Total					
0.3	1714712	1515544	1615128	140833	9	1282144	1154552	1218348	90221	7
1.0	1708488	1425296	1566892	200247	13	942936	734432	838684	147435	18
3.0	1556000	1307040	1431520	176041	12	849576	784224	816900	46211	6
5.0	1668032	1201232	1434632	330077	23	690864	700200	695532	6602	1

*TRM = Tennessee River Mile.
†STD = Standard Deviation.
‡CV = Coefficient of Variation.

Table B-3. Results of Two-Way Analysis of Variance on Total Phytoplankton and Group Cell Densities, Operational Monitoring During 1986 at Sequoyah Nuclear Plant, Chickamauga Reservoir

	Chlorophyta		Chrysophyta		Cyanophyta		Total Phytoplankton	
	F-Ratio	P>F	F-Ratio	P>F	F-Ratio	P>F	F-Ratio	P>F
<u>May 1986</u>								
Station	32.03	0.0001*	564.01	0.0001*	13.10	0.0001*	32.26	0.0001*
Depth	5.68	0.0056*	46.06	0.0001*	3.34	0.0401*	7.38	0.0016*
Interaction	1.30	0.2904	8.10	0.0001*	3.62	0.0054*	3.62	0.0055*
<u>Aug. 1986</u>								
Station	51.14	0.0001*	21.88	0.0001*	57.96	0.0001*	52.87	0.0001*
Depth	7.23	0.0018*	3.50	0.0345*	24.90	0.0001*	17.85	0.0001*
Interaction	2.48	0.0348*	4.92	0.0009*	3.18	0.0001*	1.39	0.2478

*Significant at = 0.05

Table B-4. Disposition of Phytoplankton Density (Cells/L) Data Sets with Significant F-Ratios Identified in Table 5, Operational Monitoring During 1986 at Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Test Group	Sample Depth (m)	F-Ratio Two-Way ANOVA	F-Ratio One-Way ANOVA	SNK* High Mean Low Mean
May 1986	Chlorophyta†		32.03§		5 3 4 2 1
	Chrysophyta‡	0.3		120.76§	1 2 4 3 5
		1.0		372.31§	1 2 3 5 4
		3.0		67.48§	1 2 3 5 4
		5.0		347.44§	1 2 3 5 4
	Cyanophyta‡	0.3		10.45§	1 4 5 2 3
		1.0		28.05§	1 4 5 2 3
		3.0		2.62	1 5 4 2 3
		5.0		0.64	1 3 5 2 4
	Total Phytoplankton‡	0.3		22.28§	1 4 2 5 3
		1.0		42.22§	1 5 3 4 2
		3.0		16.14§	1 5 2 3 4
		5.0		3.08	1 3 2 5 4
Aug. 1986	Chlorophyta‡	0.3		19.00§	2 3 4 1 5
		1.0		13.83§	4 2 1 3 5
		3.0		28.04§	3 2 1 4 5
		5.0		10.31§	2 3 4 1 5
	Chrysophyta‡	0.3		2.71	4 3 2 1 5
		1.0		21.80§	1 4 2 3 5
		3.0		2.94	3 4 2 1 5
		5.0		11.63§	2 3 4 1 5
	Cyanophyta‡	0.3		9.20§	1 2 3 4 5
		1.0		22.96§	2 1 3 4 5
		3.0		69.26§	2 3 1 4 5
		5.0		9.82§	2 1 4 3 5

Table B-4. (Continued)

Date	Test Group	Sample Depth (m)	F-Ratio Two-Way ANOVA	F-Ratio One-Way ANOVA	SNK* High Mean	SNK* Low Mean
	Total Phytoplankton†			52.87§		
	2 1 3 4 5					

*Student, Newman, Keuls Multiple Range Test; means ranked lowest to highest using station numbers; means underscored by same line are not significantly different at α = 0.05, means not so underscored are significantly different.

Tennessee River Mile 472.8 = station 1
Tennessee River Mile 478.2 = station 2
Tennessee River Mile 483.4 = station 3
Tennessee River Mile 484.5 = station 4
Tennessee River Mile 490.5 = station 5

†Depths not tested separately.

‡Depths tested separately with one-way ANOVA because interaction was significant in two-way ANOVA.

§Significant at = 0.05

Table B-5. Mean Phytoplankton Densities (No. X 100)/ at Each Sample Station (Depths Combined) During Operational Monitoring (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

	May 1986					August, 1986				
	Tennessee River Mile									
	472.8	478.2	483.4	484.5	490.5	472.8	478.2	483.4	484.5	490.5
Chlorophyta										
Acanthosphaera	0	23	27	8	12	23	27	19	4	8
Actinastrum	47	51	97	93	113	0	0	39	175	163
Ankistrodesmus	253	198	657	506	622	31	187	128	105	54
Botryococcus	0	0	0	0	0	0	0	0	0	31
Characium	0	4	0	16	0	0	0	0	0	0
Chlamydomonas	311	121	66	78	148	167	222	245	245	167
Chlorella	35	74	198	187	156	152	191	109	124	70
Chodatella	54	70	27	35	39	27	35	51	12	0
Closteriopsis	4	4	4	0	4	0	0	0	0	0
Coelastrum	233	124	401	506	529	249	245	124	331	109
Cosmarium	0	0	0	62	0	0	0	0	0	0
Crucigenia	109	144	222	241	724	342	420	300	331	373
Dictyosphaerium	498	642	848	1062	1315	249	292	319	187	70
Echinosphaerella	0	0	0	0	0	0	39	0	0	0
Elakatothrix	54	47	124	47	93	39	23	31	31	8
Euastrum	0	0	0	0	0	4	4	4	0	0
Eudorina	0	0	0	0	0	0	0	0	373	0
Gloeoactinium	89	0	109	0	0	0	16	0	0	0
Golenkinia	0	12	78	19	35	27	23	35	8	19
Gonium	0	0	0	0	0	78	187	580	257	280
Kirchneriella	23	214	296	148	354	86	373	443	202	101
Micractinium	545	510	1155	867	1424	86	265	0	136	16
Oocystis	62	31	47	70	31	78	31	97	0	31
Pandorina	0	62	62	0	0	529	373	249	311	124
Pediastrum	78	167	498	249	428	249	533	451	467	171
Pteromonas	0	0	23	16	27	19	4	0	16	27
Scenedesmus	2104	2198	4205	3392	4166	2805	3034	2882	2225	1023

Table B-5. (Continued)

	May 1986					August, 1986				
	Tennessee River Mile									
	472.8	478.2	483.4	484.5	490.5	472.8	478.2	483.4	484.5	490.5
Schroederia	206	113	117	70	62	47	62	51	62	39
Staurastrum	8	8	8	0	0	47	58	35	27	27
Tetrallantos	0	0	31	0	0	0	0	0	0	0
Tetrastrum	0	0	16	31	31	4	0	0	47	0
Treubaria	0	0	0	8	0	35	31	31	23	19
Chrysophyta										
Achnanthes	8	58	31	8	12	31	23	51	39	31
Asterionella	327	136	39	97	93	0	0	0	0	0
Attheya	428	268	405	257	331	121	47	82	35	16
Chaetoceros	43	335	358	510	654	140	412	366	323	179
Cocconeis	0	0	0	0	0	4	0	0	4	4
Cymbella	8	4	8	16	23	27	16	16	4	8
Diatoma	0	0	0	0	0	8	4	4	0	4
Dinobryon	78	0	78	31	78	0	12	51	47	0
Fragilaria	8819	3944	926	759	720	0	0	0	109	0
Melosira	7722	3925	2964	1614	1751	1303	1369	1144	1494	840
Navicula	8	12	27	35	35	35	19	27	43	35
Nitzschia	0	4	8	12	12	0	0	0	4	4
Rhizosolenia	206	117	105	109	128	8	54	58	39	31
Rhoicosphenia	0	0	39	31	0	0	0	0	0	0
Stephanodiscus	230	202	342	226	296	86	159	128	89	74
Synedra	323	358	319	338	233	681	661	774	556	510
Cryptophyta										
Cryptomonas	1797	1225	1330	902	961	327	428	412	323	272
Cyanophyta										
Anabaena	148	62	0	0	0	0	0	0	0	0
Anacystis	0	0	257	408	171	4567	3894	2805	1867	1789

Table B-5. (Continued)

	May 1986					August, 1986				
	Tennessee River Mile									
	472.8	478.2	483.4	484.5	490.5	472.8	478.2	483.4	484.5	490.5
Merismopedia	156	381	829	832	949	3380	4579	3194	2287	1424
Oscillatoria	13102	5633	2801	6473	5602	1782	1836	1961	1027	0
Raphidiopsis	0	0	0	0	0	949	1062	1039	906	685
Euglenophyta										
Euglena	183	89	39	23	31	54	58	66	89	31
Phacus	0	4	0	0	0	0	0	0	0	0
Trachelomonas	51	43	54	23	62	70	16	19	31	19
Pyrrhophyta										
Ceratium	23	23	39	8	19	12	8	16	8	4
Glenodinium	0	4	0	0	0	0	0	0	0	0
Gymnodinium	0	0	8	0	70	39	54	74	93	31
Peridinium	0	0	0	0	0	0	0	0	4	0

Table B-6. Similarity of Phytoplankton Community Composition/Structure During Operational Monitoring in 1986 Based on Sorensen's Quotient of Similarity and Percentage Similarity, Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Station Comparison	Sorensen's Quotient of Similarity (%)	Percentage Similarity (%)
May	TRM* 490.5-484.5	93	88
	TRM 490.5-483.4	94	82
	TRM 490.5-478.2	87	70
	TRM 490.5-472.8	87	48
	TRM 484.5-483.4	90	78
	TRM 484.5-478.2	85	73
	TRM 484.5-472.8	83	52
	TRM 483.4-478.2	86	69
	TRM 483.4-472.8	87	47
	TRM 478.2-472.8	89	68
August	TRM 490.5-484.5	89	73
	TRM 490.5-483.4	89	63
	TRM 490.5-478.2	88	57
	TRM 490.5-472.8	92	60
	TRM 484.5-483.4	87	80
	TRM 484.5-478.2	87	76
	TRM 484.5-472.8	90	76
	TRM 483.4-478.2	94	88
	TRM 483.4-472.8	93	86
	TRM 478.2-472.8	94	89

*TRM = Tennessee River Mile

Table B-7. Diversity Index Values (Dbar) and Number of Taxa for Phytoplankton Communities During Operational Monitoring (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

	Tennessee River Mile									
	472.8		478.2		483.4		484.5		490.5	
Date	No. Taxa	Dbar	No. Taxa	Dbar	No. Taxa	Dbar	No. Taxa	Dbar	No. Taxa	Dbar
May 1986	37	2.84	42	3.40	46	4.00	43	3.65	41	3.82
Aug. 1986	43	3.58	44	3.75	41	3.88	46	4.15	42	3.90

Table B-8. Chlorophyll a Concentrations, Phaeophytin a Concentrations, and Phaeophytin Index Values at Each Sample Location During Operational Monitoring (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

			TRM 472.8			TRM 478.2			TRM 483.4			TRM 484.5			TRM 490.5		
Date	Depth (M)	Sample No.	Chl a Mg/M3	Pheo a Mg/M3	Pheo Index	Chl a Mg/M3	Pheo a Mg/M3	Pheo Index	Chl a Mg/M3	Pheo a Mg/M3	Pheo Index	Chl a Mg/M3	Pheo a Mg/M3	Pheo Index	Chl a Mg/M3	Pheo a Mg/M3	Pheo Index
May 86	0.3	1	13.50	1.00	1.65	13.60	1.00	1.74	17.10	1.00	1.69	13.10	1.70	1.61	27.80	1.00	1.72
		2	14.00	1.00	1.68	12.50	1.50	1.62	16.40	1.00	1.67	17.10	1.70	1.63	23.90	1.00	1.68
		x	13.75	1.00	1.67	13.05	1.25	1.68	16.75	1.00	1.68	15.10	1.70	1.62	25.85	1.00	1.70
		s	0.35	0.00	0.02	0.78	0.35	0.08	0.49	0.00	0.01	2.83	0.00	0.01	2.76	0.00	0.00
		cv	2.57	0.00	1.27	5.96	28.28	5.05	2.96	0.00	0.84	18.73	0.00	0.87	10.67	0.00	1.66
	1.0	1	13.20	1.70	1.61	12.10	2.10	1.58	19.90	1.00	1.67	14.90	1.00	1.66	22.00	1.60	1.65
		2	15.00	1.00	1.74	11.70	1.00	1.66	16.60	1.00	1.69	14.90	4.10	1.52	26.00	1.00	1.68
		x	14.10	1.35	1.68	11.90	1.55	1.62	18.25	1.00	1.68	14.90	2.55	1.59	24.00	1.30	1.67
		s	1.27	0.49	0.09	0.28	0.78	0.06	2.33	0.00	0.01	0.00	2.19	0.10	2.83	0.42	0.42
		cv	9.03	36.66	5.49	2.38	50.18	3.49	12.79	0.00	0.84	0.00	85.96	6.23	11.79	32.64	1.27
	3.0	1	18.00	1.80	1.63	11.90	1.00	1.67	19.50	2.50	1.61	19.80	8.30	1.45	19.20	3.00	1.59
		2	20.50	1.00	1.71	13.60	1.00	1.69	18.70	1.00	1.67	15.10	3.30	1.56	23.10	1.60	1.65
		x	19.25	1.40	1.67	12.75	1.00	1.68	19.10	1.75	1.64	17.45	5.80	1.51	21.15	2.30	1.62
		s	1.77	0.57	0.06	1.20	0.00	0.01	0.57	1.06	0.04	3.32	3.54	0.08	2.76	0.99	0.99
		cv	9.18	40.41	3.39	9.43	0.00	0.84	2.96	60.61	2.59	19.05	60.96	5.17	13.04	43.04	2.62
	5.0	1	18.50	2.60	1.60	13.00	1.00	1.68	18.40	1.00	1.69	14.00	1.00	1.66	11.20	1.50	1.61
		2	18.70	1.00	1.69	13.30	2.80	1.56	17.10	4.40	1.53	16.50	2.60	1.59	11.10	3.80	1.48
		x	18.60	1.80	1.65	13.15	1.90	1.62	17.75	2.70	1.61	15.25	1.80	1.63	11.15	2.65	1.55
		s	0.14	1.13	0.06	0.21	1.27	0.08	0.92	2.40	0.11	1.77	1.13	0.05	0.07	1.63	1.63
		cv	0.76	62.85	3.87	1.61	66.99	5.24	5.18	89.04	7.03	11.59	62.85	3.05	0.63	61.37	5.95

Table B-8. (Continued)

Date	Depth (M)	Sample No.	TRM 472.8 Chl a Mg/M3	TRM 472.8 Pheo a Mg/M3	TRM 472.8 Pheo Index	TRM 478.2 Chl a Mg/M3	TRM 478.2 Pheo a Mg/M3	TRM 478.2 Pheo Index	TRM 483.4 Chl a Mg/M3	TRM 483.4 Pheo a Mg/M3	TRM 483.4 Pheo Index	TRM 484.5 Chl a Mg/M3	TRM 484.5 Pheo a Mg/M3	TRM 484.5 Pheo Index	TRM 490.5 Chl a Mg/M3	TRM 490.5 Pheo a Mg/M3	TRM 490.5 Pheo Index
Aug. 86	0.3	1	6.30	1.40	1.56	9.50	2.10	1.56	9.30	1.00	1.64	8.50	1.00	1.67	5.70	1.00	1.59
		2	4.80	1.50	1.50	9.20	2.00	1.56	8.40	2.90	1.48	7.80	1.00	1.64	5.50	1.40	1.53
		x	5.55	1.45	1.53	9.35	2.05	1.56	8.85	1.95	1.56	8.15	1.00	1.66	5.60	1.20	1.56
		s	1.06	0.07	0.04	0.21	0.07	0.00	0.64	1.34	0.11	0.49	0.00	0.02	0.14	0.28	0.28
		cv	19.11	4.88	2.77	2.27	3.45	0.00	7.19	68.90	7.25	6.07	0.00	1.28	2.53	23.57	2.72
	1.0	1	6.70	1.50	1.55	11.60	5.80	1.41	7.90	1.70	1.56	8.80	1.00	1.62	5.00	1.00	1.63
		2	5.50	1.40	1.53	8.30	1.80	1.55	9.20	2.00	1.56	9.70	1.50	1.59	5.90	1.00	1.63
		x	6.10	1.45	1.54	9.95	3.80	1.48	8.55	1.85	1.56	9.25	1.25	1.61	5.45	1.00	1.63
		s	0.85	0.07	0.01	2.33	2.83	0.10	0.92	0.21	0.00	0.64	0.35	0.02	0.64	0.00	0.00
		cv	13.91	4.88	0.92	23.45	74.43	6.69	10.75	11.47	0.00	6.88	28.28	1.32	11.68	0.00	0.00
	3.0	1	6.10	1.50	1.54	9.30	2.60	1.52	7.00	1.00	1.63	8.10	2.40	1.51	5.90	1.00	1.73
		2	6.70	1.50	1.55	9.50	3.00	1.50	7.90	1.70	1.56	7.10	1.00	1.62	5.80	1.00	1.76
		x	6.40	1.50	1.55	9.40	2.80	1.51	7.45	1.35	1.60	7.60	1.70	1.57	5.85	1.00	1.75
		s	0.42	0.00	0.01	0.14	0.28	0.01	0.64	0.49	0.05	0.71	0.99	0.08	0.07	0.00	0.00
		cv	6.63	0.00	0.46	1.50	10.10	0.94	8.54	36.66	3.10	9.30	58.23	4.97	1.21	0.00	1.22
	5.0	1	6.20	1.00	1.77	8.20	1.00	1.64	8.10	1.20	1.60	8.30	1.40	1.59	5.80	1.00	1.65
		2	7.00	1.10	1.59	9.70	2.90	1.51	9.10	1.80	1.57	5.70	6.60	1.14	4.90	1.00	1.65
		x	6.60	1.05	1.68	8.95	1.95	1.58	8.60	1.50	1.59	7.00	4.00	1.37	5.35	1.00	1.65
		s	0.57	0.07	0.13	1.06	1.34	0.09	0.71	0.42	0.02	1.84	3.68	0.32	0.64	0.00	0.00
		cv	8.57	6.73	7.58	11.85	68.90	5.84	8.22	28.28	1.34	26.26	91.92	23.31	11.90	0.00	0.00

Table B-9. Results of Statistical Analyses (One- and Two-Way Analyses of Variance and Student, Newman, Keuls Multiple Range Text) on Phytoplankton Chlorophyll a Data, Operational Monitoring During 1986 Near Sequoyah Nuclear Plant, Chickamauga Reservoir

Results of Two-Way ANOVA

	Station		Depth		Interaction	
	F-Ratio	P>F	F-Ratio	P>F	F-Ratio	P>F
May	23.53	0.0001*	5.20	0.0081*	9.07	0.0001*
Aug.	23.39	0.0001*	0.89	0.4636	0.76	0.6706

Results of One-Way ANOVA and SNK on Data Sets with Significant F-Ratios

Date	Sample Depth (m)	F-Ratio One-Way ANOVA	SNK† High $\bar{X}$				Low $\bar{X}$
May	0.3	14.45	5	3	4	1	2
	1.0	18.15	5	3	4	1	2
	3.0	5.22	5	1	3	4	2
	5.0	26.90	1	3	4	2	5
Aug.			2	3	4	1	5

*Significant at = 0.05.

†Student, Newman, Kuels Multiple Range Test; means ranked lowest to highest using station numbers; means underscored by same line are not significantly different at = 0.05; means not so underscored are significantly different.

Station 1 = Tennessee River Mile 472.8
Station 2 = Tennessee River Mile 478.2
Station 3 = Tennessee River Mile 483.4
Station 4 = Tennessee River Mile 484.5
Station 5 = Tennessee River Mile 490.5

Table B-10. Chlorophyll Fluorescence Measurments - Sequoyah Nuclear Plant - 1986

TRM*	Depth (Meters)	May 20, 1986 Raw Fluorescence†	May 20, 1986 FRI‡	August 28, 1986 Raw Fluorscence	August 28, 1986 FRI
478.2	0.3	15.8	0.633	8.2	0.559
	1.0	16.8	0.658	7.6	0.586
	3.0	16.8	0.644	7.9	0.576
	5.0	17.7	0.631	7.9	0.537
	7.0	14.9	0.619	7.9	0.569
	9.0	11.7	0.635	8.2	0.552
	11.0	6.1	0.606	7.9	0.545
	13.0	2.3	0.500	7.9	0.554
	14.0	2.5	0.457	--	--
	15.0	--	--	7.9	0.554
	17.0	--	--	7.9	0.576
482.0	0.3	17.1	0.603	8.2	0.574
	1.0	17.4	0.605	7.6	0.593
	3.0	17.4	0.605	8.2	0.566
	5.0	9.5	0.605	7.9	0.554
	7.0	5.4	0.593	7.6	0.579
	9.0	3.3	0.582	7.6	0.579
	11.0	2.3	0.617	7.6	0.579
	13.0	2.2	0.577	7.6	0.593
	15.0	2.1	0.500	6.6	0.604
	17.0	--	--	7.6	0.579
483.4	0.3	23.0	0.558	8.9	0.582
	1.0	24.0	0.600	9.2	0.574
	3.0	24.0	0.586	8.9	0.555
	5.0	22.0	0.621	7.3	0.639
	7.0	22.0	0.621	7.3	0.639
	9.0	13.9	0.579	8.2	0.580
	11.0	10.4	0.614	8.2	0.574
	13.0	5.2	0.578	8.2	0.580
	15.0	3.0	0.375	7.3	0.634
	17.0	3.0	0.500	8.9	0.562
484.5	0.3	16.4	0.609	7.9	0.627
	1.0	16.4	0.589	7.6	0.625
	3.0	15.2	0.611	7.9	0.603
	5.0	13.6	0.600	8.5	0.572
	7.0	12.6	0.579	8.2	0.580
	9.0	11.1	0.590	8.2	0.587

Table B-10. (Continued)

TRM*	Depth (Meters)	May 20, 1986 Raw Fluorescence†	FRI‡	August 28, 1986 Raw Fluorscence	FRI
	11.0	8.9	0.562	7.9	0.583
	13.0	6.4	0.587	7.3	0.610
	14.0	3.8	0.518	--	--
	15.0	--	--	7.9	0.583
	17.0	--	--	7.6	0.607

*Tennessee River Mile

†All readings equalized to maximum instrument sensitivity

‡Fluorescence Response Index

Table B-11. Carbon Assimilation Rates at Each Sample Location During Operational Monitoring (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Depth (m)	Sample No.	mg C/m^3/hour TRM* 472.8	TRM 478.2	TRM 483.4	TRM 484.5	TRM 490.5
May 86	0.3	1	2.15	9.53	8.99	7.04	9.68
		2	1.87	12.49	8.83	7.07	9.34
		X†	2.01	11.01	8.91	7.05	9.51
		S‡	0.19	2.09	0.11	0.02	0.24
		CV§	9.56	18.99	1.27	0.29	2.56
	1.0	1	8.34	12.26	12.89	3.82	15.85
		2	8.74	11.80	10.31	5.98	14.48
		X	8.54	12.03	11.60	4.90	15.17
		S	0.29	0.32	1.82	1.53	0.97
		CV	3.37	2.70	15.72	31.19	6.39
	3.0	1	2.26	3.79	1.89	1.60	2.49
		2	1.43	3.74	1.19	1.85	2.45
		X	1.84	3.76	1.54	1.73	2.47
		S	0.59	0.03	0.49	0.18	0.03
		CV	31.90	0.87	32.19	10.26	1.22
	5.0	1	0.00	0.79	0.40	0.34	0.31
		2	0.00	0.89	0.32	0.44	0.29
		X	0.00	0.84	0.36	0.39	0.30
		S	0.00	0.07	0.06	0.07	0.01
		CV	.	8.43	16.27	18.13	4.18
mg C/m^2/day			159	274	242	145	333
Aug. 86	0.3	1	11.71	17.12	16.50	15.86	12.42
		2	12.19	17.21	14.81	15.68	12.09
		X	11.95	17.16	15.66	15.77	12.25
		S	0.34	0.06	1.19	0.13	0.24
		CV	2.83	0.37	7.61	0.82	1.92
	1.0	1	7.23	7.82	8.92	16.89	8.63
		2	8.97	8.06	8.93	16.57	8.66
		X	8.10	7.94	8.92	16.73	8.64
		S	1.23	0.17	0.01	0.23	0.02
		CV	15.21	2.16	0.07	1.38	0.24
	3.0	1	1.99	1.06	3.13	2.00	1.26
		2	2.59	1.02	3.80	2.41	1.84
		X	2.29	1.04	3.46	2.20	1.55
		S	0.43	0.03	0.47	0.29	0.41
		CV	18.58	3.24	13.67	12.96	26.76

Table B-11. (Continued)

Date	Depth (m)	Sample No.	mg C/m^3/hour TRM* 472.8	TRM 478.2	TRM 483.4	TRM 484.5	TRM 490.5
Aug. 86	5.0	1	0.48	0.16	0.81	0.25	0.30
		2	0.50	0.14	0.71	0.35	0.15
		$\bar{X}$	0.49	0.15	0.76	0.30	0.23
		S	0.02	0.02	0.07	0.08	0.11
		CV	3.15	12.30	9.40	25.12	47.76
mg C/m^2/day			202	214	184	201	125

*TRM = Tennessee River Mile

†$\bar{X}$ = Mean

‡S = Standard Deviation

§CV = Coefficient of Variation.

Table B-12. Results of Statistical Analyses (One- and Two-Way Analyses of Variance and Student, Newman, Keuls Multiple Range Text) on Phytoplankton Carbon Assimilation Rates, Operational Monitoring During 1986 Near Sequoyah Nuclear Plant, Chickamauga Reservoir

Results of Two-Way ANOVA

	Station		Depth		Interaction	
	F-Ratio	P>F	F-Ratio	P>F	F-Ratio	P>F
MAY	57.36	0.0001*	791.71	0.0001*	15.49	0.0001*
AUG	4.61	0.0084*	119.93	0.0001*	2.81	0.0199*

Results of One-Way ANOVA and SNK on Data Sets with Significant F-Ratios

Date	Sample Depth (m)	F-Ratio One-Way ANOVA	SNK** High $\bar{X}$ → Low $\bar{X}$
MAY	0.3	87.24	2 5 3 4 1
	1.0	16.37	5 2 3 1 4
	3.0	7.69	2 5 1 4 3
	5.0	78.58	2 4 3 5 1
AUG	0.3	37.61	2 4 3 5 1
	1.0	43.66	4 3 5 1 2
	3.0	13.69	3 1 4 5 2
	5.0	21.75	3 1 4 5 2

*Significant at $\alpha = 0.05$.

†Student, Newman, Kuels Multiple Range Test; means ranked lowest to highest using station numbers; means underscored by same line are not significantly different at $\alpha = 0.05$; means not so underscored are significantly different.

‡Station 1 = Tennessee River Mile 490.5
Station 2 = Tennessee River Mile 484.5
Station 3 = Tennessee River Mile 483.4
Station 4 = Tennessee River Mile 478.2
Station 5 = Tennessee River Mile 472.8

APPENDIX C

ZOOPLANKTON DATA AND RESULTS OF
STATISTICAL TESTS
MAY 20 AND AUGUST 27, 1986

Table C-1. Percentage Composition of Zooplankton Groups During Operational Monitoring Periods (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Zooplankton Group	Tennessee River Mile				
		472.8	478.2	483.4	484.5	490.5
May 1986	Cladocera	19	20	22	35	28
	Copepoda	55	66	66	51	54
	Rotifera	26	14	13	14	18
Aug. 1986	Cladocera	23	12	12	24	10
	Copepoda	30	10	15	22	11
	Rotifera	47	78	73	55	79

Table C-2. Summary of Zooplankton Data Collected During Operational Monitoring Periods (1986), Sequoyah Nuclear Plant

Date	River Mile	Group	Sample 1	Sample 2	Mean	Standard Deviation	C.V.*
May 86	472.8	Cladocera	92980	25100	59040	47998.4	81.30
		Copepoda	215690	120340	168015	67422.6	40.13
		Rotifera	101380	59730	80555	29451.0	36.56
		Total	410050	205170	307610	144872.0	47.10
	478.2	Cladocera	20942	39000	29971	12768.9	42.60
		Copepoda	81151	113790	97471	23079.3	23.68
		Rotifera	19307	20640	19974	942.6	4.72
		Total	121400	173430	147415	36790.8	24.96
	483.4	Cladocera	24930	12615	18773	8708.0	46.39
		Copepoda	71800	42511	57156	20710.5	36.24
		Rotifera	13325	8641	10983	3312.1	30.16
		Total	110055	63767	86911	32730.6	37.66
	484.5	Cladocera	68627	41289	54958	19330.9	35.17
		Copepoda	98923	64112	81518	24615.1	30.20
		Rotifera	26585	17072	21829	6726.7	30.82
		Total	194135	122473	158304	50672.7	32.01
	490.5	Cladocera	44417	36428	40423	5649.1	13.98
		Copepoda	94978	60651	77815	24272.9	31.19
		Rotifera	28793	24040	26417	3360.9	12.72
		Total	168188	121119	144654	33282.8	23.01

Table C-2. (Continued)

Date	River Mile	Group	Sample 1	Sample 2	Mean	Standard Deviation	C.V.*
Aug. 86	472.8	Cladocera	20655	23458	22057	1982.0	8.99
		Copepoda	28609	29587	29098	691.6	2.38
		Rotifera	27033	63186	45110	25564.0	56.67
		Total	76297	116231	96264	28237.6	29.33
	478.2	Cladocera	30435	16226	23331	10047.3	43.07
		Copepoda	23530	17327	20429	4386.2	21.47
		Rotifera	204522	103410	153966	71497.0	46.44
		Total	258487	136963	197725	85930.4	43.46
	483.4	Cladocera	20269	27778	24024	5309.7	22.10
		Copepoda	10130	49019	29575	27498.7	92.98
		Rotifera	74096	212824	143460	98095.5	68.38
		Total	104495	289621	197058	130903.8	66.43
	484.5	Cladocera	20288	44859	32574	17374.3	53.34
		Copepoda	22192	37638	29915	10922.0	36.51
		Rotifera	64659	87062	75861	15841.3	20.88
		Total	107139	169559	138349	44137.6	31.90
	490.5	Cladocera	13030	17098	15064	2876.5	19.10
		Copepoda	14313	17099	15706	1970.0	12.54
		Rotifera	90410	140673	115542	35541.3	30.76
		Total	117753	174870	146312	40387.8	27.60

*C.V. = Coefficient of Variation.

Table C-3. Results of One-Way-Analysis of Variance and Student, Newman, Keuls Multiple Range Test on Zooplankton Data for Operational Monitoring in 1986, Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Test Group	F Ratio	P > F	Tennessee River Mile SNK* High $\bar{x}$				Low $\bar{x}$
May 1986	Total zooplankton	3.18	0.1183	472.8	484.5	478.2	490.5	483.4
	Cladocera	1.40	0.3543	484.5	472.8	490.5	478.2	483.4
	Copepoda	2.78	0.1460	472.8	478.2	484.5	490.5	483.4
	Rotifera	14.87	0.0055	472.8	490.5	484.5	478.2	483.4
Aug. 1986	Total zooplankton	0.73	0.6064	478.2	483.4	490.5	484.5	472.8
	Cladocera	1.05	0.4649	484.5	483.4	478.2	472.8	490.5
	Copepoda	0.47	0.7571	472.8	484.5	483.4	478.2	490.5
	Rotifera	1.99	0.2339	478.2	483.4	490.5	484.5	472.8

*Student, Newman, Keuls Multiple Range Test; means ranked highest to lowest using Tennessee River Mile (TRM) to identify stations; means underscored by same line are not significantly different at $\alpha = 0.05$, means not so underscored are significantly different.

Table C-4. Mean Zooplankton Densities (No./m3) at Each Sample Station During Operational Monitoring (1986) Sequoyah Nuclear Plant, Chickamauga Reservoir

	May 1986					August 1986				
	472.8	478.2	483.4	484.5	490.5	472.8	478.2	483.4	484.5	490.5
Cladocera										
Alona rectangula	0	0	0	0	0	1	0	0	0	130
Bosmina longirostris	980	0	124	0	93	13685	16735	4931	22963	11192
Camptocercus rectirostris	0	0	0	0	0	0	0	2	0	0
Ceriodaphnia lacustris	0	0	0	0	0	158	314	3	88	0
Chydorus sp.	0	0	5	0	0	2	157	0	0	1
Daphnia retrocurva	15620	10647	8279	13015	5005	0	0	0	176	0
Diaphanosoma leuchtenbergianum	38595	19270	9007	41911	34429	7891	5414	16111	7816	3352
Ilyocryptus spinifer	0	0	124	0	0	1	2	2	2	1
Leptodora kindtii	3845	50	1234	32	897	0	0	0	0	0
Moina micrura	0	0	0	0	0	317	707	2976	1528	389
Pleuroxus denticulatus	0	5	2	0	0	2	0	0	0	0
Sida crystallina	0	0	0	0	0	2	2	1	2	1
Simocephalus serrulatus	0	0	0	0	0	1	0	0	0	0
Copepoda										
Calanoid imm.	380	164	753	92	790	0	0	134	0	0
Cyclopoid imm.	5185	4942	2431	1195	4358	3156	1021	2380	4679	2316
Cyclops bicuspidatus thomasi	0	240	124	0	0	0	0	0	0	0
Cyclops vernalis	0	404	520	0	351	0	0	204	0	0
Diaptomus pallidus	385	164	124	5	444	0	0	0	0	0
Diaptomus reighardi	765	884	2443	360	1243	0	0	0	0	1
Ergasilus sp.	0	0	0	0	0	2	2	134	0	1
Eucyclops agilis	0	0	0	0	0	1	1	1	1	0
Mesocyclops edax	2945	2258	2233	1661	966	317	157	409	4057	261
Nauplii	158355	88417	48528	78206	69664	25624	18779	26315	21059	13126
Tropocyclops prasinus	0	0	2	0	0	0	471	0	120	3

Table C-4. (Continued)

	May 1986					August 1986				
	472.8	478.2	483.4	484.5	490.5	472.8	478.2	483.4	484.5	490.5
Rotifera										
Asplanchna herricki	0	0	0	0	0	53	434	809	264	0
Brachionus angularis	1040	1451	839	4485	13873	3423	20463	13295	4711	26807
Brachionus budapestinensis	0	0	0	87	88	526	9613	2238	2694	3093
Brachionus calyciflorus	0	0	1	0	0	0	589	409	88	0
Brachionus caudatus	0	0	87	0	366	4054	20226	12329	6230	7473
Brachionus quadridentatus	0	0	0	87	0	53	157	0	565	256
Brachionus urceolaris	0	0	0	0	0	0	0	0	88	0
Cephalodella sp.	0	0	124	0	0	0	0	0	0	0
Collotheca sp.	0	0	0	0	0	212	157	0	176	0
Conochiloides sp.	0	0	0	0	370	5954	29878	14193	6676	3491
Conochilus hippocrepis	0	0	0	0	0	1108	2413	1226	88	0
Conochilus unicornis	0	0	0	700	527	11406	16084	16856	4534	3109
Epiphanes macrourus	380	491	3677	523	0	0	0	0	0	0
Filinia longiseta	0	0	0	0	1668	0	0	134	0	0
Hexarthra intermedia	0	0	0	0	0	106	0	0	0	0
Kellicottia bostoniensis	4170	0	0	0	0	0	0	0	0	0
Kellicottia longispina	12960	13603	3776	9371	3055	0	0	0	0	0
Keratella cochlearis	46370	3535	864	407	0	106	1098	1021	0	259
Keratella crassa	3810	0	0	0	278	0	628	817	0	0
Keratella earlinae	2670	164	173	1048	1072	474	1706	204	0	259
Keratella quadrata	0	0	0	0	0	0	275	0	88	259
Lecane sp.	0	0	0	0	0	0	0	204	0	0
Machrochaetus subquadratus	0	0	0	0	0	0	0	879	88	0
Platyias patulus	0	0	0	0	0	527	2061	1696	0	766
Ploesoma truncata	0	0	0	233	0	1947	14810	3935	2236	5424
Polyarthra sp.	1860	240	370	0	911	5424	11948	18447	16744	18409
Synchaeta stylata	7295	491	1074	4889	4031	9636	21273	54638	30592	45939
Trichocerca sp.	0	0	0	0	181	106	157	134	0	0

Table C-5. **Similarity of Zooplankton Community Composition/Structure During Operational Monitoring in 1986 Based on Sorensen's Quotient of Similarity and Percentage Similarity, Sequoyah Nuclear Plant, Chickamauga Reservoir**

Date	Station Comparison	Sorensen's Quotient of Similarity (%)	Percentage Similarity (%)
May	TRM* 490.5-484.5	71	83
	TRM 490.5-483.4	69	65
	TRM 490.5-478.2	71	73
	TRM 490.5-472.8	76	56
	TRM 484.5-483.4	67	62
	TRM 484.5-478.2	79	81
	TRM 484.5-472.8	79	65
	TRM 483.4-478.2	84	68
	TRM 483.4-472.8	76	41
	TRM 478.2-472.8	84	64
August	TRM 490.5-484.5	70	71
	TRM 490.5-483.4	68	72
	TRM 490.5-478.2	83	62
	TRM 490.5-472.8	79	52
	TRM 484.5-483.4	72	67
	TRM 484.5-478.2	83	62
	TRM 484.5-472.8	73	70
	TRM 483.4-478.2	83	67
	TRM 483.4-472.8	77	59
	TRM 478.2-472.8	88	57

*Tennessee River Mile.

Table C-6. Zooplankton Diversity Index Values During Operational Monitoring Periods (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

	Tennessee River Mile									
	472.8		478.2		483.4		484.5		490.5	
Date	No. Taxa	Dbar	No. Taxa	Dbar	No. Taxa	Dbar	No. Taxa	Dbar	No. Taxa	Dbar
May 1986	16	2.83	16	2.49	23	3.15	16	2.20	20	2.54
Aug. 1986	30	3.31	30	3.56	30	3.24	26	3.15	24	2.82

APPENDIX D

WATER QUALITY DATA ON
JULY 27 AND AUGUST 31, 1987

/TYPA/AMBNT/STREAM

471 23
35 13 30.0 085 14 59.0 2
CHICKAMAUGA RESERVOIR
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040901
TENNESSEE RIVER 434.5
131TVAC 950910 06020001022 0010.630 ON
0050 FEET DEPTH

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00098 VSAMPLOC DEPTH METERS	00002 HSAMPLOC % FROM RT BANK	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	82079 TURBIDTY LAB NTU	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L
87/07/27	12[illegible]	WATER	1	.3	80	28.7	1[illegible]0	6.6	8.50	61	2.0	.23	.03
87/07/27	120[illegible]	WATER	3	1.0	80	28.6	191	6.6	8.50	61	2.0	.23	.01
87/07/27	12[illegible]	WATER	5	1.5	80	28.3	191	7.6	8.25				
87/07/27	1207	WATER	7	2.0	80	28.0	1[illegible]2	6.7	7.79				
87/07/27	12[illegible]	WATER	[illegible]	2.5	80	28.0	1[illegible]2	5.4	7.75				
87/07/27	1211	WATER	1[illegible]	3.0	80	27.8	182	6.2	7.68	61	2.0	.15	.01K
87/07/27	1212	WATER	1[illegible]	4.5	80	27.7	162	5.6	7.57	61			
87/07/27	1215	WATER	16	5.0	80						2.0	.15	.03
87/07/27	121[illegible]	WATER	2[illegible]	6.0	80	27.2	1[illegible]2	4.7	7.42				
87/07/27	1217	WATER	26	7.5	80	27.1	1[illegible]2	4.4	7.36				
87/07/27	121[illegible]	WATER	3[illegible]	9.0	80	27.0	1[illegible]2	4.3	7.32				
87/07/27	121[illegible]	WATER	34	10.5	80	26.9	1[illegible]2	4.[illegible]	7.29				
87/07/27	122[illegible]	WATER	3[illegible]	12.0	80	26.9	1[illegible]3	4.[illegible]	7.26				
87/07/27	1221	WATER	44	13.5	80	26.9	1[illegible]2	4.[illegible]	7.22				
87/07/27	122[illegible]	WATER	46	13.9	80	26.9	1[illegible]1	3.9	7.21				
87/0[illegible]/31	12[illegible]	WATER	1	.3	80	26.5	1[illegible]5	5.7	7.40	70	1.6	.14	.[illegible]2
87/0[illegible]/31	12[illegible]	WATER	1	.30	[illegible]						1.5	.1[illegible]	.02
87/0[illegible]/31	120[illegible]	WATER	[illegible]	1.0	80	26.5	1[illegible]5	5.7	7.40	70	1.7	.14	.02
87/0[illegible]/31	12[illegible]	WATER	5	1.5	80	26.5	155	5.7	7.40				
87/0[illegible]/31	121[illegible]	WATER	1[illegible]	3.0	80	26.5	155	5.7	7.40	70	1.6	.19	.02
87/0[illegible]/31	1215	WATER	16	5.0	80	26.5	1[illegible]5	5.7	7.40	70	1.7	.15	.01
87/0[illegible]/31	1217	WATER	26	8.0	80	26.5	1[illegible]5	5.[illegible]	7.40				
87/0[illegible]/31	121[illegible]	WATER	36	11.0	80	26.5	155	5.[illegible]	7.50				
87/0[illegible]/31	1221	WATER	4[illegible]	14.0	80	26.5	1[illegible]6	5.[illegible]	7.5[illegible]				

475 23
35 13 31.0 085 4 54.0 2
CHICKAMAUGA RESERVOIR
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 060201
TENNESSEE RIVER 484.5
131TVAC 850810 06020001022 0010.630 ON
0000 FEET DEPTH

/TYPA/AMNT/STREAM

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00630 NO2&NO3 N-TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	01022 BORON B,TOT UG/L	01027 CADMIUM CD,TOT UG/L
87/07/27	12[illegible]	WATER	1	.06	.03	.01K	3.6	4.30A	1.00K	1.55A	1.75A		
87/07/27	1205	WATER	3	.06	.04	.01	3.7	5.45A	1.35A	1.70A	1.75A		
87/07/27	12[illegible]	WATER	5									50K	.1
87/07/27	121[illegible]	WATER	10	.05	.04	.01K	3.4	11.75A	1.40A	2.30A	1.65A		
87/07/27	1215	WATER	16	.12	.03	.02	3.1	11.20A	1.35A	2.05A	1.35A		
87/08/31	120[illegible]	WATER	1	.13	.01K	.01K	1.5	4.90A	1.00K	1.00K	1.60A		
87/08/31	1201	WATER	1	.13	.01K		1.2						
87/08/31	1205	WATER	3	.13	.01	.01K	1.4	5.30A	1.05K	1.00K	1.70A		
87/08/31	12[illegible]	WATER	5									50K	.1K
87/08/31	121[illegible]	WATER	10	.13	.02	.01K	1.3	5.05A	1.00K	1.00K	1.65A		
87/08/31	121[illegible]	WATER	16	.13	.01K	.01K	1.3	5.20A	1.00K	1.00K	1.00K		

475 .35
35 15 32.0 085 14 54.0 2
CHICKAMAUGA RESERVOIR
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040931
TENNESSEE RIVER 449.5
/TYPA/AMBNT/STREAM
131TVAC 950810 06020001022 0010.630 ON
0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	01051 LEAD PB,TOT UG/L	01067 NICKEL NI,TOTAL UG/L	01105 ALUMINUM AL,TOT UG/L	00078 TRANSP SECCHI METERS	84002 CODE GENERAL REMARKS	00008 LAB IDENT. NUMBER
87/07/27	1200	WATER	1						9593
87/07/27	1205	WATER	3						9594
87/07/27	1205	WATER	5	1K	2	50K			9565
87/07/27	1210	WATER	10						9595
87/07/27	1215	WATER	15						9596
87/08/31	1200	WATER	1				1.50	01	11353
87/08/31	1201	WATER	1					02	11354
87/08/31	1205	WATER	3						11355
87/08/31	1205	WATER	5	2	2	50K			11350
87/08/31	1210	WATER	10						11356
87/08/31	1215	WATER	16						11357

475314 1835
35 22 45.0 085 05 29.0 2
CHICKAMAUGA RESERVOIR
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 060601
TENNESSEE RIVER 483.40
131TVAC 06020001022 0009.056 ON
0000 FEET DEPTH

/TYPA/AMBNT/STREAM

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00098 VSAMPLOC DEPTH METERS	00002 HSAMPLOC % FROM RT BANK	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	82079 TURBIDTY LAB NTU	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L
87/07/27	1200	WATER	1	.3	17	29.4	180	9.6	8.71	59	2.0	.23	.01
87/07/27	1201	WATER	1	.30	170						2.0	.19	.01
87/07/27	1205	WATER	3	1.0	17	29.4	180	9.6	8.70	59	2.0	.28	.01
87/07/27	1206	WATER	5	1.5	17	29.3	180	9.7	8.72				
87/07/27	1210	WATER	10	3.0	17	29.3	180	9.5	8.66	60	2.0	.22	.02
87/07/27	1212	WATER	13	4.0	17	29.0	181	9.6	8.48				
87/07/27	1215	WATER	16	5.0	17	28.9	181	7.9	8.24	62	2.0	.18	.02
87/07/27	1216	WATER	19	5.5	17	28.4	182	6.9	7.91				
87/07/27	1217	WATER	20	6.0	17	28.6	183	5.6	7.59				
87/07/27	1218	WATER	21	6.5	17	27.8	182	5.4	7.48				
87/07/27	1219	WATER	26	8.0	17	27.6	182	5.0	7.44				
87/07/27	1220	WATER	31	9.5	17	27.3	182	4.7	7.35				
87/07/27	1221	WATER	36	11.0	17	27.3	181	4.6	7.31				
87/07/27	1222	WATER	41	12.5	17	27.2	182	4.5	7.26				
87/07/27	1223	WATER	46	14.0	17	27.2	183	4.5	7.25				
87/07/27	1224	WATER	51	15.5	17	27.3	182	4.5	7.24				
87/07/27	1225	WATER	56	17.0	17	27.2	182	4.5	7.23				
87/07/27	1226	WATER	58	17.8	17	27.2	181	4.5	7.23				
87/08/31	1200	WATER	1	.3	17	26.6	196	5.7	7.10	74	1.6	.18	.02
87/08/31	1205	WATER	3	1.0	17	26.6	196	5.7	7.10	72	1.6	.16	.02
87/08/31	1207	WATER	5	1.5	17	26.6	196	5.6	7.20				
87/08/31	1210	WATER	10	3.0	17	26.6	196	5.6	7.30	67	1.6	.11	.02
87/08/31	1215	WATER	16	5.0	17	26.5	196	5.6	7.30	65	1.5	.16	.01
87/08/31	1216	WATER	26	8.0	17	26.5	196	5.6	7.30				
87/08/31	1217	WATER	33	11.0	17	26.6	196	5.6	7.30				
87/08/31	1218	WATER	46	14.0	17	26.6	194	5.6	7.30				
87/08/31	1219	WATER	56	17.0	17	26.6	195	5.4	7.30				
87/08/31	1220	WATER	59	18.0	17	26.6	195	5.3	7.30				

/TYPA/AMBNT/STREAM

475... 1735
35 12 45.0 085 15 25.0 2
CHICKAMAUGA RESERVOIR
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040801
TENNESSEE RIVER 483.40
131TVAC 06020001022 0009.050 ON
0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00630 NO2&NO3 N-TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	01022 BORON B,TOT UG/L	01027 CADMIUM CD,TOT UG/L
87/07/27	1200	WATER	1	.03	.04	.01K	4.4	12.30	1.20	2.10	1.00K		
87/07/27	1201	WATER	1	.03	.04	.01K	3.5	13.10	1.10	1.80	1.00K		
87/07/27	1205	WATER	3	.04	.04	.01K	3.6	13.65A	1.60A	2.45A	1.20A		
87/07/27	1208	WATER	5									50K	.1
87/07/27	1210	WATER	10	.04	.04	.01	3.3	11.75A	1.45A	2.20A	2.00A		
87/07/27	1215	WATER	15	.05	.03	.01K	2.9	12.55A	1.40A	2.35A	1.15A		
87/08/31	1200	WATER	1	.13	.01K	.01K	1.4	5.45A	1.00K	1.00K	1.45K		
87/08/31	1205	WATER	3	.13	.02	.01K	1.0	4.25A	1.00K	1.00K	2.25A		
87/08/31	1207	WATER	5									50K	.1K
87/08/31	1211	WATER	10	.13	.06	.01K	1.2	4.60A	1.10K	1.15K	1.35A		
87/08/31	1215	WATER	15	.13	.02	.01K	1.2	4.40A	1.00K	1.00K	1.65A		

/TYPA/AMBNT/STREAM

475314 1225
35 12 45.0 085 15 25.0 2
CHICKAMAUGA RESERVOIR
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040901
TENNESSEE RIVER 483.40
131TVAC 06020001022 0009.050 ON
0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	01051 LEAD PB,TOT UG/L	01067 NICKEL NI,TOTAL UG/L	01105 ALUMINUM AL,TOT UG/L	00078 TRANSP SECCHI METERS	84002 CODE GENERAL REMARKS	00008 LAB IDENT. NUMBER
67/07/27	12[illegible]	WATER	1					01	9588
67/07/27	1201	WATER	1					02	9589
67/07/27	1205	WATER	3						9590
67/07/27	1208	WATER	5	1	1	60			9586
67/07/27	1210	WATER	10						9591
67/07/27	1215	WATER	15						9592
67/08/31	1200	WATER	1				1.50		11356
67/08/31	1205	WATER	3						11359
67/08/31	1207	WATER	5	1K	2	50K			11351
67/08/31	1210	WATER	10						11360
67/08/31	1215	WATER	15						11361

/TYPA/AMBNT/STREAM

477152
35 13 26.0 085 05 17.0 2
SEQUOYAH NUCLEAR PLANT INTAKE POND
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 060602 .
ADJACENT TO TENNESSEE RIVER 484.5
131TVAC 871024 06020001
0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00098 VSAMPLOC DEPTH METERS	00002 HSAMPLOC % FROM RT BANK	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	82079 TURBIDTY LAB NTU	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L
87/07/27	1122	WATER	1	.3		27.4	183	4.4	7.14				
87/07/27	1123	WATER	3	1.0		27.4	183	4.4	7.14				
87/07/27	1124	WATER	7	2.0		27.2	183	4.3	7.13				
87/07/27	112[illegible]	WATER	13	4.0		27.2	183	4.3	7.12				
87/07/27	1125	WATER	16	5.0									
87/07/27	1126	WATER	20	6.0		27.2	182	4.3	7.13				
87/07/27	1127	WATER	26	8.0		27.2	182	4.2	7.13				
87/07/27	1128	WATER	33	10.0		27.2	182	4.2	7.15				
87/07/27	1129	WATER	36	10.9		27.2	182	4.2	7.15				
87/07/31	1038	WATER	1	.3		26.6	183		7.32				
87/07/31	1039	WATER	3	1.0		26.6	183		7.33				
87/07/31	1040	WATER	7	2.0		26.6	183		7.33				
87/07/31	1041	WATER	10	3.0		26.5	183		7.33				
87/07/31	1042	WATER	16	5.0		26.6	183		7.33				
87/07/31	1043	WATER	23	7.0		26.6	183		7.33				
87/07/31	1044	WATER	30	9.0		26.6	184		7.33				
87/07/31	1045	WATER	34	10.3		26.6	183		6.93				

477352
35 13 28.0 085 05 17.0 2
SEQUOYAH NUCLEAR PLANT INTAKE POND
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040602
ADJACENT TO TENNESSEE RIVER 484.5
131TVAC 871024 06020001
0000 FEET DEPTH

/TYPA/AMBNT/STREAM

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OP DEPTH (FT)	00630 NO2&NO3 N-TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	01022 BORON B,TOT UG/L	01027 CADMIUM CD,TOT UG/L
87/07/27	1125	WATER	15					2.83A	1.00K	1.00K	1.20A		
87/0-/31	1042	WATER	15					4.40A	1.00K	1.00K	1.20K		

[illegible] /71/12 [illegible]

477552
35 13 2?.? ??5 ?5 17.? 2
SEQUOYAH NUCLEAR PLANT INTAKE POND
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 060802
ADJACENT TO TENNESSEE RIVER 484.5
131TVAC 571024 06020001
0000 FEET DEPTH

/TYPA/AMBNT/STREAM

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	01051 LEAD PB,TOT UG/L	01067 NICKEL NI,TOTAL UG/L	01105 ALUMINUM AL,TOT UG/L	00078 TRANSP SECCHI METERS	84002 CODE GENERAL REMARKS	00008 LAB IDENT. NUMBER
87/07/27	1125	WATER	16						9609
87/05/31	1042	WATER	16						11371

[illegible] /.1/.1 PGMRET

477.51
35 13 34.0 085 15 29.0 2
SEQUOYAH NUCLEAR PLANT DIFFUSER POND
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040802
ADJACENT TO TENNESSEE RIVER 483.4
131TVAC 871024 06020001
0000 FEET DEPTH

/TYPA/IND/TREATD/CCTFL/NONAMB/PIPE/IMPORT

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00058 VSAMPLOC DEPTH METERS	00002 HSAMPLOC % FROM RT BANK	00010 WATER TEMP CENT	00094 CNDUCTVY FIELD MICROMHO	00300 DO MG/L	00400 PH SU	00431 T ALK FIELD MG/L	82079 TURBIDTY LAB NTU	00605 ORG N N MG/L	00610 NH3+NH4- N TOTAL MG/L
87/07/27	1405	WATER	1	.3		28.2	183	5.4	7.20				
87/07/27	1406	WATER	3	1.0		28.1	183	5.2	7.20				
87/07/27	1407	WATER	10	3.0		28.2	184	5.1	7.10				
87/07/27	1407	WATER	11	3.5									
87/07/27	1408	WATER	16	5.0		27.9	183	4.9	7.10				
87/07/27	1409	WATER	20	6.0		27.8	184	4.8	7.10				
87/08/31	1219	WATER	1	.3		26.7	182		7.04				
87/08/31	1220	WATER	3	1.0		26.7	183		7.07				
87/08/31	1221	WATER	7	2.0		26.7	183		7.08				
87/08/31	1222	WATER	10	3.0		26.7	184		7.09				
87/08/31	1222	WATER	11	3.5									
87/08/31	1223	WATER	12	3.8		26.7	183		7.08				

PGM=?ET

477151
35 13 34.0 085 05 26.0 2
SEQUOYAH NUCLEAR PLANT DIFFUSER POND
47065 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040802
ADJACENT TO TENNESSEE RIVER 483.4
/TYPA/INC/TREATD/CUTFL/NONAMB/PIPE/IMPCNT
131TVAC 871024 06020001
0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	00630 NO2&NO3 N-TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P	00680 T ORG C C MG/L	32211 CHLRPHYL A UG/L CORRECTD	32212 CHLRPHYL B UG/L	32214 CHLRPHYL C UG/L	32218 PHEOPHTN A UG/L	01022 BORON B,TOT UG/L	01027 CADMIUM CD,TOT UG/L
87/07/27	1435	WATER	1									50K	.3
87/07/27	1437	WATER	11					2.70A	1.00K	1.10K	1.65A		
87/08/31	1219	WATER	1									50K	.1n
87/08/31	1222	WATER	11					4.50A	1.00K	1.00K	1.20A		

[illegible] DATE [illegible] 1/12 [illegible]

477[illegible]
35 13 [illegible] 2
SEQUOYAH NUCLEAR PLANT DIFFUSER POND
47365 TENNESSEE HAMILTON
TENNESSEE RIVER BASIN 040802
ADJACENT TO TENNESSEE RIVER 483.4
131TVAC 971024 06020001
[illegible] FEET DEPTH

/TYPA/IND/TREATD/OUTFL/[illegible]/PIPE/IMPDNT

DATE FROM TO	TIME OF DAY	MEDIUM	SMK OR DEPTH (FT)	01051 LEAD PB,TOT UG/L	01067 NICKEL NI,TOTAL UG/L	01105 ALUMINUM AL,TOT UG/L	00078 TRANSP SECCHI METERS	[illegible] CODE GENERAL REMARKS	00008 LAB IDENT. NUMBER
87/07/27	1435	WATER	1	4	4	110			9587
87/07/27	1437	WATER	11						9608
87/[illegible]/31	121[illegible]	WATER	1	1	2	50K			11352
87/[illegible]/31	1222	WATER	11						11369

APPENDIX E

PHYTOPLANKTON DATA AND RESULTS OF STATISTICAL TESTS, JULY 27 AND AUGUST 31, 1987

Table E-1. Percentage Composition of Phytoplankton Groups During Operational Monitoring Periods (1987), Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Phytoplankton Group	Tennessee River Mile 483.4	Tennessee River Mile 484.5	Inplant Station Cooling Return	Inplant Station Diffuser Pond	Inplant Station Intake
July 1987	Chlorophyta	30	33	50	39	28
	Chrysophyta	13	15	28	23	23
	Cyanophyta	0	0	0	0	0
	Cyanophyta	56	50	22	37	49
	Euglenophyta	0	0	0	0	0
	Pyrrophyta	0	0	0	0	0
August 1987	Chlorophyta	32	36	42	37	46
	Chrysophyta	27	25	20	34	26
	Cyanophyta	1	1	1	1	1
	Cyanophyta	39	37	36	27	26
	Euglenophyta	0	1	1	0	0
	Pyrrophyta	0	0	1	0	1

Table E-2. Individual Sample Totals, Means, Standard Deviations, and Coefficients of Variation for Total Phytoplankton and Group Cell Densities (No./L) During Operational Monitoring (1987), Sequoyah Nuclear Plant, Chickamauga Reservoir

	July 87									
	TRM 483.4					TRM 484.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
				Chlorophyta						
0.3	2141056	2057032	2099044	59414	3	2408688	2218856	2313772	134231	6
1.0	2063256	1795624	1929440	189244	10	1680480	1727160	1703820	33008	2
3.0	1484424	1297704	1391064	132031	9	1649360	1543552	1596456	74818	5
5.0	1518656	1244800	1381728	193645	14	1627576	1384840	1506208	171640	11
				Chrysophyta						
0.3	921152	778000	849576	101224	12	1269696	697088	983392	404895	41
1.0	899368	827792	863580	50612	6	824680	762440	793560	44010	6
3.0	591280	613064	602172	15404	3	843352	715760	779556	90221	12
5.0	790448	697088	743768	66015	9	665968	619288	642628	33008	5
				Cryptophyta						
0.3	34232	28008	31120	4401	14	12448	24896	18672	8802	47
1.0	34232	21784	28008	8802	31	21784	9336	15560	8802	57
3.0	18672	28008	23340	6602	28	21784	31120	26452	6602	25
5.0	15560	28008	21784	8802	40	21784	18672	20228	2201	11
				Cyanophyta						
0.3	3815312	4235432	4025372	297070	7	3535232	3071544	3303388	327877	10
1.0	3616144	3469880	3543012	103424	3	2757232	2713664	2735448	30807	1
3.0	2962624	2894160	2928392	48411	2	2586072	2502048	2544060	59414	2
5.0	2638976	2172176	2405576	330077	14	2150392	2178400	2164396	19805	1

Table E-2. (Continued)

	July 87									
	TRM 483.4					TRM 484.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
				Euglenophyta						
0.3	31120	28008	29564	2201	7	40456	46680	43568	4401	10
1.0	24896	21784	23340	2201	9	31120	6224	18672	17604	94
3.0	6224	6224	6224	0	0	34232	18672	26452	11003	42
5.0	9336	6224	7780	2201	28	12448	9336	10892	2201	20
				Pyrrophyta						
0.3	24896	21784	23340	2201	9	9336	15560	12448	4401	35
1.0	9336	12448	10892	2201	20	18672	21784	20228	2201	11
3.0	18672	9336	14004	6602	47	15560	15560	15560	0	0
5.0	15560	6224	10892	6602	61	12448	6224	9336	4401	47
				Total						
0.3	6967768	7148264	7058016	127630	2	7275856	6074624	6675240	849399	13
1.0	6647232	6149312	6398272	352083	6	5333968	5240608	5287288	66015	1
3.0	5081896	4848496	4965196	165039	3	5150360	4826712	4988536	228854	5
5.0	4988536	4154520	4571528	589738	13	4490616	4216760	4353688	193645	4

Table E-2. (Continued)

	July 87														
	Intake pond					Diffuser pond					Cooling channel return				
	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
Chlorophyta	348544	357880	353212	6602	2	360992	469912	415452	77018	19	273856	329872	301864	39609	13
Chrysophyta	280080	298752	289416	13203	5	149376	336096	242736	132031	54	143152	189832	166492	33008	20
Cryptophyta	0	0	0	0	.	0	0	0	0	.	0	0	0	0	.
Cyanophyta	628624	628624	628624	0	0	233400	557048	395224	228854	58	133816	136928	135372	2201	2
Euglenophyta	3112	3112	3112	0	0	3112	0	1556	2201	141	0	0	0	0	.
Pyrrophyta	0	0	0	0	.	9336	0	4668	6602	141	0	0	0	0	.
Total	1260360	1288368	1274364	19805	2	756216	1363056	1059636	429101	40	550824	656632	603728	74818	12

Table E-2. (Continued)

	Aug. 87									
	TRM 483.4					TRM 484.5				
Depth (M)	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
				Chlorophyta						
0.3	628624	659744	644184	22005	3	771776	628624	700200	101224	14
1.0	631736	637960	634848	4401	1	634848	525928	580388	77018	13
3.0	566384	665968	616176	70417	11	473024	417008	445016	39609	9
5.0	441904	332984	387444	77018	20	532152	379664	455908	107825	24
8.0	314312	289416	301864	17604	6	348544	376552	362548	19805	5
11.0	336096	357880	346988	15404	4	497920	463688	480804	24206	5
14.0	248960	242736	245848	4401	2	270744	270744	270744	0	0
17.0	367216	252072	309644	81419	26					
				Chrysophyta						
0.3	606840	746880	676860	99023	15	575720	622400	599060	33008	6
1.0	572608	395224	483916	125429	26	373440	336096	354768	26406	7
3.0	491696	482360	487028	6602	1	329872	286304	308088	30807	10
5.0	429456	426344	427900	2201	1	230288	264520	247404	24206	10
8.0	295640	336096	315868	28607	9	283192	245848	264520	26406	10
11.0	292528	261408	276968	22005	8	292528	255184	273856	26406	10
14.0	186720	171160	178940	11003	6	270744	273856	272300	2201	1
17.0	205392	174272	189832	22005	12					
				Cryptophyta						
0.3	12448	12448	12448	0	0	31120	18672	24896	8802	35
1.0	6224	9336	7780	2201	28	18672	12448	15560	4401	28
3.0	6224	12448	9336	4401	47	18672	12448	15560	4401	28
5.0	12448	18672	15560	4401	28	12448	18672	15560	4401	28
8.0	9336	9336	9336	0	0	12448	18672	15560	4401	28
11.0	6224	9336	7780	2201	28	15560	9336	12448	4401	35
14.0	6224	3112	4668	2201	47	12448	9336	10892	2201	20
17.0	6224	15560	10892	6602	61					

Table E-2. (Continued)

Depth (M)	TRM 483.4 Sample 1	Sample 2	Mean	STD	CV	TRM 484.5 Sample 1	Sample 2	Mean	STD	CV
	Aug. 87									
				Cyanophyta						
0.3	905592	725096	815344	127630	16	911816	837128	874472	52812	6
1.0	709536	824680	767108	81419	11	665968	516592	591280	105625	18
3.0	715760	846464	781112	92422	12	759328	519704	639516	169440	26
5.0	345432	379664	362548	24206	7	609952	420120	515036	134231	26
8.0	756216	650408	703312	74818	11	208504	304976	256740	68216	27
11.0	360992	398336	379664	26406	7	264520	280080	272300	11003	4
14.0	174272	177384	175828	2201	1	320536	239624	280080	57213	20
17.0	438792	311200	374996	90221	24					
				Euglenophyta						
0.3	12448	6224	9336	4401	47	12448	9336	10892	2201	20
1.0	6224	3112	4668	2201	47	3112	9336	6224	4401	71
3.0	3112	18672	10892	11003	101	6224	3112	4668	2201	47
5.0	3112	3112	3112	0	0	9336	6224	7780	2201	28
8.0	9336	6224	7780	2201	28	6224	6224	6224	0	0
11.0	3112	9336	6224	4401	71	3112	3112	3112	0	0
14.0	3112	6224	4668	2201	47	9336	6224	7780	2201	28
17.0	3112	3112	3112	0	0					
				Pyrrophyta						
0.3	9336	6224	7780	2201	28	3112	9336	6224	4401	71
1.0	3112	6224	4668	2201	47	9336	6224	7780	2201	28
3.0	12448	0	6224	8802	141	3112	3112	3112	0	0
5.0	3112	3112	3112	0	0	3112	6224	4668	2201	47
8.0	3112	6224	4668	2201	47	9336	9336	9336	0	0
11.0	3112	12448	7780	6602	85	6224	6224	6224	0	0
14.0	3112	3112	3112	0	0	3112	6224	4668	2201	47
17.0	6224	6224	6224	0	0					

Table E-2. (Continued)

Depth (M)	Aug. 87									
	TRM 483.4					TRM 484.5				
	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
				Total						
0.3	2175288	2156616	2165952	13203	1	2305992	2125496	2215744	127630	6
1.0	1929440	1876536	1902988	37409	2	1705376	1406624	1556000	211250	14
3.0	1795624	2025912	1910768	162838	9	1590232	1241688	1415960	246458	17
5.0	1235464	1163888	1199676	50612	4	1397288	1095424	1246356	213450	17
8.0	1387952	1297704	1342828	63815	5	868248	961608	914928	66015	7
11.0	1002064	1048744	1025404	33008	3	1079864	1017624	1048744	44010	4
14.0	622400	603728	613064	13203	2	886920	806008	846464	57213	7
17.0	1026960	762440	894700	187044	21					

Table E-2. (Continued)

	Aug. 87														
	Intake pond					Diffuser pond					Cooling channel return				
	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV	Sample 1	Sample 2	Mean	STD	CV
Chlorophyta	379664	264520	322092	81419	25	242736	494808	368772	178242	48	255184	463688	359436	147435	41
Chrysophyta	183608	177384	180496	4401	2	314312	373440	343876	41810	12	183608	149376	166492	24206	15
Cryptophyta	6224	9336	7780	2201	28	6224	21784	14004	11003	79	6224	12448	9336	4401	47
Cyanophyta	171160	196056	183608	17604	10	264520	280080	272300	11003	4	426344	183608	304976	171640	56
Euglenophyta	3112	3112	3112	0	0	3112	3112	3112	0	0	9336	3112	6224	4401	71
Pyrrophyta	9336	3112	6224	4401	71	6224	3112	4668	2201	47	3112	6224	4668	2201	47
Total	753104	653520	703312	70417	10	837128	1176336	1006732	239856	24	883808	818456	851132	46211	5

Table E-3. Results of Two-Way-Analysis of Variance on Phytoplankton Cell Densities from Reservoir Sites on Chickamauga Reservoir, July and August 1987

	P > F			
Test Data	Total Phytoplankton	Chlorophyta	Chrysophyta	Cyanophyta
July 1987				
Station	0.0792	0.2703	0.7060	0.0008*
Depth	0.0002*	0.0004*	0.1333	0.0001*
Interaction	0.3340	0.2102	0.3753	0.4233
August 1987				
Station	0.0801	0.2240	0.0007*	0.0436*
Depth	0.0001*	0.0001*	0.0001*	0.0001*
Interaction	0.0026*	0.0496*	0.0003*	0.0004*

*Significant at $\alpha = 0.05$

Table E-4. Disposition of Phytoplankton Density (Cell/L) Date Sets with Significant Station Differences Identified in Table E-3

Date	Test Group	Sample Depth (m)	P>F Two-Way	P>F One-Way	Location Rank Low → High Mean	
July	Cyanophyta*	-	0.0008	-	TRM 484.5	TRM 483.4
August	Chrysophyta†	0.3	-	0.4005		
		1.0	-	0.2658		
		3.0	-	0.0232	TRM 484.5	TRM 483.4
		5.0	-	0.0155	TRM 484.5	TRM 483.4
		8.0	-	0.2035		
		11.0	-	0.9041		
		14.0	-	0.0107	TRM 483.4	TRM 484.5
	Cyanophyta†	0.3	-	0.5920		
		1.0	-	0.2138		
		3.0	-	0.4092		
		5.0	-	0.2237		
		8.0	-	0.0377	TRM 484.5	TRM 483.4
		11.0	-	0.0282	TRM 484.5	TRM 483.4
		14.0	-	0.0891		

*Depths not tested separately.
†Depths tested separately with one-way ANOVA because interaction was significant in two-way ANOVA.

Table E-5. Results of One-Way-Analysis of Variance on Phytoplankton In-Plant Data July and August 1987

Test Data	Date	P > F	Location Rank Low → High Mean	
Total Phytoplankton	July	0.5214		
	August	0.2006		
Chlorophyta	July	0.3658		
	August	0.8435		
Chrysophyta	July	0.5942		
	August	0.0183*	Intake	Diffuser Pond
Cyanophyta	July	0.3295		
	August	0.0329*	Intake	Diffuser Pond

*Significant at $\alpha = 0.05$.

Table E-6. Mean Phytoplankton Densities (No. X 100/L) at Each Sample Station (Depths Combined) During Operational Monitoring (1987), Sequoyah Nuclear Plant, Chickamauga Reservoir

	Collection Sites*							
	July 1987				August 1987			
	483.4	484.5	P1	P2	483.4	484.5	P1	P2
Chlorophyta								
Acanthosphaera	109	128	0	0	8	37	0	0
Actinastrum	914	996	498	171	198	117	0	296
Ankistrodesmus	195	159	0	265	241	156	124	109
Characium	43	0	0	0	0	0	0	0
Chlamydomonas	350	443	16	0	198	235	109	109
Chlorella	241	412	31	0	76	70	16	0
Chlorococcum	0	4	0	0	0	0	0	0
Chodatella	70	58	0	0	2	18	0	0
Closteridium	0	4	0	0	0	0	0	0
Coelastrum	751	778	0	0	99	179	0	0
Cosmarium	0	0	0	0	0	4	0	0
Crucigenia	751	813	62	576	265	191	0	918
Dictyosphaerium	619	657	62	0	208	210	249	249
Elakatothrix	132	62	0	93	8	8	0	0
Euastrum	0	23	16	0	0	0	0	0
Eudorina	654	124	0	0	187	249	498	0
Gloeoactinium	552	459	0	0	82	54	0	0
Gloeocystis	0	0	0	0	0	19	0	0
Golenkinia	191	198	31	0	23	31	0	0
Gonium	1074	1241	156	202	358	323	249	249
Kirchneriella	1046	1416	171	124	105	130	78	93
Micractinium	311	163	0	0	21	8	0	93
Mougeotia	31	0	0	0	0	0	0	0
Oocystis	303	319	0	0	39	16	0	0
Pandorina	871	626	498	498	405	218	249	249
Pediastrum	848	825	249	249	329	346	373	0
Planktosphaeria	0	0	0	0	0	31	0	0

Table E-6. (Continued)

	Collection Sites*							
	July 1987				August 1987			
	483.4	484.5	P1	P2	483.4	484.5	P1	P2
Platydorina	451	171	0	249	249	156	0	0
Polyedriopsis	0	19	0	0	0	0	0	0
Pteromonas	66	51	0	0	18	21	0	0
Pyramimonas	16	0	0	0	0	0	0	0
Scenedesmus	5967	7204	1525	1649	1155	1188	1043	1260
Schroederia	249	249	109	78	47	51	109	47
Staurastrum	105	58	31	0	21	33	31	16
Tetrastrum	31	16	62	0	0	16	62	0
Treubaria	62	121	16	0	18	6	31	0
Chrysophyta								
Achnanthes	315	584	16	140	89	119	93	31
Asterionella	0	0	0	0	0	16	0	124
Attheya	113	70	0	0	41	41	16	0
Chaetoceros	673	486	93	187	282	263	311	358
Cymbella	35	51	0	47	0	0	0	93
Dinobryon	8	66	0	0	29	86	0	0
Fragilaria	1354	1774	654	0	14	0	0	0
Gomphonema	0	0	16	0	0	0	0	0
Gyrosigma	0	4	0	0	0	0	0	0
Melosira	4322	3894	2054	1525	2838	1964	1229	2318
Navicula	70	187	16	62	49	35	16	109
Nitzschia	4	47	0	31	0	10	0	16
Rhizosolenia	206	202	0	31	31	25	0	16
Rhoicosphenia	0	8	0	0	0	0	0	0
Stephanodiscus	307	319	16	47	68	91	47	124

Table E-6. (Continued)

	Colleciton Sites*							
	July 1987				August			
	483.4	484.5	P1	P2	483.4	484.5	P1	P2
Surirella	0	0	0	0	8	0	0	0
Synedra	241	307	31	296	348	251	93	249
Tabellaria	0	0	0	62	0	0	0	0
Cryptophyta								
Cryptomonas	261	202	0	0	97	138	78	140
Cyanophyta								
Anacystis	9068	7204	498	0	1694	1891	871	1105
Merismopedia	10900	8278	3050	2194	2077	1879	778	1416
Oscillatoria	8931	8177	2116	1494	1323	249	0	0
Oscillatoria (spiral)	0	0	0	0	109	0	0	0
Raphidiopsis	3357	3209	622	265	247	268	187	202
Euglenophyta								
Euglena	105	78	16	16	45	47	0	31
Phacus	4	0	0	0	2	0	0	0
Trachelomonas	58	171	16	0	16	12	31	0
Pyrrophyta								
Ceratium	31	16	0	0	0	0	0	0
Glenodinium	0	0	0	0	0	6	0	0
Gymnodinium	66	93	0	47	35	21	0	16
Peridinium	51	35	0	0	19	25	62	31

*Collection Sites: Tennessee River Miles 483.4 and 484.5, P1 = Intake, P2 = Diffuser Pond

Table E-7. Chlorophyll a Concentrations, Phaeophytin a Concentrations, and Phaeophytin Index Values at Each Sample Location During Operational Monitoring (1987), Sequoyah Nuclear Plant, Chickamauga Reservoir

	Depth	Sample	TRM 483.4 Chl a mg/m^3	TRM 483.4 Pheo a mg/m^3	TRM 483.4 Pheo Index	TRM 484.5 Chl a mg/m^3	TRM 484.5 Pheo a mg/m^3	TRM 484.5 Pheo Index
July 87	0.3	1	11.90	1.00	1.78	8.80	1.90	1.56
		2	13.70	1.00	1.68	10.30	1.60	1.60
		x	12.80	1.00	1.73	9.55	1.75	1.58
		s	1.27	0.00	0.07	1.06	0.21	0.03
		CV	9.94	0.00	4.09	11.11	12.12	1.79
	1.0	1	13.50	1.50	1.62	10.50	1.50	1.60
		2	16.10	1.10	1.65	11.10	2.00	1.58
		x	14.80	1.30	1.64	10.80	1.75	1.59
		s	1.84	0.28	0.02	0.42	0.35	0.01
		CV	12.42	21.76	1.30	3.93	20.20	0.89
	3.0	1	12.60	1.90	1.60	11.50	2.30	1.57
		2	13.90	2.10	1.60	14.40	1.00	1.67
		x	13.25	2.00	1.60	12.95	1.65	1.62
		s	0.92	0.14	0.00	2.05	0.92	0.07
		CV	6.94	7.07	0.00	15.83	55.71	4.36
	5.0	1	13.70	1.30	1.64	10.60	1.70	1.59
		2	13.90	1.00	1.68	13.90	1.00	1.66
		x	13.80	1.15	1.66	12.25	1.35	1.63
		s	0.14	0.21	0.03	2.33	0.49	0.05
		CV	1.02	18.45	1.70	19.05	36.66	3.05
Aug. 87	0.3	1	6.10	1.90	1.50	6.30	1.40	1.56
		2	6.90	1.00	1.61	5.80	1.80	1.50
		x	6.50	1.45	1.56	6.05	1.60	1.53
		s	0.57	0.64	0.08	0.35	0.28	0.04
		CV	8.70	43.89	5.00	5.84	17.68	2.77
	1.0	1	6.10	1.90	1.50	6.50	1.80	1.53
		2	5.40	2.60	1.41	6.50	1.60	1.54
		x	5.75	2.25	1.46	6.50	1.70	1.54
		s	0.49	0.49	0.06	0.00	0.14	0.01
		CV	8.61	22.00	4.37	0.00	8.32	0.46

Table E-7. (Continued)

Depth	Sample	TRM 483.4 Chl a mg/m^3	TRM 483.4 Pheo a mg/m^3	TRM 483.4 Pheo Index	TRM 484.5 Chl a mg/m^3	TRM 484.5 Pheo a mg/m^3	TRM 484.5 Pheo Index
3.0	1	6.30	1.40	1.56	6.00	2.20	1.47
	2	5.20	1.30	1.53	6.40	1.10	1.58
	x	5.75	1.35	1.55	6.20	1.65	1.53
	s	0.78	0.07	0.02	0.28	0.78	0.08
	CV	13.53	5.24	1.37	4.56	47.14	5.10
5.0	1	5.90	2.00	1.49	5.70	1.00	1.59
	2	5.40	1.70	1.50	5.60	1.00	1.69
	x	5.65	1.85	1.50	5.65	1.00	1.64
	s	0.35	0.21	0.01	0.07	0.00	0.07
	CV	6.26	11.47	0.47	1.25	0.00	4.31

Depth	Sample	TRM 483.4 Chl a mg/m^3	TRM 483.4 Pheo a mg/m^3	TRM 483.4 Pheo Index	TRM 484.5 Chl a mg/m^3	TRM 484.5 Pheo a mg/m^3	TRM 484.5 Pheo Index
July 87	1	3.20	1.10	1.47	3.50	1.30	1.48
	2	4.00	1.30	1.50	3.90	2.00	1.40
	x	3.60	1.20	1.49	3.70	1.65	1.44
	s	0.57	0.14	0.02	0.28	0.49	0.06
	CV	15.71	11.79	1.43	7.64	30.00	3.93
Aug. 87	1	5.80	1.40	1.55	5.70	1.60	1.52
	2	4.50	1.00	1.60	5.90	2.00	1.49
	x	5.15	1.20	1.58	5.80	1.80	1.51
	s	0.92	0.28	0.04	0.14	0.28	0.02
	CV	17.85	23.57	2.24	2.44	15.71	1.41

Table E-8. Results of Two-Way Analysis of Variance (River Stations) and One-Way Analysis of Variance (Inplant Stations) on Chlorophyll a Concentrations, and Carbon Assimilation Rates, Sequoyah Nuclear Plant, Chickamauga Reservoir July and August 1987

Test Data	P>F	
	River Stations*	Inplant Stations†
	Chlorophyll a Concentration	
July 1987		
Station	0.0100‡	0.8249
Depth	0.2187	
Interaction	0.3154	
August 1987		
Station	0.3905	0.4267
Depth	0.2956	
Interaction	0.3133	
	Carbon Assimilation Rates	
July 1987		
Station	0.0036‡	§
Depth	0.0004‡	
Interaction	0.3054	
August 1987		
Station	0.0810	§
Depth	0.0001‡	
Interaction	0.7026	

*Tennessee River Miles 483.4 and 484.5.

†Intake and Diffuser Pond; One-Way ANOVA used because samples collected at only one depth.

‡Significant at $\alpha = 0.05$; Both chlorophyll a concentrations and carbon assimilation rates were significantly higher at TRM 483.4 than at TRM 484.5.

§Samples for estimation of carbon assimilation rates not collected at inplant stations.

Table E-9. Results of Fluorometric Analyses at Each Collection Site, Aquatic Monitoring for Sequoyah Nuclear Plant, Chickamauga Reservoir, July and August 1987

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:08 AM

Location (TRM): 483.4 Survey Date: 07/27/87
Lake Elevation: 682.0 Time Collected: 1350
Collector: RNB/NMW Start Analyses (Time): 1455
Analyst: JDR End Analyses (Time): 1508

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
0.3	4.0	3.16	7.7	3.16	40.00	77.00	0.481	-Corrected Chloro a (mg/m^3) = 12.7
1.0	4.4	3.16	8.0	3.16	44.00	80.00	0.450	-Corrected Chloro a (mg/m^3) = 13.7
3.0	4.9	3.16	2.8	MS	49.00	88.48	0.446	-Corrected Chloro a (mg/m^3) = 11.0
5.0	4.8	3.16	2.8	MS	48.00	88.48	0.458	-Corrected Chloro a (mg/m^3) = 13.0
8.0	3.2	3.16	6.6	3.16	32.00	66.00	0.515	
11.0	3.4	3.16	6.8	3.16	34.00	68.00	0.500	
14.0	3.7	10.00	8.3	10.00	11.69	26.23	0.554	
17.0	3.3	10.00	7.2	10.00	10.43	22.75	0.542	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:08 AM

Location (TRM): 484.5 Survey Date: 07/27/87
Lake Elevation: 682.0 Time Collected: 1240
Collector: RNB/NMW Start Analyses (Time): 1333
Analyst: JDR End Analyses (Time): 1405

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
0.3	4.0	3.16	8.2	3.16	40.00	82.00	0.512	-Corrected Chloro a (mg/m^3) = 8.3
1.0	4.1	3.16	8.5	3.16	41.00	85.00	0.518	-Corrected Chloro a (mg/m^3) = 9.5
3.0	4.3	3.16	8.9	3.16	43.00	89.00	0.517	-Corrected Chloro a (mg/m^3) = 11.7
5.0	3.0	3.16	6.4	3.16	30.00	64.00	0.531	-Corrected Chloro a (mg/m^3) = 11.2
8.0	4.8	10.00	3.3	3.16	15.17	33.00	0.540	
11.0	3.2	3.16	6.8	3.16	32.00	68.00	0.529	
14.0	2.0	3.16	4.1	3.16	20.00	41.00	0.512	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

Table E-9. (Continued)

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:08 AM

Location (TRM): INTAKE — Survey Date: 07/27/87
Lake Elevation: 682.0 — Time Collected: 1215
Collector: RNB/NMW — Start Analyses (Time): 1320
Analyst: JDR — End Analyses (Time): 1330

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
5.0	2.4	10.00	5.5	10.00	7.58	17.38	0.564	-Corrected Chloro $\underline{a}$ (mg/m^3) = 2.4
5.0	2.4	10.00	5.5	10.00	7.58	17.38	0.564	-Corrected Chloro $\underline{a}$ (mg/m^3) = 3.2
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:08 AM

Location (TRM): DIFFUSER — Survey Date: 07/27/87
Lake Elevation: 682.0 — Time Collected: 1300
Collector: RNB/NMW — Start Analyses (Time): 1435
Analyst: JDR — End Analyses (Time): 1450

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
3.5	2.8	10.00	5.5	10.00	8.85	17.38	0.491	2.7
3.5	2.8	10.00	5.5	10.00	8.85	17.38	0.491	2.7
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

Table E-9. (Continued)

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:03 AM

Location (TRM): 483.4
Lake Elevation: ----
Collector: RNB/NWM
Analyst: JDR

Survey Date: 08/31/87
Time Collected: 0950
Start Analyses (Time): 1315
End Analyses (Time): 1410

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
0.3	3.1	10.00	7.6	10.00	9.80	24.02	0.592	-Corrected Chloro $\underline{a}$ (mg/m^3) = 5.5
1.0	3.2	10.00	7.4	10.00	10.11	23.38	0.568	-Corrected Chloro $\underline{a}$ (mg/m^3) = 4.3
3.0	2.8	10.00	7.2	10.00	8.85	22.75	0.611	-Corrected Chloro $\underline{a}$ (mg/m^3) = 4.8
5.0	3.0	10.00	7.4	10.00	9.48	23.38	0.595	-Corrected Chloro $\underline{a}$ (mg/m^3) = 4.4
8.0	3.1	10.00	7.8	10.00	9.80	24.65	0.603	
11.0	2.8	10.00	7.9	10.00	8.85	24.96	0.646	
14.0	2.7	10.00	7.2	10.00	8.53	22.75	0.625	
17.0	2.7	10.00	6.8	10.00	8.53	21.49	0.603	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:03 AM

Location (TRM): 484.5
Lake Elevation: -----
Collector: RNB/NWM
Analyst: JDR

Survey Date: 08/31/87
Time Collected: 1100
Start Analyses (Time): 1520
End Analyses (Time): 1620

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
0.3	3.8	10.00	8.7	10.00	12.01	27.49	0.563	-Corrected Chloro $\underline{a}$ (mg/m^3) = 4.9
1.0	3.8	10.00	3.0	3.16	12.01	30.00	0.600	-Corrected Chloro $\underline{a}$ (mg/m^3) = 5.3
3.0	3.3	10.00	7.8	10.00	10.43	24.65	0.577	-Corrected Chloro $\underline{a}$ (mg/m^3) = 5.1
5.0	3.1	10.00	7.9	10.00	9.80	24.96	0.608	-Corrected Chloro $\underline{a}$ (mg/m^3) = 5.2
8.0	2.5	10.00	6.1	10.00	7.90	19.28	0.590	
11.0	NA	NA	NA	NA	NA	NA	NA	
14.0	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

Table E-9. (Continued)

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:03 AM

Location (TRM): INTAKE — Survey Date: 08/31/87
Lake Elevation: ----- — Time Collected: 1030
Collector: RNB/NWM — Start Analyses (Time): 1400
Analyst: JDR — End Analyses (Time): 1410

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
5.0	2.5	10.00	6.1	10.00	7.90	19.28	0.590	-Corrected Chloro a (mg/m³) = 4.8
5.0	2.6	10.00	6.4	10.00	8.22	20.22	0.594	-Corrected Chloro a (mg/m³) = 4.0
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

SEQUOYAH OPERATIONAL SPECIAL STUDY - FLUOROMETRY SURVEY

|| Date Issued: 04-Dec-87
|| Time Issued: 08:03 AM

Location (TRM): DIFFUSER — Survey Date: 08/31/87
Lake Elevation: ----- — Time Collected: 1210
Collector: RNB/NWM — Start Analyses (Time): 1400
Analyst: JDR — End Analyses (Time): 1410

Depth (m)	F (Meter)	F (Scale)	F-dcmu (Meter)	F-dcmu (Scale)	F (Actual)	F-dcmu (Actual)	FRI	Comments
3.5	2.4	10.00	6.4	10.00	7.58	20.22	0.625	-Correcte-Corrected Chloro a (mg/m³) = 4.5
3.5	2.8	10.00	6.2	10.00	8.85	19.59	0.548	-Correcte-Corrected Chloro a (mg/m³) = 4.5
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	
NA	NA	NA	NA	NA	NA	NA	NA	

Table E-10. Carbon Assimilation Rates at Each Sample Location During Operational Monitoring (1986), Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Depth m	Sample	mg C/m^3/hour TRM 483.4	TRM 484.5
July 1987	0.0	1	8.40	6.59
		2	21.38	9.14
		x	14.89	7.86
		s	9.18	1.81
		cv	61.62	22.99
	1.0	1	11.36	9.55
		2	11.64	8.15
		x	11.50	8.85
		s	0.20	0.99
		cv	1.74	11.22
	3.0	1	8.65	1.62
		2	5.59	1.62
		x	7.12	1.62
		s	2.16	0.00
		cv	30.38	0.12
	5.0	1	4.70	0.46
		2	1.18	0.00
		x	2.94	0.23
		s	2.49	0.33
		cv	84.60	141.42
Aug. 1987	0.0	1	25.72	14.26
		2	21.60	14.14
		x	23.66	14.20
		s	2.92	0.08
		cv	12.33	0.57
	1.0	1	8.22	11.46
		2	20.19	11.27
		x	14.20	11.36
		s	8.47	0.13
		cv	59.61	1.18
	3.0	1	4.30	2.49
		2	4.94	2.53
		x	4.62	2.51
		s	0.45	0.03
		cv	9.81	1.18

Table E-10. (Continued)

Date	Depth m	Sample	mg C/m^3/hour TRM 483.4	TRM 484.5
	5.0	1	2.76	0.90
		2	0.89	1.98
		x	1.82	1.44
		s	1.32	0.76
		cv	72.44	52.74

APPENDIX F

ZOOPLANKTON DATA AND RESULTS OF STATISTICAL TEST, JULY 27 AND AUGUST 31, 1987

Table F-1. Percentage Composition of Zooplankton Groups During Operational Monitoring Periods (1987), Sequoyah Nuclear Plant, Chickamauga Reservoir

Date	Zooplankton Group	Tennessee River Mile 483.4	Tennessee River Mile 484.5	Inplant Stations: Cooling Channel Return	Inplant Stations: Diffuser Pond	Inplant Stations: Intake
July 1987	Cladocera	9	14	19	16	19
	Copepoda	11	19	32	37	33
	Rotifera	80	67	49	47	48
Aug. 1987	Cladocera	8	12	9	10	5
	Copepoda	6	10	23	10	8
	Rotifera	86	78	68	80	88

Table F-2. Summary of Zooplankton Data Collected During Operational Monitoring Periods (1987), Sequoyah Nuclear Plant

Month	Site*	Group	Sample 1	Sample 2	Mean	Standard Deviation	C.V.†
July 87	483.4	Cladocera	7770	6246	7008	1077.6	15.38
		Copepoda	5957	10221	8089	3015.1	37.27
		Rotifera	56986	62849	59918	4145.8	6.92
		Total	70713	79316	75015	6083.2	8.11
	484.5	Cladocera	6406	9843	8125	2430.3	29.91
		Copepoda	9024	12591	10808	2522.2	23.34
		Rotifera	45779	32597	39188	9321.1	23.79
		Total	61209	55031	58120	4368.5	7.52
Aug. 87	483.4	Cladocera	4189	7281	5735	2186.4	38.12
		Copepoda	4563	4971	4767	288.5	6.05
		Rotifera	63188	63228	63208	28.3	0.04
		Total	71940	75480	73710	2503.2	3.40
	484.5	Cladocera	5020	7698	6359	1893.6	29.78
		Copepoda	5856	5198	5527	465.3	8.42
		Rotifera	34635	50114	42375	10945.3	25.83
		Total	45511	63010	54261	12373.7	22.80

Table F-2. (Continued)

Month	Site*	Group	Sample 1	Sample 2	Mean	Standard Deviation	C.V.†
July 87	P3	Cladocera	2976	‡	2976		
		Copepoda	5073		5073		
		Rotifera	7597		7597		
		Total	15646		15646		
	P2	Cladocera	770	616	693	108.9	15.71
		Copepoda	873	2310	1592	1016.1	63.85
		Rotifera	1129	2873	2001	1233.2	61.63
		Total	2772	5799	4286	2140.4	49.95
	P1	Cladocera	9261	5005	7133	3009.4	42.19
		Copepoda	7700	16170	11935	5989.2	50.18
		Rotifera	22330	12705	17518	6805.9	38.85
		Total	39291	33880	36586	3826.2	10.46
Aug. 87	P3	Cladocera	616	2156	1386	1088.9	78.57
		Copepoda	4723	2669	3696	1452.4	39.30
		Rotifera	9548	11807	10678	1597.4	14.96
		Total	14887	16632	15760	1233.9	7.83
	P2	Cladocera	2967	3696	3332	515.5	15.47
		Copepoda	3871	3234	3553	450.4	12.68
		Rotifera	26324	27874	27099	1096.0	4.04
		Total	33162	34804	33983	1161.1	3.42
	P1	Cladocera	2197	3080	2639	624.4	23.66
		Copepoda	3506	5236	4371	1223.3	27.99
		Rotifera	37473	64989	51231	19456.8	37.98
		Total	43176	73305	58241	21304.4	36.58

*Collection Sites: Tennessee River Miles 483.4 and 484.5, P1=Intake; P2=Diffuser Pond, P3=Return channel.
†C. V. = Coefficient of Variation.
‡Data not available.

Table F-3. Results of One-Way-Analysis of Variance on Zooplankton Data Collect in July and August 1987, Sequoyah Nuclear Plant, Chickamauga Reservoir

Test Data	Date	P>F	Locations Ranked from Low to High Mean	
Reservoir Sites				
Total Zooplankton	July	0.0827	-	
	August	0.1917	-	
Cladocera	July	0.6414	-	
	August	0.7671	-	
Copepoda	July	0.4291	-	
	August	0.1829	-	
Rotifera	July	0.1316	-	
	August	0.1526	-	
In-Plant Sites				
Total Zooplankton	July	0.0278*	Diffuser	Intake
	August	0.1981	-	
Cladocera	July	0.0198*	Diffuser	Intake
	August	0.3536	-	
Copepoda	July	0.0779	-	
	August	0.4756	-	
Rotifera	July	0.0547	-	
	August	0.1625	-	

*Significant at $\alpha = 0.05$.

Table F-4. Mean Zooplankton Densities (No./m3) at Each Sample Station During Operational Monitoring (1987) Sequoyah Nuclear Plant, Chickamauga Reservoir

	Collection Sites*									
	July 1987					August 1987				
	483.4	484.5	P1	P2	P3	483.4	484.5	P1	P2	P3
Cladocera										
Acroperus harpae	41	0	0	0	0	0	0	0	0	0
Alona quadrangularis	0	0	0	0	0	1	0	0	0	0
Alona sp.	0	1	0	0	0	0	0	64	0	52
Bosmina longirostris	5127	6447	5968	488	0	3568	4769	2182	2618	0
Camptocercus rectirostris	0	0	0	0	2053	1	0	0	0	975
Ceriodaphnia lacustris	213	100	0	0	0	1	0	41	0	0
Chydorus sp.	87	2	11	0	0	0	0	0	77	31
Daphnia pulex	43	68	0	0	513	0	0	0	0	0
Daphnia retrocurva	294	164	0	77	0	0	0	113	0	21
Diaphanosoma leuchtenbergianum	1161	1339	963	129	205	1614	1046	116	560	52
Ilyocryptus spinifer	2	1	193	0	205	66	42	0	0	257
Leptodora kindtii	0	2	0	0	0	0	0	0	0	0
Moina imm.	0	0	0	0	0	27	0	0	0	0
Moina micrura	41	0	0	0	0	457	502	123	77	0
Pleuroxus denticulatus	1	2	0	0	0	0	1	0	0	0
Scapholebris kingi	0	1	0	0	0	0	0	0	0	0
Sida crystallina	1	1	0	0	0	1	0	0	0	0
Simocephalus serrulatus	0	1	0	0	0	1	1	0	0	0
Copepoda										
Calanoid imm.	1	71	0	26	103	0	44	21	11	0
Cyclopoid imm.	1364	1608	3658	129	103	1078	1966	719	924	975
Cyclops bicuspidatus thomasi	0	0	0	0	0	0	1	0	0	0
Cyclops vernalis	1	1	0	0	21	1	0	0	0	0
Diaptomus pallidus	0	33	0	0	0	1	0	0	0	0
Diaptomus reighardi	2	1	0	0	0	1	1	0	0	0
Diaptomus siciloides	1	0	0	0	0	0	0	0	0	0
Ergasilus sp.	0	1	0	0	0	1	1	0	0	0

Table F-4. (Continued)

	Collection Sites*									
	July 1987					August 1987				
	483.4	484.5	P1	P2	P3	483.4	484.5	P1	P2	P3
Copepoda (Continued)										
Eucyclops agilis	0	1	0	0	0	1	1	0	0	0
Eucyclops prionophorus	0	0	0	0	0	1	0	0	0	0
Eurytemora affinis	0	2	0	0	0	2	84	0	0	52
Mesocyclops edax	124	327	0	0	21	66	43	103	77	52
Nauplii	6597	8765	8278	1438	4825	3618	3388	3530	2541	2618
Tropocyclops prasinus	1	1	0	0	0	1	1	0	0	0
Rotifera										
Asplanchna herricki	122	238	770	0	0	1308	586	1912	308	154
Brachionus angularis	24591	11138	4235	385	4620	9092	5605	13630	6545	2156
Brachionus bennini	0	0	0	0	0	81	0	0	0	0
Brachionus bidentata	0	36	0	0	0	0	0	0	0	0
Brachionus budapestinensis	1655	582	193	0	205	6806	3430	3350	3850	1643
Brachionus calyciflorus	81	199	1155	0	205	314	42	64	77	0
Brachionus caudatus	3222	710	963	128	411	3296	2510	757	2002	411
Brachionus quadridentatus	786	164	0	0	0	300	210	616	77	52
Brachionus urceolaris	0	32	0	0	0	0	0	0	0	0
Collotheca sp.	81	107	0	0	0	0	42	270	77	0
Conochiloides sp.	15702	16520	6545	154	411	19633	16565	2246	924	514
Conochilus hippocrepis	0	171	0	0	0	333	251	0	0	0
Conochilus unicornis	6059	3408	578	231	0	18435	9287	5224	1848	359
Filinia longiseta	173	0	193	26	0	0	0	0	0	103
Hexarthra intermedia	0	0	0	0	0	0	42	0	77	0
Hexarthra mira	0	0	0	0	0	0	0	154	77	206
Kellicottia bostoniensis	0	0	0	0	719	0	0	180	77	0
Kellicottia longispina	0	0	0	462	0	0	0	0	0	360
Keratella cochlearis	0	0	0	0	0	54	0	0	0	0

Table F-4. (Continued)

	Collection Sites*									
	July 1987					August 1987				
	483.4	484.5	P1	P2	P3	483.4	484.5	P1	P2	P3
Rotifera (Continued)										
Keratella crassa	0	36	0	0	0	134	0	206	231	52
Keratella earlinae	548	419	2118	257	513	60	0	2772	1155	719
Lecane sp.	130	227	0	0	0	27	0	64	77	0
Monostyla sp.	124	0	0	0	0	0	0	0	77	0
Platyias patulus	216	71	0	26	0	533	335	0	231	0
Ploesoma hudsoni	0	107	0	0	0	0	0	0	0	0
Ploesoma truncata	2907	749	0	180	0	754	586	1771	1309	1386
Polyarthra sp.	735	320	193	51	0	719	879	11178	5621	1489
Synchaeta stylata	2746	3724	0	103	513	1335	1924	6738	2459	976
Trichocerca sp.	43	235	578	0	0	0	84	103	0	103

*Collection Sites = Tennessee River Miles 483.4 and 484.5; P1: Intake; P2: Discharge Pond; and P3: Return Channel.

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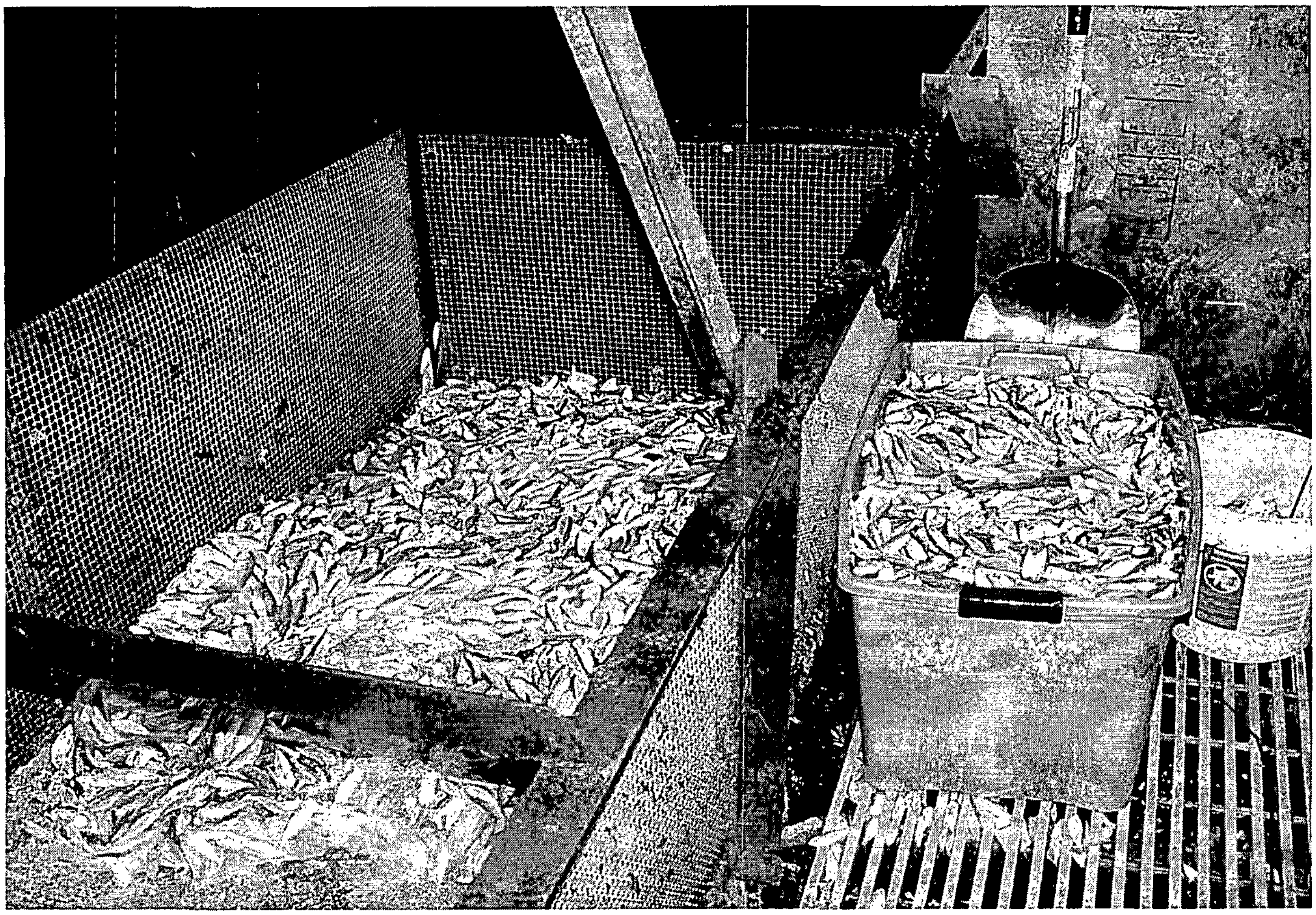
The Role of Temperature and Nutritional Status in Impingement of Clupeid Fish Species



The Role of Temperature and Nutritional Status in Impingement of Clupeid Fish Species

1014020

Final Report, March 2008

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PRODUCT DESCRIPTION

Episodic impingement of high numbers of juvenile and adult clupeid fish species such as gizzard and threadfin shad, menhaden, and herring is a common occurrence, particularly during winter at many power plant cooling water intake structures (CWIS). In fact, annual impingement estimates are frequently dominated by the large numbers of clupeids associated with these episodes. Minimizing the number of fish impinged at CWIS is important for both environmental protection and operational reasons. This report presents the results of investigations of two environmental factors, cold shock and nutritional state, that are known to contribute to the impingement of clupeids. These results can be used to help predict when impingement events are likely to occur and to assess the relative contribution of project operations and natural causes to fish impingement.

Results and Findings

A review of the literature on mass mortalities of clupeid species, particularly gizzard and threadfin shad, revealed that such events are common, especially in larger freshwater lakes, rivers, and reservoirs. However, research to date into the causes of this mortality as well as the general physiological responses of clupeids to potential environmental stressors is limited. The principal reasons for such die-offs often vary among species. Laboratory studies confirm that cold temperatures and cold shock resulting from a rapid decline in temperature can reduce swimming endurance in gizzard and threadfin shad and render them more susceptible to impingement. The results of these studies will be useful for identifying the environmental conditions under which one might expect the cause of impingement to be largely of natural origin. For example, when thermal regimes at a CWIS are similar to those that resulted in loss of equilibrium in laboratory experiments, i.e., < 2 °C for gizzard shad and < 5 °C for threadfin shad, we would expect that the bulk of impinged fish were not killed directly by impingement. This study also identified physiological indicators of susceptibility to impingement such as hematocrit and condition factor whose measurement could potentially be used to predict or explain episodic impingement events. The use of multiple indicators of stress helps to explain confounding stressors that may be present in natural ecosystems. Using physiological and performance-level indicators to assess impingement susceptibility appears promising, but further studies are needed to evaluate the relative importance of cold shock and nutritional status on impingement.

Challenges and Objectives

Under the Clean Water Act (CWA) §316(b), the applicant for a National Pollutant Discharge Elimination System (NPDES) permit must demonstrate that the location, design, construction, and capacity of its cooling water intake structure represents Best Technology Available (BTA) for minimizing adverse environmental impact. As of preparation of this report, the U.S. Environmental Protection Agency (EPA) is re-writing, per a 2007 U.S. Appeals Court finding, the Rule to implement CWA §316(b) for existing power plants (Phase II Rule). Many studies have demonstrated a relationship between the incidence of natural mortality for several fish species (particularly clupeids) and increased power plant impingement. EPA has recognized the need to evaluate naturally moribund fish and shellfish entering CWIS. In the now remanded Phase II Rule, EPA noted that estimates of impingement mortality should be based on the impingement and harm of healthy fish, not the incidental capture of moribund and dead fish. The revised EPA Phase II Rule may retain the requirements in the previous Rule; and the key challenge will be to demonstrate technical, defensible criteria for the identification of impinged fish that were already dead or dying when they entered the intake. The development of these criteria is the subject of this report and future EPRI research.

Applications, Values, and Use
This report is planned as a technical support document providing information and ideas EPRI members can use when discussing impingement compliance options with permitting agencies in areas where there are occurrences of high episodic natural mortality of fish.

EPRI Perspective
This report provides information to EPRI members to support their CWA §316(b) compliance efforts. Most notably, the report supports the documentation of the natural occurrence of dead and moribund fish, thereby reducing estimates of annual impingement mortality that can be attributed to processes and structures associated with a power plant's CWIS.

Approach
This issue was initially addressed by reviewing and summarizing the technical literature on natural mortality events exhibited by clupeids for the purpose of examining the relationship between naturally stressed and moribund fish and impingement at CWIS, as well as for designing laboratory studies to investigate key relationships. The project team then conducted laboratory studies on the responses of two common freshwater shad species (gizzard and threadfin) to rapid reductions in water temperatures and their potential for recovery from cold shock. Additional laboratory studies investigated the relationship between various physiological indicators of stress and the susceptibility of impingement by these species.

Keywords
Clean Water Act §316(b)
Impingement
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Cover photo of threadfin shad collected during an episodic event at a power plant on the Ohio River.

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1
INTRODUCTION

As a result of concerns in the late 1960s and early 1970s over the potential effects of fish entrainment and impingement losses at electric generating facilities, Congress included §316(b) as part of the amendments to the Federal Water Pollution Control Act of 1972 (commonly referred to as the "Clean Water Act"). Under the Clean Water Act §316(b), an applicant for a National Pollutant Discharge Elimination System (NPDES) permit must demonstrate that the location, design, construction and capacity of its cooling water intake structure (CWIS) represents Best Technology Available (BTA) for minimizing adverse environmental impact.

In 1995, the U.S. Environmental Protection Agency (USEPA) began a three-phased process to develop the rules related to §316(b).[1] The final Phase I Rule, for new facilities, was published on 18 December 2001 (66 FR 65255) and was amended on 19 June 2003 (68 FR 36749). The final Phase II Rule, for existing electric generating facilities was published on 9 July 2004 (69 FR 41575). The Phase II Rule applies to existing facilities whose construction commenced prior to 17 January 2002 and that have cooling water intake structures with a design capacity greater than or equal to 50 million gallons per day (MGD), and use 25 % or more of the water withdrawn for cooling purposes. The Phase III rule, for smaller (<50 MGD) power plants and certain industrial facilities, was published 16 June 2006 (71 FR 35005).

USEPA's regulations establishing requirements for cooling water intake structures at Phase II existing facilities were challenged by industry and environmental stakeholders. On judicial review, the Second Circuit decision (Riverkeeper, Inc. v. EPA, 475 F.3d 83, (2d Cir., 25 January 2007)) found some provisions illegal and remanded several provisions of the Phase II rule on various grounds. The provisions found illegal included the option to use restoration and cost-benefit analyses. The key provisions remanded to EPA include:

- EPA's determination of the BTA under §316(b);
- the rule's performance standard ranges;
- the cost-cost compliance alternative; and
- the Technology Installation and Operation Plan provision

In response to the decision, EPA suspended the Phase II rule on 9 July 2007 (72 FR 37107). In lieu of the suspended Phase II Rule EPA required that permitting authorities develop case-by-case, best professional judgment (BPJ) controls for existing facility cooling water intake structures that reflect the best technology available for minimizing adverse environmental

[1] Cronin v. Browner, No. 93 Civ. 0314 (AGS)(S.D.N.Y.), Order of 21 November 2000.

impact. CWA provision 40 CFR 125.90(b) directs permitting authorities to establish §316(b) requirements on a BPJ basis for existing facilities not subject to categorical §316(b) regulations.

Though remanded, it is anticipated that some features of the Phase II Rule related to technology-based performance standards will be retained when USEPA revises the rule in the future[2]. The suspended Phase II Rule had established performance standards for cooling water intake structures that would have required substantial reductions in impingement mortality and entrainment relative to a Calculation Baseline. The Calculation Baseline is the impingement mortality and entrainment that would hypothetically occur if the facility had a shoreline, near-surface intake, traveling screen with a standard 3/8 inch mesh with its face oriented parallel to the shoreline, but no other measures to reduce impingement mortality and entrainment. Among other requirements, the remanded Phase II Rule had required a reduction of impingement mortality by 80 to 95% from the Calculation Baseline for all Phase II in-scope power plants in the U.S.

The USEPA has recognized the need to evaluate naturally moribund fish and shellfish entering cooling water intake systems (USEPA 2006). For example, as part of the Verification Monitoring Plan for compliance alternatives in §125.94(a)(2), (3), (4), or (5), an applicant proposal was to be submitted outlining how naturally moribund fish and shellfish entering the CWIS will be identified and used to meet performance standards in §125.94(b). Although the Verification Monitoring Plan is part of the remanded Phase II rule, it is reasonable to expect that permitting authorities will take into account the numbers of naturally dead and moribund fish entering the CWIS when evaluating the need for controls to minimize adverse impacts to fish populations. In a letter regarding calculation baseline estimates at the Muscatine Power Plant (Iowa), EPA Region VII stated that "... moribund fish should <u>not</u> be counted in the impingement calculation baseline. Sampling of impingement should count <u>all</u> fish, but moribund fish should not count toward the calculation baseline" (USEPA 2006).

Many studies have demonstrated a relationship between increased power plant impingement and the incidence of natural mortality for several fish species, particularly for clupeid species (Griffith and Tomljanovich 1975; Loar et al. 1978; McLean et al. 1979; McLean et al. 1980; McLean et al. 1981; McLean et al. 1985; LaJeone and Monzingo 2000). However, field evaluations of the condition of fish (e.g., living, dead, moribund, recoverable) prior to impingement can be difficult and are rare. EPRI recently

completed[3] a 2-yr survey of impingement at 15 power plants on the Ohio River. Of the 112 seasonally-combined events (8 seasons at 13 plants and 4 seasons at 2 plants), there were 16 seasonally-combined impingement events of more than 10,000 fish that occurred at 7 of the 15 plants. These 16 seasonally combined events included large numbers of gizzard shad (*Dorosoma cepedianum*; 13 seasonally-combined events), threadfin shad (*Dorosoma petenense*; 3), freshwater drum (*Aplodinotus grunniens*; 2), and skipjack herring (*Alosa chrysochloris*; 1). During these high seasonally-combined impingement events, 25% (average) of the impinged fish were alive at the time of sample collection. In four of the seasonally-combined events living fish

[2] USEPA began a revised rule-making effort in the fall of 2007 and tentatively plan on releasing a draft revised Phase II Rule in late 2008 or early 2009. Also of note is that the 2nd Circuit Court decision of 2007 has been appealed to the U.S. Supreme Court for review.

[3] Ohio River Ecological Research Program: Impingement Mortality Characterization Study at 15 Phase II Generating Stations. EPRI Draft Report, January 2008. Final report planned for June 2008.

comprised less than 1% of the impingement counts for the predominant species. Nearly all of the fresh dead fish (i.e., those that had recently died or perhaps moribund) were captured during fall and winter samples (Figure 1-1). Studies at the Muscatine Plant (Iowa) found that more than 95% of fish entrapped on barrier nets in December (357 total fish) and February (961 total fish) were either moribund or dead (HDR LMS 2006).

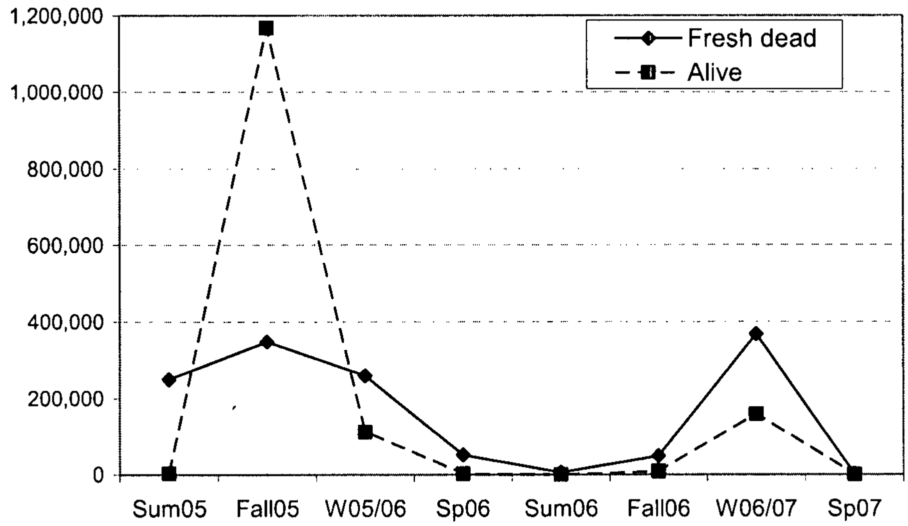


Figure 1-1
Total number of impinged fish (alive and fresh dead) per season at 15 intake structures on the Ohio River (NOTE: the impingement data for fall 2005 included almost 1.1 million live but moribund threadfin shad collected at one power plant in a single day of sampling).

Laboratory studies designed to better understand the factors that contribute to fish impingement are necessary to assign project responsibility and adjust fish protection technology performance accordingly. For example, information on the behavior and physiological state of cold-stressed fish prior to impingement may help industry, regulatory, and resource agencies determine the proportions of impinged fish that were already dead or dying when they entered the CWIS. Further, if used as a monitoring tool, behavioral or physiological indicators may be valuable for predicting the environmental conditions and/or fish population dynamics under which large impingement episodes will occur. This knowledge would enable utilities to adjust the operations of their power plants to reduce the loss of debilitated, but recoverable, fish as well as prevent blockage of cooling water flow.

Cold shock and starvation have been proposed as primary causes of winter mortality for many species including gizzard shad. White et al. (1986) conducted an extensive study on the physiological and biochemical responses of cold-shocked gizzard shad relative to susceptibility to impingement. They found that even though lipid reserves are relatively high in gizzard shad going into winter, they have trouble mobilizing this energy reserve when temperatures are very cold and thus go in to a starvation mode even though they contain high fat reserves. This results in a quick utilization of liver and muscle glycogens, which in turn results in other tissues being utilized for energy. In severe cases, liver function declines and failure of other physiological functions often follows. For example, cell membranes begun to lose their ability to transport materials properly which can result in poor energy delivery to the brain and subsequent brain dysfunction. Loss of brain function results first in disorientation and eventually a comatose condition like that seen during winter mortality events. White et al. (1986) concluded that poor over-winter survival of gizzard shad in Sandusky Bay (Ohio) is a result of enzymatic acclimation occurring too late in the season causing eventual physiological failure.

The purpose of this report is to present the results of two efforts by funded by EPRI to better understand the condition of fish that become impinged at CWIS and the environmental conditions associated with impingement events. The first study, presented in Chapter 2, was a literature review of natural mortality events in clupeid fishes (i.e., shad, menhaden, and herring species). By understanding the conditions under which natural events occur, resource managers and project operators can more accurately assess the contribution of natural causes to impingement at CWIS.

The second study, presented in Chapters 3 and 4, was a series of laboratory experiments with gizzard shad and threadfin shad under different cold shock thermal regimes and feeding history designed to better understand the relationships among cold shock, nutritional status, and susceptibility to impingement. These studies were intended to further the understanding of these relationships as reported by White et al. (1986) and others.

This report is planned as a technical support document providing information and ideas that EPRI members can use when discussing impingement compliance options with permitting agencies in areas where there are occurrences of high episodic natural mortality. The information presented in this report will help establish guidelines for identifying the time of year and temperature dynamics that are likely to result in high incidences of naturally moribund and dead fish in CWIS impingement samples.

As part of its corporate objectives to provide scientifically sound information for development of cost-effective environmental policies and regulations as well as information for cost-effective and scientifically sound compliance efforts, EPRI has supported a variety of studies that evaluated scientific methodologies and summarized potential environmental effects of cooling water withdrawals. These studies have done much to advance the current state-of-the-art for addressing issues related to §316(b). In addition to this document, other EPRI reports that provide information relevant to §316(b)-related compliance sampling include:

Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual (EPRI Report 1014934, 2007)

Effects of Fluctuating Temperatures on Fish Health and Survival (EPRI Report 1012545, 2007)

Latent Impingement Mortality Assessment of the Geiger Multi-Disc™ Screening System at the Potomac River Generating Station (EPRI Report 1013065, 2007)

Technical Resource Document for Modified Ristroph Traveling Screens: Design and Construction Technology Plan and Technology Installation and Operation Plan (EPRI Report 1013308, 2006)

Laboratory Evaluation of Modified Ristroph Traveling Screens for Protecting Fish at Cooling Water Intakes (EPRI Report 1003238, 2006)

Design Considerations and Specifications for Fish Barrier Net Deployment at Cooling Water Intake Structures (EPRI Report 1013309, 2006)

Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures: Chesapeake Bay Studies (EPRI Report 1002542, 2006)

Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes (EPRI Report 1010112, 2005)

Impingement and Entrainment Survival Studies Technical Support Document (EPRI Report 1011278, 2005)

Entrainment Abundance Monitoring Technical Support Document (EPRI Report 1011280, 2005)

Impingement Abundance Monitoring Technical Support Document (EPRI Report 1008470, 2004)

Parameter Development for Equivalent Adult and Production Foregone Models (EPRI Report 1008832, 2005)

Extrapolating Impingement and Entrainment Losses to Equivalent Adults and Production Foregone (EPRI Report 1008471, 2004)

Impacts of Volumetric Flow Rate of Water Intakes on Fish Populations and Communities (EPRI Report 1005178, 2003)

Evaluating the Effects of Power Plants on Aquatic Communities: Summary of Impingement Survival Studies (EPRI Report 1007821, 2003)

Evaluating the Effects of Power Plants on Aquatic Communities: Guidelines for Selection of Assessment Methods (EPRI Report 1005176, 2002)

Evaluating the Effects of Power Plant Operations on Aquatic Communities: An Ecological Risk Assessment Framework for §316(b) Determinations (EPRI Report 1005337, 2002)

Technical Evaluation of the Utility of Intake Approach Velocity as an Indicator of Potential Adverse Environmental Impact under Clean Water Act Section 316 (EPRI Report 1000731, 2001)

Review of Entrainment Survival Studies: 1970-2000 (EPRI Report 1000757, 2000)

Taken together these documents provide utility managers, regulators, and interested parties technically sound guidance for the §316(b) determination process. It is EPRI's intent that these documents be accepted as objective resources by a diversity of users involved in the regulatory process, including scientists, engineers, managers, and lawyers working for the utility industry, regulatory and resource management agencies, academic and private consultants, and environmental advocates.

2
NATURAL MORTALITY EVENTS IN CLUPEID FISHES: A LITERATURE REVIEW

Introduction

The family Clupeidae includes a wide diversity of prolific species, including blueback herring (*Alosa aestivalis*), alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), gizzard shad and threadfin shad. Many clupeid species have been introduced into lakes and reservoirs as a forage base for recreationally important game species. Under optimal environmental conditions and low predator pressures, clupeid populations can expand quickly. For example, in the mid-1950s, about 1,000 threadfin shad were introduced into Havasu Reservoir, Colorado, and within one year the population numbered in the millions and had spread downstream of the reservoir (Moyle 2002). Large populations without controls can quickly exceed carrying capacity for the water body, resulting in mass mortality from starvation and disease. Studies have shown correlations between clupeid density and juvenile mortality for species like gizzard shad (Stock 1971; Kampa 1984; Buynak et al. 1992; Welker et al. 1994). Owing to their large numbers, clupeids often comprise a large proportion of the fish that are impinged at CWIS (Loar et al. 1978).

Many introduced clupeids have narrow thermal and water quality tolerance ranges, causing mass mortality during harsh periods. Sudden and drastic changes in temperature cause behavioral and physiological changes in many clupeid species. A rapid drop in temperature can cause loss of swimming and schooling abilities and a decrease in feeding (Griffith and Tomljanovich 1975). At temperatures near their lower tolerance limits, clupeids experience loss of equilibrium, erratic swimming, movement to the surface, and lack of response to external stimuli (Griffith 1978). These behavioral changes not only make clupeids vulnerable to predation, but they can become more susceptible to power plant impingement. Rapid decreases in water temperature can occur naturally, or as a result of plant operations. The winter shutdown of industrial facilities that produce warmwater discharges can cause debilitating or lethal cold shock among clupeids that congregate near these warmwater discharges during winter (Burton et al. 1979).

This chapter presents the results of a literature search and review to address the relationship between the occurrences of naturally stressed and moribund fish and impingement at CWIS. This literature review focused on five members of the herring family (Clupeidae) – threadfin shad, gizzard shad, alewife, Atlantic menhaden (*Brevoortia tyrannus*), and Gulf menhaden (*Brevoortia patronus*). Each of these five species have a documented history of large scale die-offs, represent a significant component of impingement at cooling water intake structures, and are found over a broad geographic range encompassing fresh, brackish and marine waters. Specific objectives of the review were to identify and summarize available information for the species listed above related to each of the following areas:

- Susceptibility of each species to die-offs;
- Seasonality of such die-offs;
- Contributing environmental conditions and other causal factors (i.e., stressors);
- Physiological processes and indicators of stressor exposure;
- Relationship to cooling water intake impingement; and,
- Recorded occurrences of large-scale die-offs, including species and geographic locations.

The search for information was conducted in five phases. First, literature contained within library holdings at ASA Analysis & Communication, Inc. relevant to §316(b) issues were identified and accessed. Second, a thorough search of the Internet was conducted for relevant information. Third, a broad-based search was conducted through the Dialog® system. This search focused on three databases: Biosis Previews, National Technical Information Service (NTIS), and the Electric Power Database. A broad search of these databases yielded over 1,100 relevant titles. The full record, including the abstract, was printed and used to identify the most useful and relevant literature. Fourth, the reference lists in all of the literature identified in phases 1 – 3 of the search were reviewed to identify additional materials. Finally, individuals with prior research experience in areas related to fish impingement and §316(b) issues were contacted to obtain additional, often unpublished, reports and papers.

Seventy three relevant reports and published reference materials were identified and retrieved as part of this effort. An annotated listing of these materials is provided in Appendix A and is summarized by species below.

Threadfin shad

Threadfin shad is one of the most important forage species in many water bodies, especially in Southeastern lakes and reservoirs (Schael et al. 1995). In these water bodies, this species often provides an important source of food for largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), and striped bass (*Morone saxatillis*). As a result of its importance as a forage species for many recreationally important fish species, threadfin shad have been introduced over wide geographic areas of the country. However, threadfin shad are a short-lived, fragile fish prone to frequent die-offs when conditions are sub-optimal (Higginbotham 1988). For example, threadfin shad are known to suffer mass mortality when water temperatures fall below 5-6°C. In addition, this species is sensitive to dissolved oxygen depletion during summer months and can exhibit large die-offs after spawning as a result of cumulative physiological stress. The reduced physiological condition of threadfin shad during summer months is believed to have increased impingement at the Comanche Peak Steam Electric Station in Texas from 1993 through 1994 (TUEC 1994). During the period from late July to late August when water temperatures were at their highest, 81 % of the annual impingement of threadfin shad occurred at this station.

While it appears that threadfin shad can be susceptible to a wide variety of stressors, temperature appears to be the primary contributor to most large-scale mortality events. Griffith (1978) found that threadfin shad started dying at 9°C and that none of his study fish survived at 4°C. In addition, threadfin shad mortality can be high when they are exposed to water temperatures at 9°C for several months (Strawn 1965). A sudden drop in temperature can not only cause detrimental behavioral changes and decreased feeding, but can also cause loss of equilibrium and death (Griffith 1978). Loss of equilibrium due to cold shock can cause hemorrhaging and fungal infections (Colby 1973). In fact, because of their sensitivity to low water temperatures, threadfin shad survival in some water bodies may require access to warm water discharges from power plants. For example, during a 1983 survey of the upper Mississippi River threadfin shad were only collected near the Portage Des Sioux power plant, and survival of threadfin shad in Montrose Lake, Missouri, is believed to be dependent on the warm water discharges from a steam generating plant (Pflieger 1997).

Low temperatures also appear to be a primary factor affecting impingement rates at many cooling water intakes. This is a common occurrence for many Southern power plants, as threadfin shad impingement typically increases when water temperatures fall below 10°C (Loar et al. 1978). A study of 32 Southeastern United States power plants found that threadfin shad accounted for more than 90 % of all fish impinged, with peak impingement of this species occurring in winter (Loar et al. 1978). Increased threadfin shad impingement occurred at the following power plants when water temperatures were below 15°C: Green River, Kentucky; Allen, North Carolina; Marshall, North Carolina, Riverbend, North Carolina; Arkansas One, Arkansas; Oconee, South Carolina; Wateree, South Carolina; and Eagle Mountain, Texas. Impingement of large numbers of threadfin shad at Kingston Station, Tennessee, coincides with threadfin shad die-offs in the reservoir on which this steam electric power plan is located (McGee et al. 1977; McLean et al. 1985). The highest densities of impinged threadfin shad coincided with a sudden drop in water temperature (Figure 2-1). Impingement of threadfin shad at Kingston Station increased to 5,000 shad per day in December when temperatures dropped to 7°C. As water temperatures continued to decrease to 4°C, 42,000 threadfin shad were impinged on 8 December (McLean et al. 1980).

In years with mass mortality during severe winters, all age and size classes are affected and a majority of the threadfin shad population was eliminated (McLean et al. 1985). However, this highly fecund and fast-growing species has the ability to rebound quickly in the years following a significant die-off. Fish which hatch in spring are capable of spawning that same summer, enabling a population to quickly rebound following mass mortality. For example, an estimated 95 % of the threadfin shad population was removed from Watts Bar Reservoir during the winters of 1976-1977 and 1977-1978 as a result of impingement mortality and winter kill. However, the threadfin shad population had rebounded by autumn of each year following the die-offs (McLean et al. 1980).

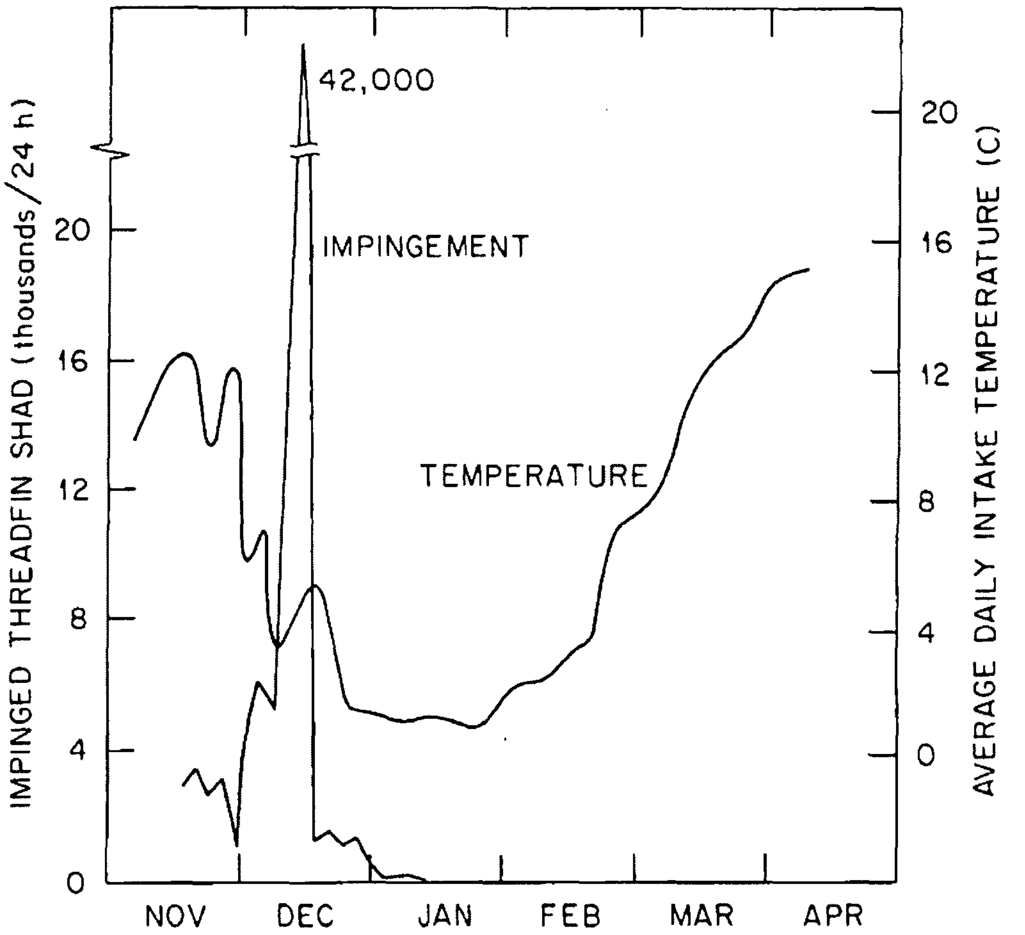


Figure 2-1
Impingement of threadfin shad at Kingston Steam Plant and water temperatures at the intake canal from November 1976 through April 1977. (From: McGee et al. 1977).

The following reports provide details of documented mass mortality events of threadfin shad:

Watts Barr Reservoir, Tennessee 1976-1977 – Mass threadfin shad mortality due to a severe winter (McLean et al. 1985)

Pee Dee River, North Carolina May 2002 (NCDWQ 2002)

Sacramento - San Joaquin Delta, California – Mass die-off during winters when temperatures drop to 6-8°C (Moyle 2002)

Clear Lake, California – Extirpated during severe winter of 1990-1991 (Moyle 2002)

White River Basin, Missouri – Occasional massive winter mortality (Pflieger 1997)

Lake Texoma, OK 2001 – Severe winter kill in mid-February 2001 (OK Department of Wildlife Conservation 2001)

Bull Shoals Reservoir, Arkansas 1983-1984– Severe winter kill (Arkansas Game and Fish Commission 1995)

Norfolk Lake, Arkansas 1996 – Severe winter kill (Arkansas Game and Fish Commission 1997)

Smith Mountain Lake, Virginia 2002-2003 – Nearly complete die-off of population due to severe winter (Virginia Department of Game and Inland Fisheries 2004)

Gizzard Shad

Gizzard shad are native to most Southeastern states, but have since been introduced throughout much of the country (Cooper 1983; Kirtland 1844, cited in HDR LMS 2006). Introduced as a forage base for game species, gizzard shad, unfortunately, often outgrow their predators and quickly overpopulate a system. In many systems, gizzard shad are viewed as a nuisance fish as a result of an overpopulation of large adult fish. In addition, gizzard shad can compete with juvenile predators and other planktivorous fishes leading to declines in sport and native fish communities (Johnson et al. 1988; Michaletz 1997).

Overpopulations of gizzard shad combined with severe winters and low dissolved oxygen often lead to mass mortalities. Typically, mass gizzard shad mortalities tend to occur in the northern part of their range as a result of severe winters. For example, Kirtland (1844, cited in HDR LMS 2006) reported heavy winter kills of gizzard shad in the Ohio River, and White (1986) described the winter kills as being density dependent. Gizzard shad larvae and juvenile survival has been correlated with water temperature in several midwest reservoirs; early cohorts not only grew slower as a result of lower temperatures, but also suffered higher mortalities than later age classes (Michaletz 1997). Winter die-offs are often more severe for younger age classes, as they typically deplete energy reserves more rapidly than do larger gizzard shad (Shuter and Post 1990). In addition, gizzard shad which are spawned later in the year have less time to build-up fat reserves (White et al. 1986). For example, during severe winters in Sandusky Bay, Lake Erie 100 % mortality has been recorded for young-of-the-year (YOY) gizzard shad in the 40-85 mm size range and 99.9 % mortality for YOY between 90-140 mm (White et al. 1986). In other studies on Lake Erie, gizzard shad populations exhibited a shift in size range of YOY fish from mid-autumn through early spring. Because growth does not occur during this period, this shift in mean length and length range has been attributed to size selective mortality over the winter (Caroots 1976). Similarly, high gizzard shad impingement counts at the Muscatine Plant in Iowa were initially dominated by YOY fish; later in the winter, the mean size of impinged shad increased (HDR LMS 2006). Gizzard shad often dominate fish biomass in many bodies of water and can consume all of the food resources that might otherwise be available to other fish species. For example, higher gizzard shad levels can yield reduced growth in bluegills (Michaletz 1998). This reduced bluegill growth can lead to reduced growth in largemouth bass which preferentially feed on bluegills.

Periods of higher impingement rates for gizzard shad often correspond with periods of large winter die-offs; further, the size range of impinged gizzard shad also tends to overlap with size ranges of those fish subject to winter mortality. For example, gizzard shad impinged from 1979 through 1984 at Eastlake, Avon Lake, and Edgewater generating facilities located in Lake Erie's Central Basin comprised mainly YOY fish in the 40-125 mm size range, similar to the size of fish which exhibited natural mortality (White et al. 1986).

Gizzard shad are most susceptible to winter die-offs in the northern part of their range, as they are not physiologically adapted for survival during extended cold periods. Gizzard shad begin showing signs of disorientation when water temperatures are around 6 or 7°C (Cox and Coutant 1975). Gizzard shad rely on stored lipid reserves during the winter months, as feeding stops when water temperature declines to around 11°C, but level of activity remains unchanged (White et al. 1986). In addition, when water temperatures drop below 8°C, gizzard shad are unable to mobilize fat reserves and begin utilizing liver, muscle glycogens, and other tissues as sources of energy even though lipids remain. As the liver is metabolized, liver function begins to fail causing jaundice. In cold water, gizzard shad lose cell function and are unable to diffuse waste and materials across cell membranes. After several weeks of these stressful conditions, gizzard shad begin to lose brain function which results in loss of equilibrium, erratic swimming, and finally ends in a comatose state and death (White et al. 1986).

The following reports provide details of documented mass mortality events for gizzard shad:

Several East Tennessee Reservoirs Spring 1983 – Large gizzard shad die-offs due to cumulative stresses and low lipid reserves (Adams et al. 1985)

Sandusky Bay, Lake Erie – Mortality of 5 million gizzard shad per acre (White et al. 1986)

Ohio River near Cincinnati, Ohio 1844 – Large winter kill (Kirtland 1844)

Buckeye Lake, Ohio 1928 and 1940 – Winter die-off after cold snap; gizzard shad struggling at surface (Trautman 1928; Trautman 1940)

Lewis and Clark Lake, South Dakota – 100 % mortality of age 0+ age class after 103 days of ice cover (Walburg 1964)

Western Basin Lake Erie 1955 – winter kill after cold snap; erratic swimming behavior (Bodola 1955)

Huron River, Ohio 1982 – Die-off of millions of yearling gizzard shad after cold snap in weather (Cleveland Plain Dealer 1982)

Acton Lake, Ohio – Complete mortality of age 0+ age class (Hlohowskyj 1983)

Elephant Butte Lake, New Mexico (Jester and Jensen 1972) and Presque Isle Bay. PA (Neumann et al. 1977) – large winter kill

Nebraska Lakes – Winds breaking down stratification causing deep waters to cool rapidly from 4°C to 0°C which caused mortality in gizzard shad (Heidinger 1983)

Alewife

Alewife have been introduced both purposely and accidentally into many northern lakes, such as the Great Lakes, and serve as a forage base for native and introduced salmonids and walleye. Although the alewife has lower thermal tolerances than other clupeids, such as threadfin shad, seasonal die-offs are common in land-locked populations. In Lake Ontario and Lake Michigan, large seasonal alewife die-offs occurred in the 1960s and 1970s following severe winters (O'Gorman and Schneider 1986; Flath and Diana 1985).

As a result of introductions of Pacific salmon and the revitalized lake trout (*Salvelinus namaycush*) and walleye (*Stizostedion vitreum*) stocks, the alewife is a vital link in the food chain of the Great Lakes. In the 1960's, Lake Michigan alewife experienced an average yearly mortality rate of 68 % which was attributed to winterkill and spawning stresses (Brown 1968). These large die-offs in Lake Michigan are thought to be an indirect result of competition leading to a reduction in fat reserves (Brown 1972). Annual die-offs in Lake Michigan correlated with the time of year in which energy reserves are lowest, an indication of insufficient feeding due to environmental stresses, competition, or a reduced plankton population (Flath and Diana 1985). As a result of population declines in several of the Great Lakes, large alewife die-offs are no longer a common occurrence; poor recruitment following the severe winters of 1976-1982 are believed to be the primary cause of Lake Michigan alewife declines (Eck and Wells 1987).

Sudden exposure to warmer temperatures in littoral areas may also cause spring and early summer die-offs in alewife populations (McCauley and Binkowski 1982). Alewife may succumb to warm inshore waters after prolonged exposure to cold temperatures during harsh winters which deplete fat reserves (Colby 1973). The large die-offs in Lake Michigan in June and early July 1967 are believed to be a result of fish encountering warm littoral water as they moved inshore from deep cold water. This theory is supported by the fact that fish appeared robust, many contained rapidly digestible zooplankton, and all size classes of male and female alewife were affected (Brown 1968). Studies have indicated the upper lethal temperature for alewife is 25°C (McCauley and Binkowski 1982). Seasonal percent lipids stored by alewife from Lake Michigan are typically at their lowest (3-5 %) in late spring and early summer (Flath and Diana 1985).

A severe winter in 1992-1993 in Lake Ontario was believed to have severely stressed the alewife population, causing a winter kill; many alewives remained in the littoral areas after spawning instead of moving to deeper water, which increased their vulnerability to impingement (Ross et al. 1996). A sound deterrent system used at James A. Fitzpatrick Nuclear Power Plant during this period exhibited decreased effectiveness when water temperatures were below 13°C, as a result of a diminished response of fish (Ross et al. 1996). Although severe winters can greatly reduce alewife populations, high fecundity and high early life stage survival allow alewife populations to quickly recover in 1 to 2 years (Brown 1972; Kohler and Ney 1981).

The following reports provide details of documented mass mortality events for alewife:

Lake Michigan June and July 1967 – Large alewife die-off, possible temperature shock or algal toxicity (Stanley and Colby 1971; Brown 1968)

Lake Michigan Early 1980s – Large decline in alewife population (Eck and Wells 1987)

Lake Ontario, New York Spring 1993 – Highest mortality in 10 years (Schneider and Schaner 1994)

Lake Ontario, New York – Alewife winter kill (O'Gorman and Schneider 1986; Bergstedt and O'Gorman 1989)

Lake Michigan and Lake Ontario – Alewife mass mortality mainly in spring (Pritchard 1929; Graham 1956; Smith 1968)

Lake Michigan 1960s – 68 % average yearly mortality (Brown 1968)

Claytor Lake, Virginia 1977-1978 – Large alewife die-off associated with severe winter (Kohler and Ney 1981)

Lake Wononskopomuc, Connecticut – Alewife die-off (Warshaw 1972)

Atlantic & Gulf Menhaden

Both species of menhaden are found in marine and brackish waters along the Atlantic and Gulf coasts. Atlantic menhaden are found from Western Nova Scotia to Florida, while the Gulf menhaden occurs from Cape Sable, Florida, to Veracruz, Mexico. Both species serve as important forage for a variety of larger aquatic predators and also, as adults, support important commercial fisheries in certain regions. While most examples of significant mortality events have been reported for Atlantic menhaden, it is reasonable to expect similar events in the closely related Gulf menhaden.

Menhaden mass mortalities appear to be less influenced by temperature stresses and more commonly caused by disease and overcrowding. For example, the interactions of large populations of menhaden with predatory fish can promote large fish kills, as predators like bluefish and striped bass pursue schools of menhaden into small coves. These overcrowded menhaden schools quickly deplete dissolved oxygen concentrations in the small embayments, leading to anoxic conditions and large menhaden kills (ASMFC 2001). For example, a school of Atlantic menhaden near Core Banks, North Carolina in 1997 was estimated to have a biomass of 60,000 million tons, with fish 9 m deep in the water column. This large concentration of fish is believed to have led to oxygen depletion and a large kill (Smith 1999). Oviatt et al. (1972) reported that dissolved oxygen concentrations within small schools of Atlantic menhaden were depleted by 12 % compared to the concentrations in water outside of the school.

In addition to the effects of temporary anoxia, Atlantic menhaden mortalities have been reported in numerous estuaries along the East Coast as a result of ulcerative mycosis disease and toxic dinoflagellates (Ahrenholz et al. 1987; Noga et al. 1991; Burkholder et al. 1992; Faisal and Hargis 1992). Sudden decreases in water temperature as a result of winter shutdown at large power plants can cause Atlantic menhaden mortalities. For example, a temperature decrease from 15 to 5°C caused all menhaden to die within 36 hr in laboratory studies (Burton et al. 1979).

Details of Atlantic menhaden mass mortalities are provided in the following reports:

Pamlico River, North Carolina May 2002 – Increasing water temperature and changes in dissolved oxygen may have caused fish kill (NCDWQ 2002)

Alligator Creek, North Carolina April 2002 – Shallow creek, no explanation for large kill (NCDWQ 2002)

Neuse River, North Carolina July 2002 – High water temperatures and low dissolved oxygen (NCDWQ 2002)

New York Harbor – Annual die-off of millions of menhaden (Westman and Nigrelli 1955)

Chesapeake Bay – Annual die-off caused by virus (spinning disease) (Stephens et al. 1980)

Southern Maine 1980s & 1990s – Menhaden kills due to oxygen depletion in coves (Vaughan 1990; Conniff 1992)

East Coast Estuaries – Kills caused by toxic dinoflagellates (Ahrenholz et al. 1987; Sindermann 1988; Noga et al. 1991; Burkholder et al. 1992; Faisal and Hargis 1992)

Core Banks, North Carolina 1997 – School induced low dissolved oxygen concentrations (Smith 1999)

Oyster Creek Nuclear Generating Station, NJ 1972, 1973, 1974, 1975 – Menhaden kills likely a result of cold shock (Coutant 1977)

Discussion

Based on the summarized literature, reports of mass mortalities of clupeids are quite common, especially in larger freshwater lakes, rivers and reservoirs, and brackish and marine embayments. However, to date, studies of the causes of this mortality as well as the general physiological responses of clupeids to potential environmental stressors have been limited. This lack of published research often leaves fisheries managers guessing at the causes of mass mortality, how to prevent such occurrences, and how to predict large clupeid die-offs.

Perhaps the most extensive research on the topic was conducted by White et al. (1986). These studies provide detailed information on the physiological response of gizzard shad to thermal stress and provide clues to link mass mortalities to cold stress, but it is unclear whether such information is relevant to other clupeids. The authors found that the amount of stored lipids appears to play a role in determining winter kill of several clupeid species, but is not an effective means of determining cold stress mortality in gizzard shad, as gizzard shad are unable to utilize stored fat reserves below 8°C. At these low temperatures, gizzard shad begin metabolizing liver tissue and lose cellular function, which eventually leads to decreased liver and brain function.

Necropsies of gizzard shad that died in cold stress-related mass mortality events revealed loss or breakdown of liver function, enlarged gallbladder, scale base hemorrhaging, jaundiced internal organs and eyes, and progressive darkening of bile.

Unfortunately, details on menhaden, alewife, and threadfin shad mass mortality are not as well documented. Alewife mass mortality was a common occurrence in the Great Lakes, Lake Huron, Lake Michigan, Lake Erie, and Lake Ontario. These die-offs seemed to be linked to severe winters, but since the introduction of predatory salmonids, mass mortality has not been as common an occurrence. Alewife populations in several of the Great Lakes have been significantly reduced by poor recruitment following winterkill, predation by Pacific salmon and lake trout, or by competition with other planktivores and invasive dreissenid mussels, and coincidentally die-offs have not been as noticeable. These observations suggest that mass winter mortality may be a density-dependent process. Research indicates the mass alewife mortalities which occurred in 1983-1984 were a result of poor condition in the alewife population, as temperatures were not as severe as previous winters (Bergstedt and O'Gorman 1989). In direct contrast, alewife collected prior to the severe winter of 1981-1982 were in good condition and, as a result, winter mortality was not severe (O'Gorman 1986). In contrast to gizzard shad energetics, fat reserves have been reported to play an important role in alewife survival during harsh winters and may be an effective tool for predicting mass die-off (Brown 1972; Colby 1973; Bergstedt and O'Gorman 1989).

Based on documented occurrences, mass mortality of menhaden appears most likely to result from either a sudden change in water quality or disease. Menhaden often travel in large schools which have the ability to quickly degrade oxygen concentrations when confined in small areas. Theories of mass menhaden mortality include large schools being chased into small confined embayments by predators such as bluefish and striped bass. The respiration of several hundred thousand menhaden in a small area could quickly consume available dissolved oxygen, leading to asphyxiation. Other sources of mass menhaden mortality include ulcerative mycosis disease, toxic dinoflagellates, and thermal shock as a result of power plant shutdown (Coutant 1977; Smith 1999).

Although predicting mass mortalities is often difficult and problematic, identifying symptoms of cold shock in fishes is well documented. Fish exposed to temperatures at or near lower tolerances exhibit a short period of increased swimming and hyperactivity, followed by decreased movements, a decrease in response, and finally loss of equilibrium, which is shortly followed by death (Coutant 1977). Cold stress in clupeids also leads to vulnerability to predation and power plant impingement. Several Southeastern power plants have documented high threadfin shad impingement coinciding with a substantial drop in temperature and mass natural mortality (Griffith and Tomljanovich 1975; Loar et al. 1978; McLean et al. 1985). Laboratory studies suggest the uncoordinated swimming of cold-stressed threadfin shad prevents escape from power plant intake structures (Griffith and Tomljanovich 1975).

3
LABORATORY STUDIES ON CRITICAL THERMAL LIMITS

Introduction

As noted in Chapter 2, high power plant impingement rates among clupeids have often coincided with observations of cold-stress-related reductions in swimming capabilities and mass mortalities in the nearby river and reservoir. Recognizing that naturally cold-stressed and moribund fish may contribute to high impingement counts, it is important to quantify the effects of low temperatures on clupeid behavior, physiology, and mortality. That is, to better understand the relationship between natural environmental conditions and impingement events we need a better understanding of the thermal tolerances of clupeids.

One traditional approach to quantifying temperature tolerance (both minimum and maximum) of fishes is the critical thermal methodology (CTM). The critical minimum temperature (CTMin) is defined as the pre-death lower thermal point at which locomotion becomes disorganized and a fish loses the ability to escape from conditions which may ultimately lead to its death. This method usually involves exposing fish to a constant linear decrease in temperature until loss of equilibrium (LOE) or another endpoint is reached. The CTMin is typically defined as the median temperature at which individuals in a group of fish began to exhibit LOE. CTMin is species-specific and is a function of acclimation temperature (Beitinger et al. 2000; Brett 1956; Elliot 1981), acclimation time (Doudoroff 1942), and rate of temperature decline (Gunter and Hildebrand 1951). Fish acclimated to higher temperatures typically have a higher CTMin and, conversely, fish acclimated to low temperature may have a lower CTMin. The effect of rate of temperature decline on CTMin is not as straightforward. It is generally accepted that, if the rate of decline is fast, there is little time for acclimation and the CTMin will be higher than at slower rates of decline where some acclimation occurs along the way. However, recent work with critical maximum temperatures suggest that slower rates of temperature increase can result in lowered CTMax because of a longer exposure time to temperatures above some threshold where thermal stress occurs (EPRI 2007). A similar relationship might also exist for CTMin.

A range of temperatures causing general distress, loss of equilibrium, and mortality have been reported for gizzard and threadfin shad (Griffith and Tomljanovich 1975; Cox and Coutant 1976; Neumann et al. 1977; Griffith 1978; Heidinger 1983; McLean et al. 1985). The variability in methods and reported responses makes it difficult to assess the contribution of environmental conditions to impingement at cooling water intake structures. The primary objective of this study was to determine the cold tolerance of gizzard and threadfin shad from a Tennessee reservoir during either gradual or immediate cold shock. A secondary objective that evolved during the study was to determine the ability of these species to recover after LOE.

Methods

Fish Collection and Care

Gizzard shad were collected in March 2006 and threadfin shad in September 2006 by electrofishing on the Clinch River, Tennessee. Live shad were transported to Oak Ridge National Laboratory in 151-L barrels filled with ambient river water, equipped with aerators, and treated with 400 g of sodium chloride. Shad were then held at 24°C for 3 to 5 d in 889-L circular tanks. Each tank was equipped with an aerator, and a constant 0.6 L/min flow through was maintained. Shad were acclimated to feeding on frozen brine shrimp and laboratory conditions during this period. Following the 3-5 d acclimation, test fish were transferred to a 530-L rectangular tank, receiving 0.25 L/min of flow.

Gradual Cold Shock and Subsequent Recovery

Test groups of 22 gizzard shad (mean total length = 143 mm, weight = 24 g) or 20 threadfin shad (mean total length = 128 mm, weight = 17 g) were placed in a 530-L rectangular tank and acclimated for one week at 15 ± 0.2°C prior to testing. Each group was then subjected to a cold shock at a declining rate of 0.5°C/hr until LOE. Portable chillers paired with temperature controllers were used to regulate exposure temperatures within ± 0.2°C. As tank temperature dropped, the time and temperature at which LOE occurred was recorded. Individuals within a test group exhibited LOE at different temperatures; we considered the CTMin to be the median temperature at which fish in a group lost equilibrium. Half of the fish were randomly assigned a holding period of 30 min in the cold shock tank after losing equilibrium before being placed in a recovery tank. The other half of the test group was transferred immediately after LOE to one of 12 recovery aquaria (30.5 cm^3) within a larger tank, which was the same size as the cold shock tank. The larger tank was filled to a depth of 17.8 cm to serve as a water bath and maintained at the same temperature as the cold shock tank. The 12 recovery aquaria were filled to a depth of 17.8 cm and equipped with a water supply and aerator. Individual fish were placed into an aquarium and water was dripped into the aquarium at ~25 mL/min to create a warming rate of about 1.0°C/hr. The initial aquarium temperature, time of recovery, aquarium temperature at recovery, weight, and length were recorded for each fish. If individuals regained equilibrium for more than 15 min, recovery was noted.

Instantaneous Cold Shock

A test group of 20 gizzard shad (mean total length = 143 mm, weight = 24 g) were placed in a 530-L rectangular tank and acclimated for one week at 15 ± 0.2°C prior to testing. Ten fish were plunged into a rectangular tank maintained at 4°C and another 10 fish into a tank maintained at 6°C. The tanks remained at these temperatures for the first 24 hr after which the tanks were allowed to warm at room temperature for the next 4 d. Time and temperature at which LOE occurred and recovery from LOE were recorded during the experiment if either occurred.

Results–Gizzard shad

Critical Thermal Minimum Determination and Recovery

Activity levels decreased as temperatures approached 5°C, and fish became totally lethargic by 4°C. Below 4°C there was little response to vibration in the water and capture by netting. The median LOE temperature for gizzard shad exposed to cold shock at 0.5°C/hr was 1.7°C and ranged from 1.0 to 2.7°C (Figure 3-1). All gizzard shad recovered as water warmed within recovery aquaria. On average, recovery occurred at 2.6°C, 0.8°C above the average LOE temperature.

Instantaneous Cold Shock

Gizzard shad plunged into the 6°C water bath did not lose equilibrium or die during the 5 d of testing. The 10 fish plunged into the 4°C water bath all experienced LOE during the 5 d period (Figure 3-2). Within the first 15 min of being transferred from the holding tank to the 4°C water bath, 8 of 10 had lost equilibrium. The remaining two fish experienced LOE during the 24-48 hr period. Two fish died on the third day of testing and one fish on the fourth day. The fact that the water warmed to 24°C (9°C higher than the acclimation temperature) during the recovery period may have contributed to the three mortalities. The seven remaining fish recovered (i.e., regained equilibrium) and survived the 5 d of testing.

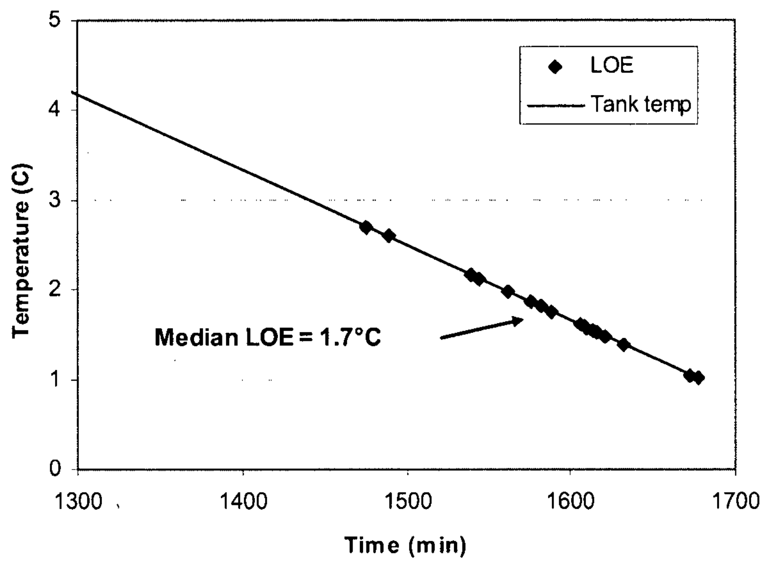


Figure 3-1
Time and temperature of LOE of 22 gizzard shad exposed to cold shock at a rate of 0.5°C/hr and acclimation temperature of 15°C.

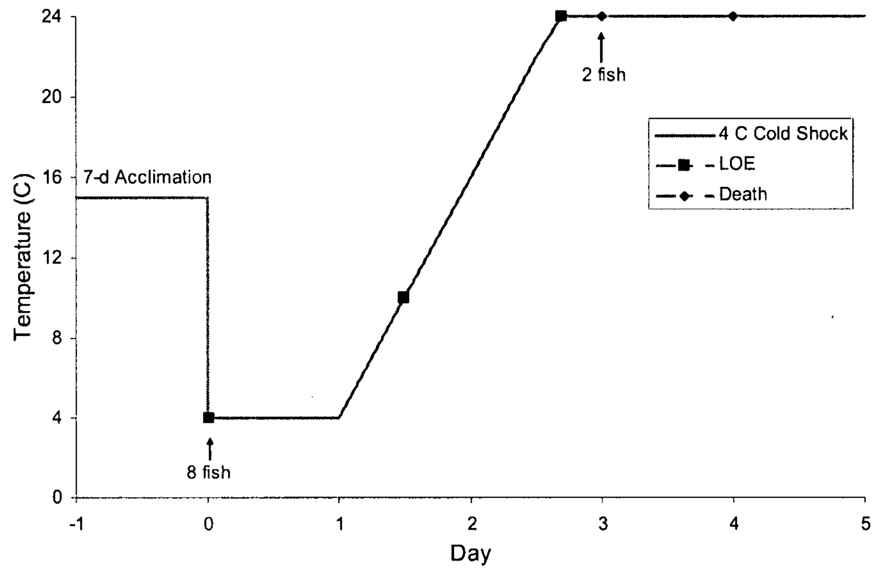


Figure 3-2
Time of LOE and death for 10 gizzard shad acclimated to 15ºC then plunged into 4ºC water bath for 24 hr and then warmed at room temperature over a 5-d period.

Results–Threadfin shad

Critical Thermal Minimum Determination and Recovery

Several anecdotal signs of distress were observed in threadfin shad during the cold shock treatment. Individuals began to swim out of sequence rather than in a school, often swimming into the side of the tank. Although the general activity level of these fish appeared to increase as temperatures decreased, there was little direct response to vibration and netting at 8.5°C. The median LOE temperature for threadfin shad exposed to cold shock at 0.5°C/hr was 4.8°C and ranged from 4.6 to 6.4°C (Figure 3-3). All threadfin shad recovered as water was warmed within the recovery aquaria. On average, recovery occurred at 7.5°C, 2.5°C above the average LOE temperature.

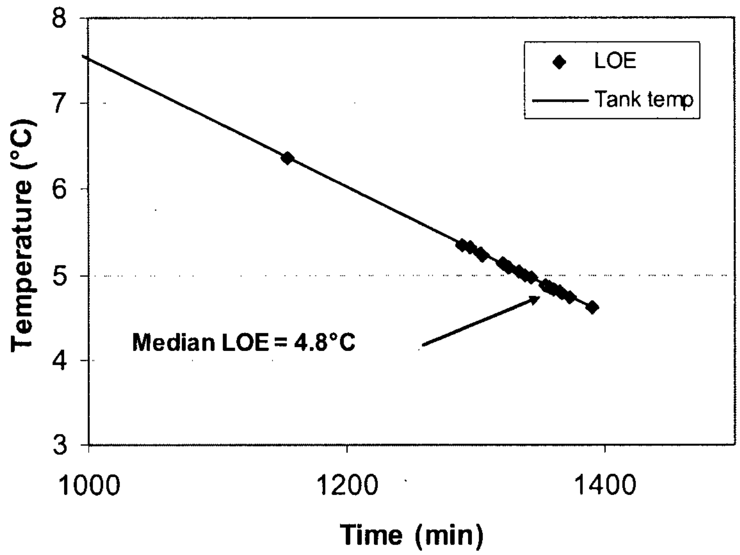


Figure 3-3
Time and temperature of LOE of 20 threadfin shad exposed to cold shock at a rate of 0.5°C/hr and acclimation temperature of 15°C.

Discussion

The CTMin value we determined for gizzard shad is consistent with those reported by others, with one exception. We found the CTMin for gizzard shad to be 1.7°C. Neumann et al. (1977) reported survival at temperatures below 1°C for a short period, and Heidinger (1983) suggested that mortality occurs in gizzard shad at temperatures between 0 and 4°C. Cox and Coutant (1976) performed acute cold shock testing with gizzard shad acclimated at 15°C and reported a CTMin of 6°C whereas we observed no LOE at that temperature when applying similar methods. The CTMin values for gizzard shad exposed to gradual cold shock and instantaneous cold shock varied. Gizzard shad exposed to acute cold shock experienced LOE at 4°C whereas LOE did not begin to occur until 2.7°C under gradual cold shock. Some individuals did not lose equilibrium until 1°C. Obviously, the rate of temperature change affects the CTMin of gizzard shad.

We found the CTMin for threadfin shad to be 4.8°C. Griffith (1978) found CTMin values for threadfin shad between 4 and 6°C with mortality of the least tolerant at low temperatures as high as 9°C and 100 % mortality by 4°C. Similarly, McLean et al. (1985) reported impingement of threadfin shad increased significantly when water temperatures dropped below 7°C. Threadfin shad were not exposed to instantaneous drops in temperature, therefore the relationship is still unclear for this species. However, Griffith (1978) reported a CTMin similar to ours for threadfin shad using a rate of change of 1.0°C/hr compared to our 0.5°C/hr.

Signs of behavioral distress during cold shock prior to LOE or death in threadfin shad have been reported by other investigators. Griffith (1978) found that threadfin shad exposed to acute temperature declines began showing signs of behavioral distress as much as 5°C higher than lethal temperature, and he observed a lack of response to movement and vibration at 6-7°C above lethal temperature. Griffith and Tomljanovich (1975) reported moribund threadfin shad exposed to 1-4°C temperature declines in 4 hr swam individually rather than in schools prior to LOE. These observations are consistent with the anecdotal signs of distress in gizzard and threadfin shad we observed.

Various acclimation temperatures were not tested to determine how the CTMin was affected for either species, although we know that CTMin generally declines with acclimation temperature to a point. Cox and Coutant (1976) reported that the timing of equilibrium loss for gizzard shad was a function of exposure and acclimation temperature. However, the variation in CTMin was less than 1°C at the three acclimation temperatures of 15, 17.5, and 20°C tested by Cox and Coutant (1976).

Threadfin and gizzard shad that experienced LOE under the gradual cold shock recovered when exposed to warmer water. We found 100 % survival regardless of the CTMin temperature for any given individual. However, we did not monitor long term survival, and we declared recovery if equilibrium was regained for greater than 15 min. Griffith (1978) also reported threadfin shad were capable of recovery if placed into water 3.0°C above an individual's CTMin but survival was not 100 %; fish with the lowest temperature tolerance had greater survival. The recovery ability of gizzard shad after reaching their CTMin has not been previously reported for comparison. However, gizzard shad are the more temperature tolerant species and would be expected to recover under colder conditions than threadfin shad.

In summary, the CTMin of gizzard shad appears to be between 1.5 and 4°C depending on the acclimation temperature and possibly other factors. Rate of temperature decline is an important factor when determining the CTMin for gizzard shad. Acute temperature drops yielded CTMin values several degrees warmer than those resulting from gradual cold stress. This is important considering that many natural die-offs are the result of strong cold fronts chilling water bodies quickly. Rates of change greater than 1.0°C/hr appear necessary to affect the CTMin of gizzard or threadfin shad. If water temperatures drop below 6°C, threadfin shad may begin to lose equilibrium, regardless of the rate of temperature decline. If temperatures drop below 3°C, gizzard shad may also become susceptible. These values can be used to make general rules about assigning the relative role of natural mortality during winter impingement events. Power plant managers should monitor water temperatures in the vicinity of water intakes for these critical limits. If critically low ambient water temperatures are imminent, the impingement of threadfin and gizzard shad might be reduced by altering plant operations.

This study has shown the importance of differentiating between moribund, impaired, and unimpaired fish relative to susceptibility to impingement. By definition, it is assumed that moribund fish would not recover and would die regardless of impingement, whereas impaired fish (such as those stressed by cold water temperatures in our experiment) would not necessarily die due to natural causes, but their condition may lead to death via impingement. Similarly, impaired shad are more susceptible than healthy shad to natural predation. As an analogy to natural predation, power plants could be considered selective predators that remove weak individuals from the population that would have been removed by natural predators. Several studies have related cold shock to increased predation rates in fish (Coutant et al. 1974; Coutant et al. 1976; Wolters and Coutant 1976). Best professional judgment of the permitting authorities (or future USEPA regulations for Phase II facilities) will apparently allow the estimation of impingement losses to account for moribund fish (EPA 2006). However, further scientific evidence would be useful to clarify the natural environmental fate of shad impaired by cold shock.

4
ASSESSING COLD SHOCK EFFECTS THROUGH PERFORMANCE AND PHYSIOLOGICAL RESPONSE

Introduction

In the NPDES permitting process for cooling water intake structures, best professional judgment of the permitting authorities (or future USEPA regulations for Phase II facilities) may allow the estimation of impingement losses to be corrected for moribund fish. Presently, moribund fish entering the intake are identified by observational or visual criteria. However, observation of general fish behavior as an indicator of prior impairment may be misleading; cold-stressed shad may increase their activity level, even though swimming is impaired and susceptibility to impingement is increased. Quantification of other parameters, such as the fish's physiological state or particular components of its behavior, may be useful techniques for evaluating the influence of natural environmental conditions on impingement.

Impingement likely increases when shad are subjected to temperatures that affect their physiological function and performance. Increased susceptibility to impingement occurs at some point above the LOE temperature for both gizzard shad and threadfin shad, and may be an indicator of natural mortality in the water body induced by cold shock. The premise for the studies reported in this chapter is that the level of acute and chronic cold stress prior to LOE can be quantified using physiological bioindicators, and that these stress responses are related to moribundity.

The use of plasma cortisol and chloride to quantify sub-lethal stress responses in fish is well established (Barton et al. 2002, Strange and Schreck 1978). White et al. (1986) used plasma cortisol and chloride to quantify stress response to cold shock in gizzard shad. Reduced ration has also been shown to affect natural mortality in gizzard shad (Adams et al.1985). Lipids are typically stored during periods of high food availability (summer and fall) and utilized during periods of low food availability or non-feeding periods (winter and early spring) (Adams 1999). The influence of feeding at cold temperatures and duration of starvation on susceptibility to impingement has not been investigated. Bodola (1966) reported that gizzard shad discontinued feeding at 11°C. Both gizzard and threadfin shad are lethargic during cold periods, but the energy demand to maintain physiological homeostasis continues, which requires the utilization of energy reserves if feeding has ceased. The physiological condition of fish, quantified using various bioindicators of nutrition, could reveal the role of ration in natural mortality. Hematocrit, triglycerides, and total protein have been used as general indicators of nutrition and starvation in fish (Adams et al. 1985, 1992; Barton et al. 2002). The condition factor (K), an index that relates weight and length, reflects energy storage and metabolism due to starvation (Dutil et al. 2003).

Swimming performance or endurance is a useful behavioral measurement for relating physiological condition to impingement. Griffith and Tomljanovich (1975) used swimming performance to determine the ability of cold-shocked threadfin shad to avoid impingement and found high impingement mortality below 8°C. Martinez et al. (2004) demonstrated that starved Atlantic cod (*Gadus morhua*) exhibited a reduced swimming endurance compared to cod that had been fed. However, the combined effects of reduced ration and cold shock on swimming performance have not been investigated.

The challenge for environmental managers and regulators is to determine whether fish impinged on intake screens would have died anyway because of natural environmental conditions. Bioassessment techniques can be used to reveal the effects of suboptimal environmental conditions on swimming performance and physiological state. When coupled with onsite observations of water temperatures, wind speed and direction, and fish condition, this performance and physiological response data may help explain the causes of impingement events. To assist in assessing the causes of impingement, a bioassessment tool or simplified procedure is required that can quantify the stress condition of gizzard and threadfin shad as they become vulnerable to impingement.

In this regard, the primary objectives of this study were to: 1) identify the critical points where cold shock and reduced ration affect the ability of gizzard and threadfin shad to escape impingement and 2) identify physiological and performance indicators that may indicate increased susceptibility of gizzard and threadfin shad to impingement.

Methods

Fish Collection and Care

Gizzard and threadfin shad were collected by electrofishing from August to October 2005 on the Clinch River, Tennessee. Water temperatures ranged from 20-28°C. Live shad were transported to Oak Ridge National Laboratory in 151-L barrels equipped with aerators and treated with 400 g of sodium chloride. Shad were then held at 24°C for 3 to 5 days in 889-L circular tanks. Each tank was equipped with an aerator and a constant 0.6 L/min through-flow was maintained. Shad were acclimated to feeding on frozen brine shrimp and laboratory conditions during this period.

General Methods

Following the 3-5 day acclimation, test fish were transferred to 530-L rectangular tanks receiving 0.25 L/min of flow in groups of either 34 gizzard shad (mean total length = 153 mm, weight = 30 g) or 45 threadfin shad (mean length = 134 mm, weight = 17 g) per tank. The number of individuals in each test group exceeded the number required for testing to allow for mortality during acclimation. Portable refrigeration units paired with temperature controllers were used to regulate exposure temperatures within ± 0.2°C. Each group was acclimated for one week at 15 ± 0.2°C prior to testing in one of two general treatments, either cold shock alone or a combination of reduced ration with cold shock. The protocol used for the two experiments is illustrated in Figure 4-1. A single test group for each experiment was repeated for each species.

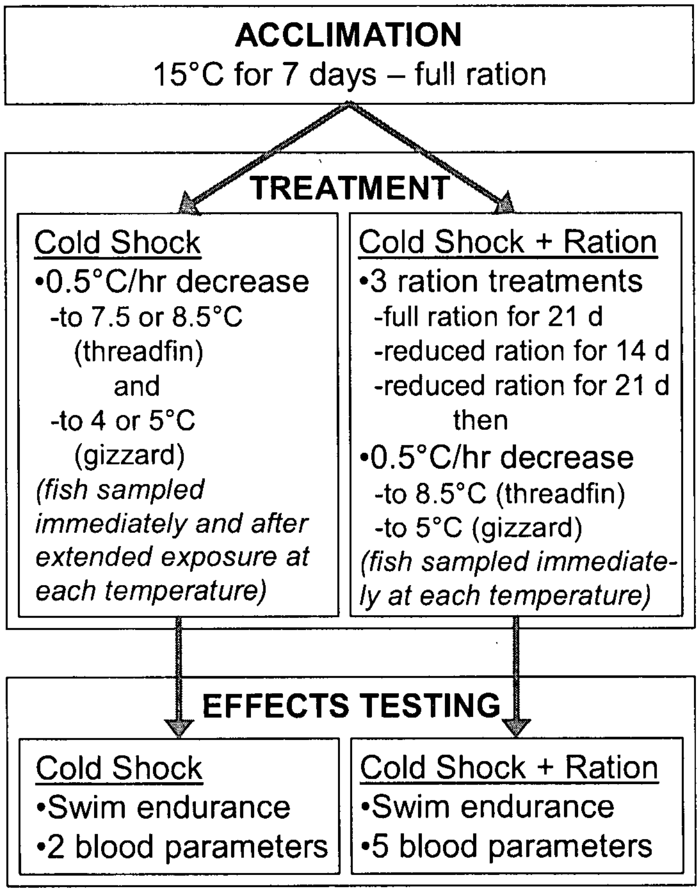


Figure 4-1
Summary of the protocol used during cold shock and reduced ration experiments.

At the time of testing, 18 gizzard or 24 threadfin shad were removed from their exposure tanks for blood collection. Shad were quickly removed from the exposure tanks with small dip nets to minimize handling stress and immediately anesthetized with tricaine methanesulfonate (MS-222). Three shad were removed at a time and bled within 2 to 4 min of being placed in MS-222. Fish were bled using 21G1 Vacutainer™ needles paired with 13 X 75 mm heparinized Kendall™ collection tubes. Total length (mm) and weight (g) were measured for each individual. Within a test, blood samples were randomly pooled, due to the low volume of serum derived from individuals, to form 6 pooled groups of 3 gizzard or 4 threadfin shad for each treatment. Threadfin shad were smaller than gizzard shad so more individuals were needed per pooled group. Hematocrit was measured for each pooled sample. Plasma was separated from whole blood by centrifugation, transferred to 1.5-mL cryotubes, and stored in liquid nitrogen until analysis. Plasma cortisol concentration was determined via Coat-A-Count® solid-phase 125I-cortisol radioimmunoassay. Plasma chloride was determined using a spectrophotometric assay by Pointe Scientific™.

For swimming performance tests, 10 gizzard or threadfin shad were removed from treatment tanks (the same tanks from which the fish to be bled were taken) and placed into the corral area of the swimming performance (test) channel (Figure 4-2). The dimensions of the test channel and methods of the test allowed 5 fish to be tested simultaneously. The test channel was maintained at the target temperature using portable refrigeration units. The flow (~0.15 m/s) in the test channel was produced by a ¾ horsepower centrifugal pump. Water was pumped from the corral zone and introduced to the upper end of the test channel through a series of increasing-diameter pipes and a 0.32-cm mesh screen to even the flow distribution within the test zone of the channel. The performance test channel was 10.8 cm wide X 122 cm long. Water depth was held at 14.6 cm. The power to the pump was surged 3-4 times to allow the fish to orient upstream and gain swimming balance prior to initiating full flow velocity.

Each individual was observed during a maximum period of 1 hr to determine if impingement occurred at the rear screen for > 15 s. Impinged fish were removed immediately, and total swim time (≤ 1 hr), total length (mm), and weight (g) of each individual were recorded. Condition factor (weight / ($length^3$) * 1000) was calculated for individuals.

Statistical analyses on all data were performed using SAS, version 9.1, and SPSS, version 14. A value of $P < 0.05$ was considered significant for all tests and simultaneous confidence was held at $P = 0.05$ for all *post hoc* tests. Correlations between variables were investigated using Pearson correlation coefficients. Differences between test groups in swimming performance and physiological indicators were analyzed with analysis of variance (ANOVA). The Shapiro-Wilk statistic was used to test the assumption of normally distributed errors. If data were not normal, a natural log transformation of the dependent variable or ranked data was used in the ANOVA. Homogeneity of variance between treatments was assessed with Levene's test. If significant differences in mean values were indicated by the ANOVA F test, paired means were evaluated using the least significant difference (LSD) test. Dunnett's mean separation test for unequal group variances was used when heterogeneous group variances exceeded a 3-fold difference between any treatment pair (van Belle 2002).

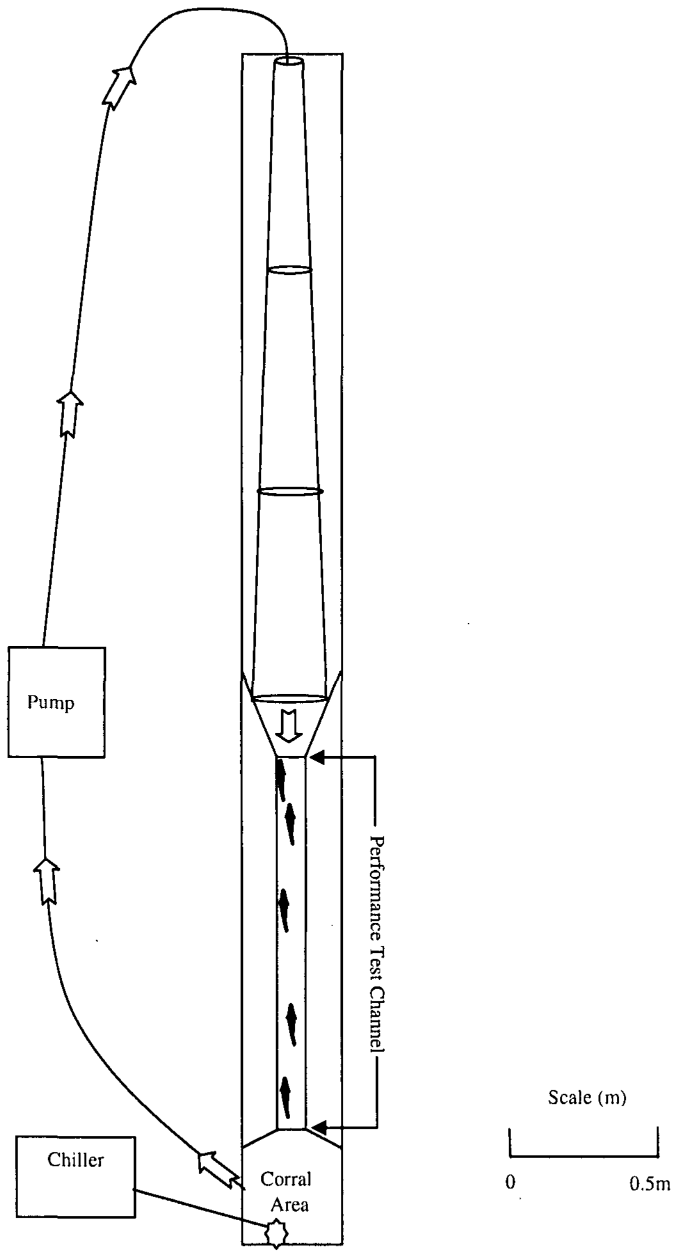


Figure 4-2
Schematic of the swimming performance channel (top view).

Experiment 1. Effects of Cold Shock on Swimming Performance and Physiological Condition

The CTMin results reported in Chapter 3 were used to determine the cold shock treatment temperatures for the swimming performance and physiological state experiments (Fost 2006). Cold shock was induced by decreasing temperature at 0.5°C/hr starting at the acclimation temperature of 15°C and concluding at one of two target temperatures, either 4 or 5°C. We also tested gizzard shad that were held for an additional 6 hr after reaching the target temperatures to determine the effect of extended or prolonged exposure at those temperatures. We expected that extended exposure at a stressful temperature would either increase the level of thermal stress and be apparent in the bioindicators or, alternatively, provide some level of acclimation resulting in a less stressful response. Figure 4-3 illustrates the four different thermal scenarios tested for each species (plus 15°C controls).

We repeated one treatment for each species to evaluate experiment repeatability and determine if any changes occurred over the period of time fish collections were being made. The 5°C gizzard shad test group was repeated 4 weeks after the initial tests, and results were compared to the initial test group of the same thermal regime.

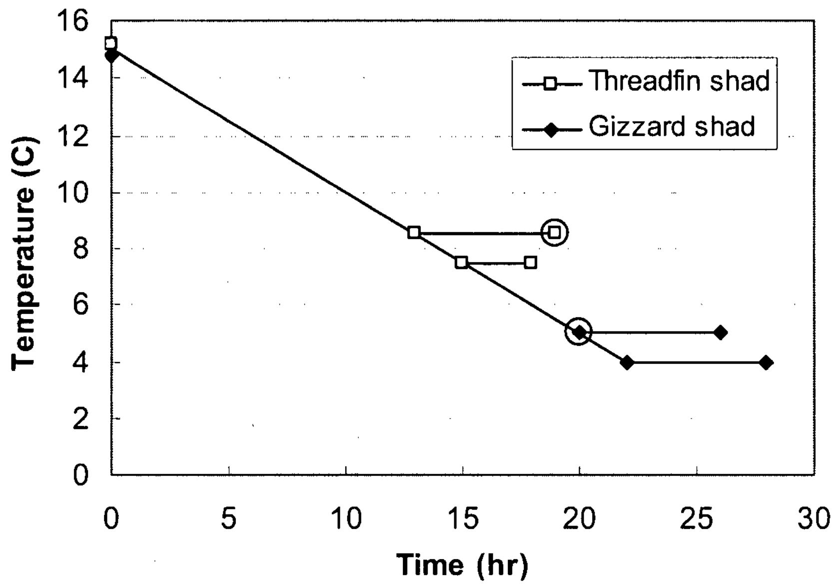


Figure 4-3
Thermal scenarios tested (lines) with points of sampling for both threadfin shad (n=24 at each square) and gizzard shad (n=18 gizzard shad at each diamond). Repeated trials are indicated by open circles.

Cold shock experimentation with threadfin shad was the same as that for gizzard shad except that target temperatures were 7.5° and 8.5°C (Figure 4-3). Two groups of threadfin shad were held for extended exposure at 8.5°C (6 hr) and 7.5°C (3 hr) after the initial temperature decline. We repeated the 8.5°C extended treatment 3 weeks after the initial test and the results were averaged with the initial treatment used for comparison. Controls for both species were sampled at the acclimation temperature of 15°C.

Fish were monitored for abnormal behavior or signs of distress during the cold exposure. Plasma cortisol (ng/mL) and chloride (mEq/L) levels in each pooled group were measured to determine acute stress response to the test temperatures. Swim tests were also performed on the same pool of fish but not the same fish to determine if swimming performance was related to physiological condition. Condition factor was calculated for each individual to determine if swimming performance was also correlated with condition.

Experiment 2. Effects of Combined Cold Shock and Reduced Ration on Swimming Performance and Physiological Condition

Each test group was fed a reduced ration of 0.5 % of their mass in frozen brine shrimp for 14 and 21 days. Following these 14 and 21 d feeding periods, the control groups were fed 5 % of their mass in frozen brine shrimp for 14 days. Gizzard shad were cold shocked to a temperature of 5°C and threadfin shad to a temperature of 8.5°C at a rate of 0.5°C/hr from 15°C. The entire 21-day reduced ration group was repeated 24 hr after the initial for each species and the results were averaged with the initial treatments for comparison. The test groups were observed for changes in swimming activity during the reduced ration period.

Following the reduced ration period and cold shock treatment, blood was withdrawn, and total length (mm) and weight (g) were measured for each individual. We measured plasma cortisol (ng/mL), chloride (mEq/L), total protein (mg/dL), triglycerides (mg/dL), and hematocrit (%) level in each pooled group. Total protein and triglycerides were determined using a centrifugal fast analyzer (Cobas brand). A separate group of fish from the same treatment tank was tested for swimming endurance.

In March 2006 we collected additional fish from the field to determine if the nutritional status of laboratory shad after 14 or 21 days of reduced ration was similar to that found in fish collected from the reservoir in late winter.

Results

Effects of Cold Shock on Swimming Performance and Physiological Condition

Gizzard Shad–

- As in the experiments in Chapter 3, we observed signs of distress (abnormal behavior) during the gizzard shad cold shock treatments. Activity levels decreased as temperatures approached 5°C and fish became totally lethargic (but upright) by 4°C. There was little startle response to vibration in the water and netting at 4°C.
- In swimming performance tests, cold-shocked gizzard shad had significantly lower mean swimming times for all treatment groups than the control (P=0.005; Figure 4-4). Mean swimming time was less in gizzard shad cold shocked to 4°C than to 5°C. Swimming performance of gizzard shad in extended test groups (referred to henceforth as '4°C Ext' and '5°C Ext') was not different statistically from fish sampled immediately upon reaching the temperature, but the pattern of decreased endurance with increased exposure to cold was consistent with the overall trend.
- Mean condition factor was not different among test groups and there was no correlation between condition factor and mean swimming performance for gizzard shad.

- Cold shock affected cortisol and chloride ($P<0.001$) levels in gizzard shad. Mean plasma cortisol and chloride were significantly higher in all cold shocked groups compared to controls (Figure 4-4). Mean plasma cortisol was highest for the two treatments at 4°C (the lowest temperature tested), but mean plasma chloride did not differ among cold shock treatments.
- There was not a significant correlation between swimming performance and either cortisol ($R^2=0.62$; $p=0.11$) or chloride ($R^2=0.56$; $p=0.14$; Figure 4-5).

Threadfin Shad—

- As in the experiments in Chapter 3, we observed signs of distress in threadfin shad during the cold shock treatments at temperatures 2-3°C above the LOE. Individuals began to swim out of sequence rather than in a school, often swimming into the side of the tank. The activity level of these fish appeared to increase as temperatures decreased. There was little response to vibration and netting at 8.5°C and below.
- Cold shock had a significant effect on swimming performance of threadfin shad ($P<0.01$). As with gizzard shad, the results show a clear trend of decreasing swim endurance with increasing exposure to cold (Figure 4-4).
- Mean condition factor did not differ among test groups, and, like gizzard shad, there was no correlation between condition factor and mean swimming performance for threadfin shad.
- Mean plasma cortisol was significantly lower in three of the four threadfin shad test groups compared to the control ($P<0.001$; Figure 4-4). Plasma cortisol levels for the 7.5°C Ext test group were significantly lower than those sampled immediately (Figure 4-4).
- We found no correlation between swimming performance and cortisol ($R^2=0.28$; $p=0.27$) or chloride ($R^2=0.0004$; $p=0.975$; Figure 4-5). Mean plasma chloride was significantly different from the control for only two treatments, the 8.5°C Ext and the 7.5°C Ext ($P<0.005$; Figure 4-4). The 7.5°C test group had the lowest mean chloride among the test groups (Figure 4-4).

Repeated Treatments for both Species—The gizzard shad repeated treatment did not differ from the initial group in swimming performance or mean chloride but did differ in mean cortisol (Table 4-1). The threadfin shad repeated treatment had a significantly longer mean swimming performance and lower mean cortisol compared to the initial group but no difference in mean chloride (Table 4-1).

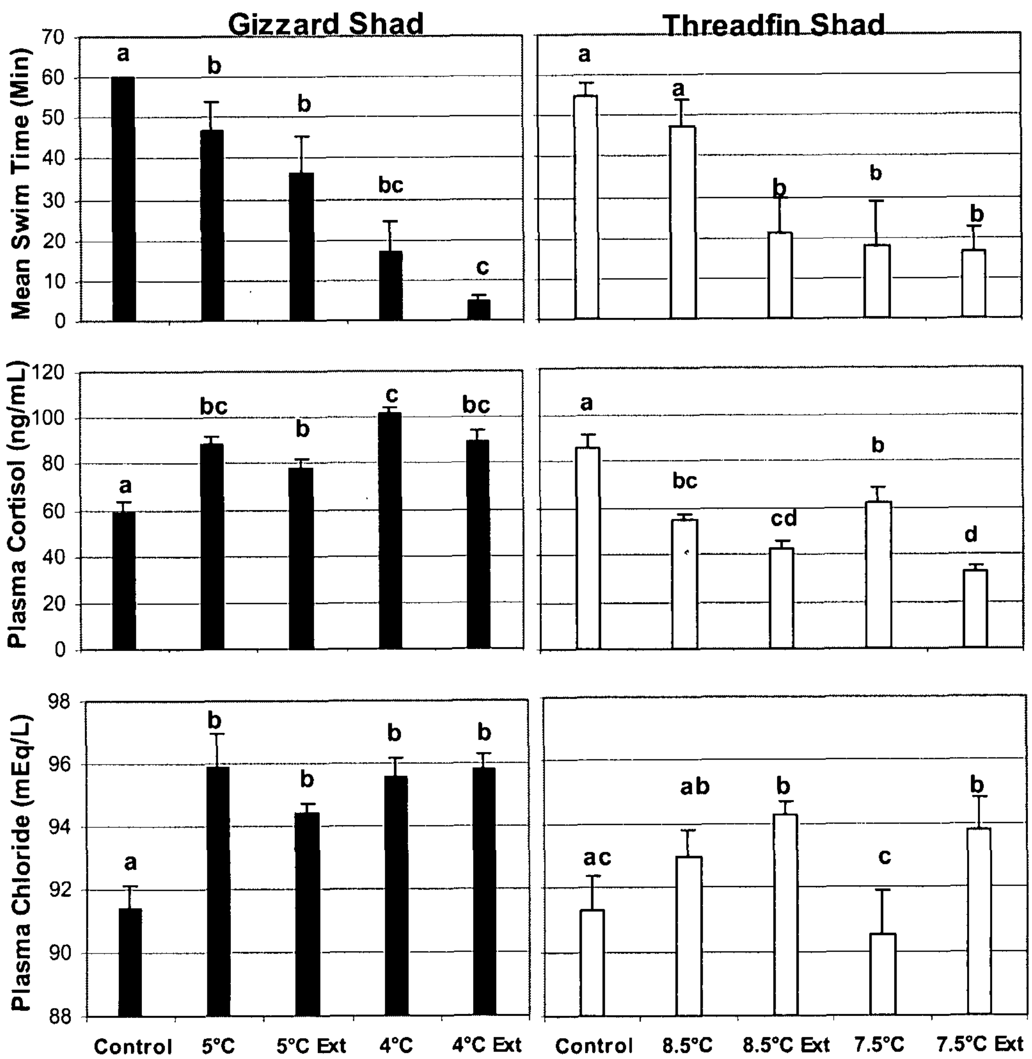
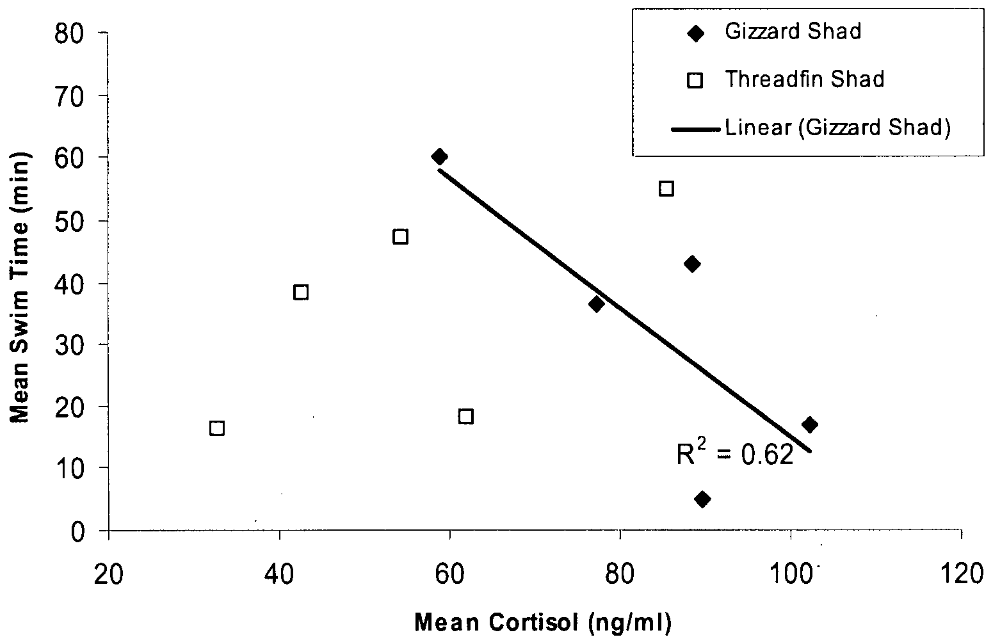


Figure 4-4
Mean (+1 SE) swimming time, plasma cortisol, and plasma chloride of gizzard and threadfin shad exposed to cold shock treatment beginning at 15°C and declining at a rate of 0.5°C/hr to the test temperature. Gizzard shad were tested at 15°C (control), 5°C, after 6 hr at 5°C (5°C Ext), 4°C, and after 6 hr at 4°C (4°C Ext). Threadfin shad were tested at 15°C (control), 8.5°C, 8.5°C + 6 hr (8.5°C Ext), 7.5°C, and 7.5°C + 3 hr (7.5°C Ext). Treatments that are statistically different ($P < 0.05$) have different letters.



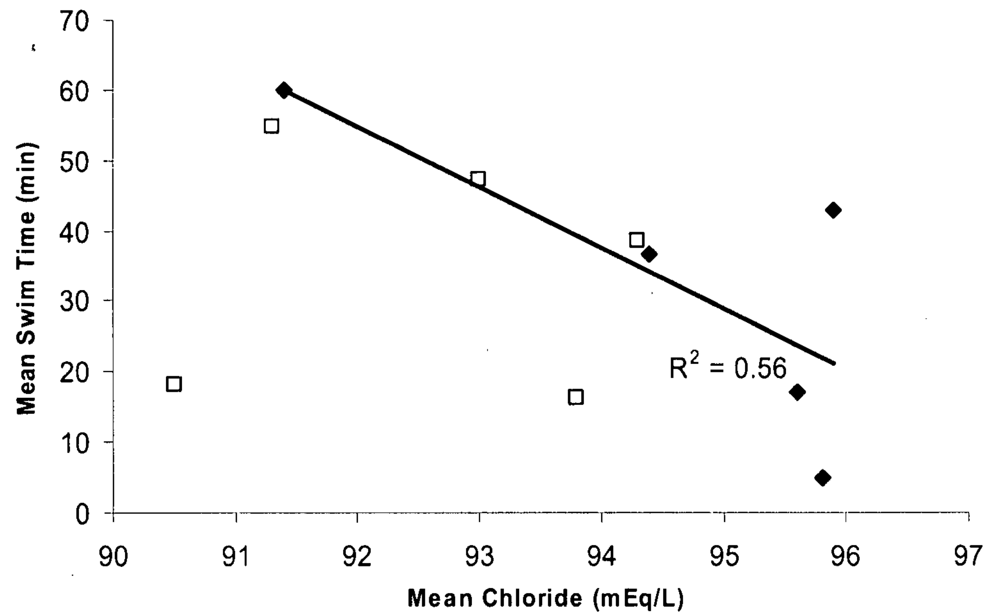


Figure 4-5
Linear correlations of mean cortisol and mean chloride to mean swim time of gizzard and threadfin shad.

Table 4-1
A comparison of several stress indicators (means) for original and repeated test groups of gizzard and threadfin shad. The 5°C test group (cold shock) and the 21 d test group (reduced ration and cold shock) were repeated with gizzard shad. The 8.5°C Ext test group (cold shock) and the 21 d test group (reduced ration and cold shock) were repeated with threadfin shad. Significant differences (P < 0.05) between means are indicated by asterisks.

Dependent Variables (test group repeated)	Original Treatment	Repeat Treatment	P value
Cold Shock			
Gizzard Shad (5°C test group)			
Swim Time (min)	42.33	43.60	0.9382
Cortisol (mEq/L)	88.60	69.52	<0.0001*
Chloride (ng/ml)	95.92	93.90	0.0871
Threadfin Shad (8.5°C Ext test group)			
Swim Time	22.32	54.56	0.0049*
Cortisol	42.63	21.64	0.0001*
Chloride	94.28	94.25	0.9568
Reduced Ration + Cold Shock			
Gizzard Shad (21 d test group)			
Swim Time	60.00	37.85	0.0250*
Cortisol	93.95	71.08	<0.0001*
Chloride	96.50	96.23	0.8498
Total Protein (mg/Dl)	95.83	97.50	0.4605
Triglycerides (mg/Dl)	83.42	81.42	0.5877
Hematocrit (%)	21.33	21.00	0.3960
Condition Factor	8.64	8.35	0.8743
Threadfin Shad (21 d test group)			
Swim Time	51.28	55.40	0.3722
Cortisol	44.54	50.51	0.0400*
Chloride	93.42	91.44	0.1453
Total Protein	70.00	72.50	0.1670
Triglycerides	27.00	45.08	0.0008*
Hematocrit	15.67	16.00	0.2891
Condition Factor	7.24	7.21	0.1248

Effects of Combined Cold Shock and Reduced Ration on Swimming Performance and Physiological Condition

Gizzard Shad–

- Gizzard shad generally remained active during the treatment periods (14 or 21 d) of reduced ration.

- Groups fed a reduced ration did not have significantly different mean swimming performance after cold shock than fish fed a full ration (P=0.69; Figure 4-6). A treatment effect of reduced ration was observed for both cortisol and chloride (P<0.001).
- Mean cortisol for the 14-d reduced ration group was higher than both the 21-d reduced ration group and control (Figure 4-6, Table 4-2).
- Mean plasma chloride values for both reduced ration groups were lower than the control.
- Treatment effects were also observed in total protein (P<0.01), triglycerides (P<0.0001), and condition factor (P<0.01; Figure 4-7).
- Mean plasma total protein was significantly higher in the 21-d reduced-ration group than the 14-d reduced-ration group.
- Mean plasma triglycerides decreased between 14 and 21 d of reduced ration.
- Mean condition factor was lower in the 21-d group than control.
- Gizzard shad collected in March of 2006 had lower mean condition (K=7.4) than fall-collected fish held in the laboratory for 21-d of reduced ration (K=8.1).

Threadfin Shad—

- Threadfin shad schooled and remained active during the reduced-ration test period.
- Groups fed a reduced ration did not have significantly different swimming performance compared to controls (P=0.61; Figure 4-6).
- Treatment effects were not found with cortisol (P=0.60) or chloride (P=0.08; Figure 4-6).
- Treatment effects were observed for total protein (P=0.0001), triglycerides (P<0.0001), hematocrit (P<0.0001), and condition factor (P<0.01; Figure 4-7).
- Total protein was significantly lower in the reduced ration groups, but there was no difference between the two reduced ration groups.
- Triglycerides were significantly higher in the 14-d reduced-ration group than controls and 21-d reduced-ration group.
- Hematocrit was significantly lower in both reduced ration groups than the control with those held longest (21-d group) having the lowest hematocrit.
- Condition factor was lower in the 21-d reduced-ration group than the 14-d group or control, which were not different.
- As with gizzard shad, threadfin shad collected in March of 2006 had lower mean condition (K=6.7) than fall-collected fish after 21-d of reduced-ration (K=6.9).

Repeated Treatments for both Species—Mean swimming performance and mean cortisol were significantly lower in the repeated 21-d reduced ration group of gizzard shad compared to the initial 21-day reduced ration group (Table 4-1). No other differences were found between the repeated and initial group of gizzard shad. Higher mean cortisol and lower mean triglycerides were the only differences between the repeated and initial 21-d reduced ration groups of threadfin shad.

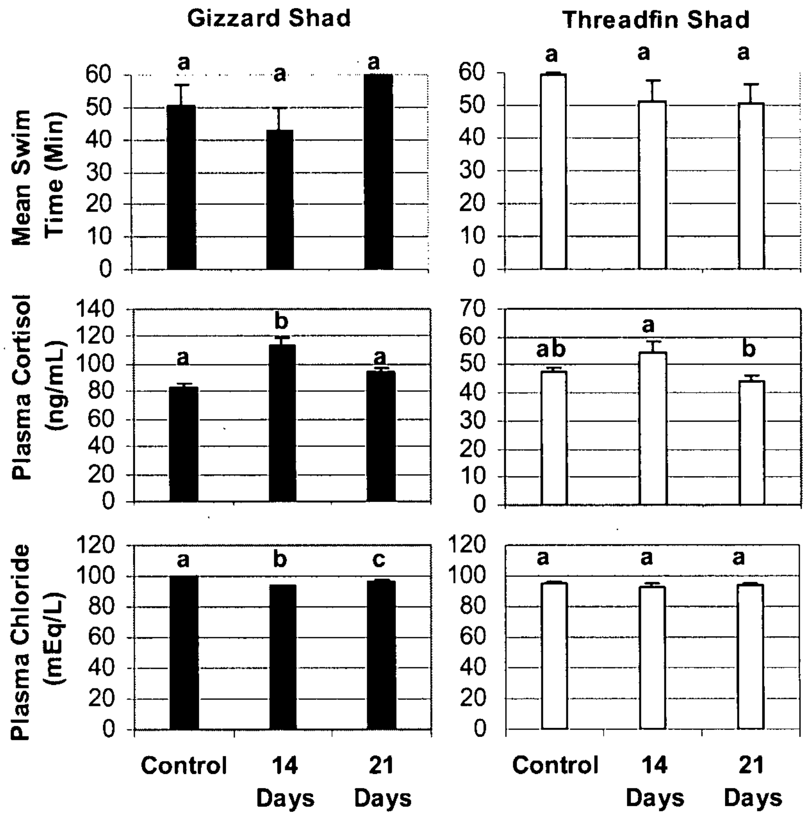


Figure 4-6
Mean (+1 SE) swimming time, plasma cortisol, and plasma chloride of gizzard and threadfin shad exposed to cold shock after one of three protocols: 14 d of full ration, 14 d of reduced ration, or 21 d of reduced ration. Treatments that are statistically different ($P<0.05$) have different letters.

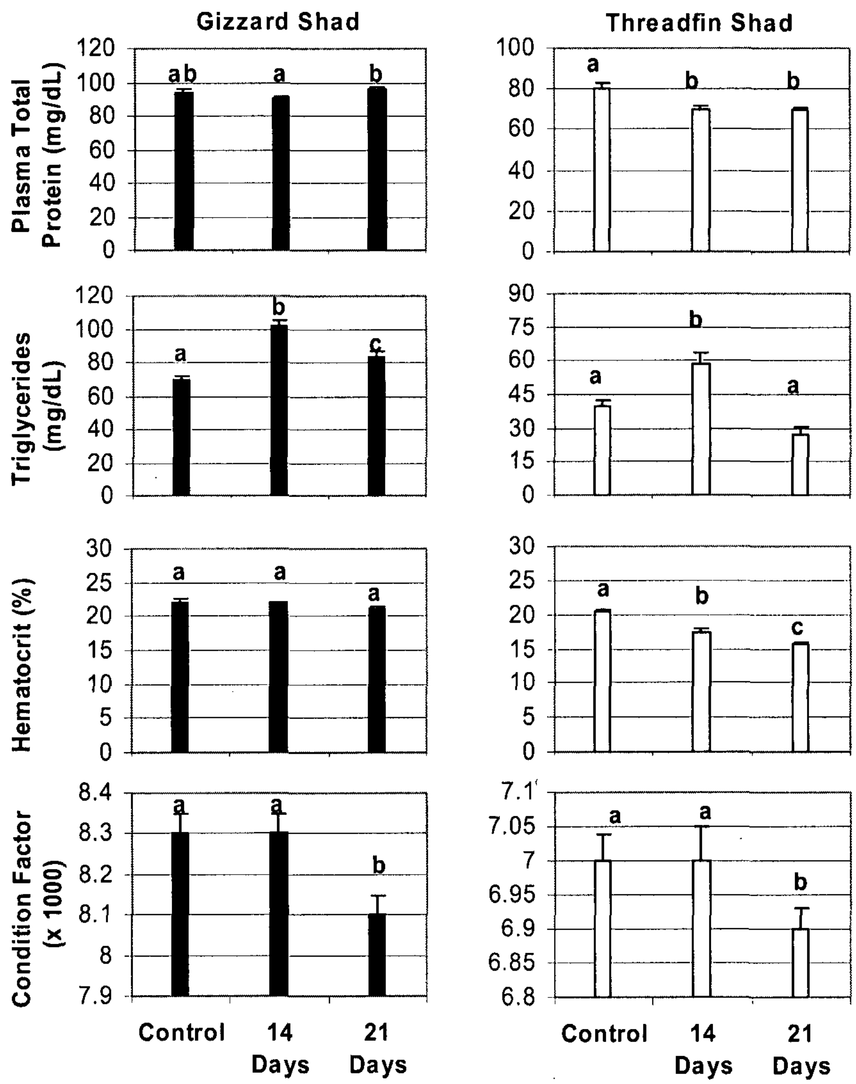


Figure 4-7
Mean (+1 SE) condition factor, hematocrit, plasma total protein, and plasma triglycerides of gizzard and threadfin shad exposed to cold shock after one of three ration treatments: 14 d of full ration, 14 d of reduced ration, or 21 d of reduced ration. Treatments that are statistically different (P<0.05) have different letters.

Discussion

The responses of gizzard and threadfin shad to cold shock alone and to a combination of starvation and cold shock were measured to gain insight into various factors that may contribute to impingement of these species at CWIS. Swimming endurance, cortisol, and chloride levels of gizzard shad and threadfin shad all responded to cold shock treatment, though not always as expected.

Swimming endurance of gizzard shad acclimated to 15°C was reduced at water temperatures of 4 to 5°C, suggesting that susceptibility to impingement likely increases at these temperatures and below. For threadfin shad, we did not find a statistically significant decrease in endurance at 8.5°C, but that appears to be the point below which we are likely to see effects. Significant effects were observed at a test exposure temperature of 7.5°C. Similarly, Griffith and Tomljanovich (1975) showed that the ability of threadfin shad to resist impingement was severely impaired at temperatures below 8°C, but at higher temperatures impingement was slightly or not at all impaired. The temperature at which threadfin shad were affected was warmer than for gizzard shad, making them more susceptible to cold-stress-related impingement when the two occur in the same water body. It is worth noting that most of the shad used in the control trials were able to sustain swimming for the maximum period of 60 min at a velocity of 0.5 ft/s, which is the velocity often used as design criteria for cooling water intake screens.

Cortisol was expected to increase as a response to cold-shock-induced stress, which has been observed in similar studies. Hyvarinen et al. (2004) found increasing cortisol levels when brown trout were cold shocked in an ice bath. In this study, we found the expected response for gizzard shad, but for threadfin shad, we found the opposite response. This may be due to a reduced ability of threadfin shad to mount a stress response under abnormally cold temperatures, as was reported by Strange (1980) for channel catfish. Davis (2004) also showed that fish held at colder temperatures had delayed responses in cortisol (and chloride) in comparison to those fish held at warmer temperatures. Alternatively, the lack of a statistically significant response by threadfin shad could be the result of the control group experiencing unknown stressors such as reduced water quality or handling effects that also elevated cortisol levels. The cortisol levels in the control groups for both species were higher than resting values reported for most fish species (0-50 ng/mL; Davis 2004); however, no published research involving shad cortisol levels was found for comparison. Because the control group had abnormally higher levels of cortisol compared to reported resting levels for other species, we suspect that the presence of an unknown stressor is the most likely explanation for the threadfin shad outcome.

Chloride levels in fish typically decline in response to a stressor. For example, Miles et al. (1974) observed decreases in plasma chloride in muskellunge (*Esox masquinongy*) resulting from capture and handling. However, we found in this experiment that levels usually increased with cold shock. Baseline chloride values were lower in all groups than those typically reported for unstressed fish (100-130 mEq/L; Barton et al. 2002). As with cortisol, there may have been an unaccounted for stressor that affected the fish while held in the laboratory. Additionally, the acclimation period of one week at 15°C may not have been sufficient to stabilize osmoregulatory function in this species, or perhaps laboratory confinement was more stressful for these species than those species tested by other investigators.

One objective of this study was to find indicators of susceptibility to impingement. We compared the bioindicator responses to swimming endurance and found cortisol and chloride in gizzard shad to be negatively correlated with endurance, which suggests that either of these could be potential indicators of susceptibility to impingement. In most species, chloride changes are the inverse of cortisol (Davis 2004), but in this case chloride response tracked that of cortisol. Johansen et al. (1994) found that when cortisol levels of rainbow trout increased above resting levels due to a stressor (toxicant), swimming performance decreased.

Prolonged exposure at cold temperatures seemed to worsen the effect on swimming endurance for both species,. With extended exposure of 3-6 hr at a test temperature, we found no evidence of additional stress in cortisol and chloride measures. To the contrary, based on cortisol in gizzard shad and both cortisol and chloride in threadfin shad, there appeared to be acclimation or recovery from stress. Strange (1980) showed that channel catfish became acclimated to stress after several days and cortisol subsequently declined. Similarly, Strange and Schreck (1978) showed that cortisol levels in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) began to decrease 3.5 hr after a stressor was presented and removed.

Compromised nutritional status as a result of several weeks or months of reduced food availability has been correlated with impingement of fish in late winter and early spring (Adams et al. 1985). Previous studies on a variety of fish species indicated that swimming performance, total protein, triglycerides, hematocrit, and condition factor would decline as the duration of the starvation increased. Martinez et al. (2004) demonstrated that starved Atlantic cod (*Gadus morhua*) had reduced swimming performance compared to cod that were fed. McMillan and Houlihan (1991) reported rainbow trout having reduced serum total protein after several days of fasting. Ruane et al. (2002) compared triglyceride levels in common carp (*Cyprinus carpio*) fed different rations and found a direct relationship between triglyceride and ration. Adams et al. (1985) reported lower hematocrit and condition factor levels in stressed gizzard shad compared to unstressed shad. In our study, gizzard and threadfin shad showed little response in swimming endurance or in the short-term stress indicators (cortisol and chloride) after 14 and 21 d of reduced ration followed by cold shock. The treatments did result in lowered condition factor and lowered blood hematocrit levels. We did not find a relationship between swimming endurance and any of the physiological indicators that was common between the two species. Either the lack of feeding had no effect on the stress response or the period of starvation was not long enough to cause an observed affect. Since these species typically experience periods of low food availability in winter, possible adaptation to periods of reduced feeding could occur, therefore helping to explain, in part, the lack of a clear response in the lab to reduced ration.

To better understand the implications of reduced ration under natural conditions, we collected gizzard and threadfin shad from the Clinch River in March 2006 after a winter period when feeding was greatly reduced. These fish had significantly lower condition factors, (7.4 for gizzard and 6.7 for threadfin shad) than those we had collected during the summer and held for 21 d under reduced ration (8.1 for gizzard and 6.9 for threadfin shad). Therefore, even though the reduced ration period of 21 d in the laboratory resulted in poorer condition compared to controls, condition of fish in the lab did not quite approximate that of shad collected from the reservoir in late winter. If the condition of fish in the lab had been similar to that of shad collected in the field in late winter, greater declines in nutritional status indicators and swimming performance may have occurred in those fish subjected to cold shock treatment. Changes in hematocrit and condition factor were significant in threadfin shad but not gizzard shad after 21 d of reduced ration. This differential response between species is possibly due to gizzard shad storing proportionately greater amounts of lipids than threadfin shad (Adams 1999).

Hematocrit and condition factor are relatively simple indicators that could be used in the field to rapidly determine susceptibility to impingement. These are the types of rapid assessment indicators that might be used to detect impairment of fish prior to impingement. The applicability of these measures and other easily and rapidly applied indicators of susceptibility could be further assessed by investigating physiology and swimming performance of shad whose condition replicates the condition of shad collected from the water body in late winter. Such laboratory studies could define the relationships between environmental stresses (cold shock or starvation) and responses of individual fish (e.g., hematocrit and condition) and subsequent changes in swimming performance and susceptibility to impingement. Once the relationships are established, field studies could be designed to predict the potential for large impingement events based on measurements of environmental or physiological state.

The overall results of this study indicate that rapid declines in temperature and cold temperatures, particularly those slightly above the temperatures of LOE, would render gizzard and threadfin shad more susceptible to impingement. Potential indicators of susceptibility to impingement have been identified in this study (e.g., hematocrit and condition factor) and could be performed on fish in the vicinity of intake structures as a preliminary assessment of the applicability of this assessment technique. The use of multiple indicators of stress helps detect and account for confounding stressors which may be present in natural ecosystems.

Using physiological and performance-level indicators to assess impingement susceptibility appears promising, but further studies are necessary to evaluate the relative importance of varying cold shock regimes and nutritional status to impingement susceptibility. More testing is needed for both species on the effects of:

- rate of temperature decline relative to the acclimation temperature,
- lower acclimation temperatures relative to the cold shock test temperatures, and
- a longer acclimation period prior to testing.

Further research addressing the role and importance of nutritional status on impingement susceptibility should include:

- longer starvation periods using fish collected in late winter,
- combining several different cold shock temperatures with the reduced ration treatment, and
- analysis of the physiological recovery of fish held under reduced ration and cold shocked.

This type of information would clarify the relationship between physiological indicators and susceptibility to impingement and increase capability for predicting and assessing impingement mortality.

5
SUMMARY

Summary of Results

The literature on mass mortalities of clupeid species reveals that such events are common, especially in larger freshwater lakes, rivers and reservoirs, and brackish and marine embayments. The principal reasons for such die-offs often vary among species. Research into the causes of this mortality as well as the general physiological responses of clupeids to potential environmental stressors is limited.

More reports on gizzard shad die-offs were found than for the other clupeid species, though this does not necessarily mean this species is affected more often or is more susceptible. Accompanying studies often provided detailed information on the physiological response of gizzard shad to thermal stress and provided clues to link mass mortalities to cold stress. Researchers found that the amount of stored lipids appears to play a role in determining winter kill of several clupeid species, but that parameter in itself is not an effective means of determining cold stress mortality in gizzard shad. Alewife die-offs seemed to be linked to severe winters, but there also appears to be a density-related factor. For example, greater mortality has been observed in a less-severe winter when population density was high than in a severe winter with lower alewife densities. Threadfin shad are native to the southern United States, but have been introduced as a forage base to many higher latitude states where they commonly suffer winter mortality. The inability to survive the winter in some locales has been used as a benefit by fisheries biologists trying to better control managed fish populations. Although mortalities are often severe following adverse conditions, this species has the ability to quickly repopulate a water body (McLean et al. 1980). Mass menhaden mortality appears most likely a result of a sudden change in water quality or disease.

An underlying hypothesis of the laboratory experiments presented in this report is that fish that become impinged represent a portion of the population that is in some way compromised or weaker than individuals that are not impinged. Our studies were not designed to identify the survivors or the fit individuals, but to better understand the lack of fitness of those that are most susceptible to impingement.

In studies on lower critical thermal limits, we found that threadfin shad acclimated at 15°C began to exhibit loss of equilibrium at 6.0°C, with a CTMin (median LOE) of 4.8°C. The first gizzard shad to lose equilibrium occurred at a lower temperature, 2.7°C, with a CTMin of 1.8°C. Shad acclimated to temperatures <15°C would probably have slightly lower CTMins, and exposure to a different rate of temperature change would also have an effect on the CTMin. To investigate the response to the most extreme rate of temperature change, we plunged gizzard shad acclimated at 15°C directly into water at either 4 or 6°C. No fish lost equilibrium at 6°C and all fish eventually lost equilibrium when plunged into 4°C water.

An interesting finding in our study related to the ability of gizzard shad to recover from cold shock. For fish that lost equilibrium during a gradual drop in temperature, apparent recovery occurred within 15 min of being placed into water that was no more than 2°C higher than the temperature at which they experienced LOE. It is worth noting that the length of time that fish were in a state of disequilibrium prior to being exposed to warmer temperatures during the experiment was short (on the order of a few minutes). A longer exposure to debilitating temperatures before warming is more likely in the field, which would likely reduce the rate of recovery. For those that lost equilibrium during the plunge experiments, 80 % eventually recovered when the water temperature was slowly raised over the next several days. For those fish that did not recover, mortality did not happen immediately, but occurred 3-4 d after the initial plunge.

The results of the CTMin and recovery experiments suggest that determining when a gizzard or threadfin shad becomes moribund is not straightforward, because under some circumstances fish that appear debilitated might just be temporarily impaired and might recover. These distinctions are important when trying to evaluate the relative contributions of natural causes and CWIS to fish impingement and mortality.

We also reported here on studies of the responses of gizzard and threadfin shad to cold shock alone and to a combination of starvation and cold shock to gain insight into factors that contribute to impingement of these species at CWIS. We expected that shad acclimated at 15°C would experience effects on swimming endurance as temperature fell below 8°C (for threadfin shad) and below 5°C (for gizzard shad). These values are about 3°C above the CTMin values for these species that we determined in separate experiments, and about 1-2°C above the point at which we observed apparent recovery from LOE in static water tanks. In an effort to simulate late winter nutritional status we also subjected some fish to 2-3 weeks of near starvation, but found that this did not produce an additional negative effect on swimming endurance. Subsequent field sampling suggests that a longer period of starvation is needed to simulate late-winter field conditions.

We evaluated two biochemical stress indicators for a response to cold shock alone and found that both blood serum cortisol and chloride responded to cold shock, but the responses were not consistent enough to conclude that these indicators would be useful for evaluating cold shock or predicting impingement susceptibility. The results are not easily interpreted because of the interacting effects of stress accumulation, acclimation, and recovery as well as a potential inability to mount a stress response as the organism's physiological systems become compromised due to continual stress exposure.

We examined the interaction between nutritional status and stress response by evaluating additional bioindicators – hematocrit, total protein, and triglycerides. For both shad species, hematocrit responded negatively with increased starvation, and triglycerides increased after 14 d starvation and then decreased after 7 more days. There was no relationship for either parameter with swimming endurance.

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ORNL/NUREG/TM-340

Threadfin Shad Impingement: Effect of Cold Stress

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ENVIRONMENTAL SCIENCES DIVISION
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THREADFIN SHAD IMPINGEMENT: EFFECT OF COLD STRESS

Report to the Nuclear Regulatory Commission for period October 1, 1976, to September 30, 1978

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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1495

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Task: Threadfin Shad Impingement: Effect of Cold Stress

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

ACKNOWLEDGMENTS

This project was originally funded through the ORNL/ESD Cooling Systems Program, C. C. Coutant, Manager. Principal Investigator from September 1975 to June 1977 was J. S. Griffith. Principal Investigator from July 1977 to date is R. B. McLean. Part of the work includes a thesis study by M. V. McGee. Supportive staff included J. W. Gooch and L. M. Stubbs. A portion of the project was completed with the cooperation of the Tennessee Valley Authority (D. A. Tomljanovich, Project Leader, and R. Pasch, research staff, Intake Research Project, Division of Forestry, Fisheries, and Wildlife Development) under Interagency Agreement ERDA No. Ey-77-1-03-5333 (TVA No. TV-45187A). This work was closely coordinated with a research effort, funded by the U.S. Department of Energy (189 No. 000863), entitled "Mechanical Impacts of Impingement," which is aimed at the development of criteria for intake design and for operational procedures which minimize impingement.

ABSTRACT

McLEAN, R. B., P. T. SINGLEY, J. S. GRIFFITH, and M. V. McGEE. 1980. Threadfin shad impingement: Effect of cold stress. ORNL/NUREG/TM-340 and NUREG/CR-1044. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 106 pp.

Temperature greatly influenced impingement of threadfin shad, young-of-the-year gizzard shad, and probably young-of-the-year river herring. Temperature also greatly influenced any potential effects that loss of these prey had on predators. Natural cold kills of threadfin and young-of-the-year gizzard shad masked any ecological effects due to impingement. Most of the shad, had they not been impinged, would have died due to cold stress, and these dead shad would have decomposed rather than been eaten by scavengers. Loss of shad had a measurable short-term effect on sauger, as determined by changes in condition factor, and this loss of shad contributed to an increase in percent empty stomachs of skipjack herring, striped bass, and white bass. Thermal refuges, including the Kingston Steam Plant discharge, were identified for gizzard shad and hybrid shad. Hybrid shad made up 11.2% of the total threadfin population sampled both years (1976-77 and 1977-78). Blood serum electrolytes (Na^+, K^+, Cl^-) were not found to be good predictable indicators of cold stress of young gizzard shad.

SUMMARY

The objectives of the research were to (1) determine the physical and biological causes of threadfin shad impingement at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, (2) quantify the effects of impingement on threadfin shad population number and structure, (3) quantify the effects of impingement of threadfin shad on threadfin predators, and (4) determine the feasibility of using blood serum electrolytes to quantify cold stress of shad.

The study was conducted between November 1976-April 1977 and September 1977-April 1978. The results of our research are as follows:

1. The first year an estimated 240,000 threadfin shad were impinged, representing 96% of the fish of all species impinged. The second year, 560,000 threadfin, 354,000 gizzard shad, and 338,000 skipjack herring were impinged. Peaks of impingement of threadfin and young-of-the-year gizzard shad coincide with rapid drops in temperature. Intake hydrology and negative rheotoxis behavior of threadfin may cause threadfin to concentrate in the intake canal at the power plant, thus contributing to their impingement.
2. Effects of impingement of threadfin shad on threadfin population number and structure could not be determined. A standing stock estimate, using cove rotenone samples, could be made only during the summer when water temperatures were high. Thus, changes in population number and structure between July and the beginning of impingement in November could not be estimated. Impingement plus reservoir-wide mortality of threadfin due to cold stress during the winters of 1976-77 and 1977-78 may have resulted in a 95%

reduction in the population each winter. The population rebounded by early fall each year.

3. Impingement of threadfin shad and young-of-the-year gizzard shad, the principal forage species, coupled with reservoir-wide mortality of threadfin due to cold stress, had a measurable effect on sauger and resulted in an increase in the percentage of empty stomachs of skipjack herring, striped bass, yellow bass, and white bass. During periods of low prey availability, large sauger lost relatively more condition than small sauger due to the energy demands of gonadal development of the large sauger. The loss of condition was minimized, however, because of prey switching and stores of visceral fat.
4. Threadfin shad rebounded after mass mortality. A remnant of the population may have overwintered in thermal refuges and spawned both in the spring and summer. Threadfin hatched in spring, spawned by summer. It is our hypothesis that hybridization of threadfin with gizzard shad produces a cold-tolerant fish that is also reproductively viable.
5. Short- and long-term ecological effects of the loss of a principal forage species can be determined (a) if the percent of the forage population affected is determined, (b) if the condition of the predators is monitored, (c) if the ability of predators to switch prey and store energy reserves is quantified, and (d) if resiliency of the forage population is defined.

6. Blood serum electrolytes (Na^+, K^+, Cl^-) were not found to be good predictive indicators of cold stress of shad. Electrolyte levels were sensitive to a variety of stresses, making it difficult to isolate those changes due only to temperature.

Tennessee Valley Authority, Post Office Box 2000, Spring City, Tennessee 37381-2000

February 13, 2008

Tennessee Department of Environment & Conservation
Division of Water Supply
Compliance Review Section
Sixth Floor, L & C Tower
401 Church Street
Nashville, Tennessee 37243-1549

Dear Sir:

WATTS BAR NUCLEAR PLANT (WBN) - NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMIT NO. TN0020168 - WATER WITHDRAWAL REGISTRATION FORM FOR CALENDAR YEAR 2007 AND A REVISED REGISTRATION FORM FOR CALENDAR YEAR 2006.

In accordance with the provisions of Tennessee Code Annotated Section 69-8-301 et seq., the Water Resources Information Act, enclosed are the two compliance paper copies of the Water Withdrawl Registration Form for the calendar year 2007 and two compliance paper copies of the revised Water Withdrawl Registration Form for the calendar year 2006.

Although federal agencies are not subject to laws and regulations promulgated by state governments unless Congress has clearly waived the federal government's sovereign immunity, in 2003 TVA voluntarily agreed as a matter of policy to provide the registration information in order to assist both TVA and TDEC in carrying out their water management responsibilities.

Review of the Water Withdrawl Registration Form for the calendar year 2006 revealed mathematical errors. Average daily water withdrawn was previously reported as 165.59 million gallons and the total volume of water returned was previously reported as 55947.68 million gallons. The correct amount is 166.931 million gallons and 55947.57 million gallons, respectively, as shown on the revised form.

Should you have any questions or need additional information, please contact me (423.365.8016) or Jerri Phillips (423.365.3576) of my staff.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

Darrin J. Hutchison
Chemistry/Environmental Technical Support Manager

Cc:

Dr. Richard Urban, Environmental Field Office Manager
Tennessee Department of Environment & Conservation
Division of Water Pollution Control
540 McCallie Avenue, Suite 550
Chattanooga, Tennessee 37402

B. M. Eiford-Lee, MOB 1F-WBN
M.J. Lorek , MOB 2R-WBN
A.J. Scales, MOB 2M-WBN
M. Brandon ADM 1L-WBN
D. E. Pittman, BR 4T-C
L. P. Johnson, LP 5D-C
G.R. Signer, WT 6A-K
EDMS, WT CA-K (enclosure)

DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER SUPPLY
6th Floor L & C Tower, 401 Church Street
Nashville, Tennessee 37243-1539
(615) 532-0191

WATER WITHDRAWAL REGISTRATION

In accordance with the provisions of Tennessee Code Annotated Section 69-8-301 et seq., the Water Resources Information Act; this registration is required for anyone withdrawing an average of 10,000 gallons or more of water per day.
See page 3-4 for instructions.

PART A. FACILITY & CONTACT INFORMATION

1. Withdrawal Registration No.: ____________ (For Official Use Only)

2. Water User: TVA – Watts Bar Nuclear Plant Type: Nuclear Plant
   Mailing Address: 1101 Market Street, LP 3K
   City: Chattanooga State: Tennessee Zip: 37402

3. Location (if different from mailing address): Rhea County
   Street Address: Highway 68; 1260 Nuclear Plant Road
   City: Spring City State: Tennessee Zip: 37381

4. Number of employees at location: 1049

5. Indicate the contact individual for water withdrawal information:
   Name: D.J. Hutchison Title: Chemistry/Environmental Technical Support Manager
   e-mail: djhuthchison@tva.gov Phone: 423.365.8016 Fax: 423.365.1904

PART B. WATER USE REPORTING PERIOD

6. Year: 2007 Seasonal Withdrawals Beginning (Month/Year): 01/01/2007 Ending (Month/Year): 12/31/2007

7. Water Registration: (Check One): ______ New Operation X Renewal

8. List any water problems you have experienced in the last reporting period: NA

9. Number of days ground water (springs and wells) has been withdrawn during the year: 0

10. Number of days surface water (streams) has been withdrawn during the year: 365

11. **Total number of days water has been withdrawn during the year:** 365

12. Classification of Water Use (Use all that Apply) and Percentage of Total use:

0 % a) Domestic water use (drinking, human consumption and general sanitation uses)
0 % b) Institutional or other general uses (lawn watering, laundry)
0 % c) Irrigation of crops, pastures and nursery stock
0 % d) livestock watering (includes feed lots, dairy sanitation and fish farming)
0 % e) navigation (lock usage and flow augmentation for navigation)
0 % f) thermoelectric power production, including cooling purposes (excludes hydroelectric)
0 % g) recreational use, park use, golf course irrigation, water park use
0 % h) industrial uses include manufacturing, food processing, washing, and cooling
0 % i) hydroelectric power generation (provided none of it is used consumptively)
0 % j) mining (milling or where water is used to wash or process an ore)
0 % k) dewatering (mining, quarry rock production, other operations where water is withdrawn)
100 % l) any other use not defined above. Describe: Nuclear power generation
100 % **Total (Must equal 100%)**

PART C. WATER WITHDRAWAL INFORMATION (Attach additional sheets if necessary)

Year	I.D. #	Source Name	G, S,P[1]	County	Latitude [2]	Longitude [2]	Method of Measure[3]	Million Gallons Withdrawn
2007	001	Tennessee River	S	Rhea	TRM 528		D	65702.00
2007	002	Tennessee River	S	Rhea	TRM 527		D	16235.24
	003							
	004							
13.	**Total Volume Withdrawn in Million Gallons=**							**81937.24**
14.	**Average Daily Water Withdrawal for year (Line 13 divided by Line 11)=**							**224.49**
15.	**Max. Daily Water Withdrawal (MG):** 219.289 **Month of Max. Withdrawal:** August							

[1] G=Ground water (well or spring);
S=Surface water (stream, river, holding pond, lake);
P=Purchased water

(Check One)
[2]Datum: ☐ NAD 27 ☐ NAD 83

[3]Method of Measurement Key:
A=Flow Meter
B=Calculated using pump capacity rating and duration of pumpage
C=Capacity of vessel holding water
D=Electronic flow measurement
E=Other (explain below:)

PART D. WATER DISCHARGE (Attach additional sheets if necessary)

Year	I.D. #	Discharge Site Name[4]	River Mile	County	NPDS Permit #	Lat.	Long.	Percent of effluent	Million Gallons Returned
2007	001	Tennessee River	529.2	Rhea	TN0020168	84 46 46.21W	35 36 39.07N	75%	4396.15
2007	002	Tennessee River	527.9	Rhea	TN0020168	84 47 11.95W	35 35 40.41 N	25%	1465.38
16.	**Total Volume of Water Returned (Effluent or Discharge) in Million Gallons equals:**								**5861.53**

[4]Examples of discharge sites: stream, well injection, spray, public sewer system, septic tank, field tile

PART E. SIGNATURE

I hereby certify that the information provided on this form is true to the best of my knowledge.

16. Print Name: ~~Darrin Hutchison~~ Date: 02/13/2008

17. Signature:

WATER WITHDRAWAL REGISTRATION

The Tennessee Department of Environment and Conservation (TDEC), Division of Water Supply (DWS) under the Water Resources Information Act of 2002 (T.C.A. §§ 69-8-301 et seq.) maintains a water withdrawal registration in order to better protect the water resources of the State. The registration of water withdrawals applies to all persons withdrawing water from either a surface water or ground water source if the average withdrawal meets or exceeds 10,000 gallons a day for any purpose, except those excluded by the Act. Uses specifically excluded include water used for agriculture, nonrecurring withdrawals of water, and water withdrawn for an emergency use. Also, water purchased from a utility or an industry is not required to be reported. All entities withdrawing water, whether required or excluded by the Water Resources Information Act of 2002, are encouraged to submit an annual Water Withdrawal Registration to the TN Division of Water Supply so that accurate documentation of water use is available for present and future Tennessee water resource studies.

INSTRUCTIONS:

The registration of a withdrawal is done annually. Data reported should be based on a calendar year and reported by February 15 of the next year. To determine if the volume of water withdrawn meets the requirement of an average withdrawal of 10,000 gallons per day, divide the total amount of water withdrawn (line 13) by the number of days (line 11) that water is withdrawn. A "New Operation" may not have any historical data on which to base its withdrawal data. Estimate or indicate the amount of water anticipated to be withdrawn. If this is a renewal, report the amount withdrawn during the past year in Part C.

Part A. Facility & Contact Information

1. The Withdrawal Registration No. is assigned by the Division of Water Supply (DWS). Report all annual water withdrawals using your assigned Withdrawal Registration Number. Leave blank for new operations.
2 through **5**. Complete the facility and main contact information. Select type of water users **(industrial, irrigation, mining, or thermal plant)**.

Part B. Water Use Reporting Period

6. Indicate year, the beginning month/year and the ending month/year if withdrawals are seasonal.
7. Check new or renewal water withdrawal registration.
8. List any water problems encountered during the year (supply, quality, flooding, turbidity).
9 to **11**. Complete the days water is withdrawn from ground water and/or surface water sources and give a total number of days water is withdrawn (line 11).
12. Indicate the percent of water used for any of the **12 water use classifications** applicable to your company during the year. Persons not covered by this Act that voluntarily register their water withdrawal should also use the following water use classification(s): **a)** domestic water use includes all water withdrawn by utility districts, municipal public water systems, subdivisions, prisons, colleges, and most small commercial establishments where water is used for drinking, human consumption and general sanitation, **b)** institutional or other general uses (lawn watering, laundry), **c)** irrigation of crops and nursery stock, **d)** livestock watering (includes feed lots, dairy sanitation and fish farming) **e)** navigation (lock usage and flow augmentation for navigation), **f)** thermoelectric power production, including cooling purposes (excludes hydroelectric), **g)** recreational use, park use, golf course irrigation, and water park use, **h)** industrial uses include manufacturing processing, washing, and cooling, including food processing, but excluding mining related uses, **i)** hydroelectric power generation (provided none of it is used consumptively), **j)** mining (milling or where water is used to wash or process an ore), **k)** dewatering (mining, quarry rock production, and other operations where water is withdrawn in order to remove water or conduct another activity), and **l)** any other use not defined above.
Total of lines 12(a) through 12(l) must equal 100.

Part C. Water Withdrawal Information

Identify the source point and quantity of water withdrawn from each source point.

Indicate year of withdrawal, ID number (assigned by DWS), source name commonly used by withdrawer to refer to the source, i.e. Smith Spring, Big Creek intake, Collier Road Well. Withdrawals made from multiple wells that are measured at an entry point may be reported as a single figure and described as a well field, e.g. Thomson Well Field. If there are several source points, each metered separately, please report the withdrawal of each source point.
Indicate if water is from Ground, Surface, or Purchased source.

Enter the County, Latitude and Longitude for each source point. It is important that **location information** be as accurate as possible. If you do not know the latitude and longitude of the intake, use river mile or attach a topographic map with the withdrawal point location(s) marked with a ◉ and label the mark according to Well, Stream or Spring ID used in this registration. Mark discharge point(s) with an **X**. Latitude longitude may be expressed in degrees, minutes and seconds or in decimal degrees. All USGS topographic maps are set up in degrees, minutes and seconds. USGS maps are referenced to either the North American Datum of 1927 (NAD 27) or 1983 (NAD 83). Most USGS maps are prepared in NAD 27. Newer maps are based on NAD 83. NAD information is listed in the lower left hand corner of the 7.5 minute U.S. Geological Survey topographic map. Circle the appropriate NAD datum.

Use the Method of Measurement Key (A, B, C, D, E) to indicate how the volume of water withdrawn is determined (A=flow meter, B=calculated using pump capacity and duration, C=capacity of vessel, D=electronic flow measurement, or E=other). If you select E, explain method of measurement.

13. Add all of the water withdrawals together and give the total volume withdrawn in million gallons.
14. Divide the total volume of water withdrawn **(line 13)** by the total number of days water was withdrawn **(Line 11).** This is the average water withdrawal in million gallons per day. The figure should be fairly large. For example, 2,600,000 gallons would be expressed as "2.6 MG."
15. Enter the volume in million gallons for the maximum daily withdrawal made during the year. Enter the month the maximum daily withdrawal occurred (e.g., August).

Part D. Water Discharge

It is very important to indicate the **point(s) of return** and **total discharge**. The return information is extremely helpful in identifying potential conflicts. Report water that is discharged to a stream, lake, well, spray, public sewer system, septic tank, field tile. Do not report water that is consumed in an operation e.g. irrigation of a golf course.

Indicate year of discharge, ID number (assigned by DWS), discharge site name. As in water withdrawals, discharge points in close proximity may be identified as a discharge field. If there are several discharge points, each metered separately, please report the volume of each discharge point individually.
Enter the River Mile, County, NPDS permit #, Latitude, Longitude, percent of effluent, and volume returned at each discharge site (million gallons).

16. Add all of the discharge volumes together to get the total volume of discharged water in million gallons. Total volume discharged (in million gallons) may be based on a measured point of return or estimated.

Part E. Signature

17. Print name and date.
18. Sign and mail the Water Registration to:

Division of Water Supply
TN Department of Environment and Conservation
6th Floor L&C Tower, 401 Church St.
Nashville, TN 37243-1549

<u>**Water Withdrawal Registration Forms are due to the Division of Water Supply by February 15.**</u>

For assistance in completing Water Withdrawal Registration, contact:

Wayne Muirhead
Environmental Specialist
615-253-4067 FAX:615-532-0503
wayne.muirhead@state.tn.us

DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER SUPPLY
6th Floor L & C Tower, 401 Church Street
Nashville, Tennessee 37243-1539
(615) 532-0191

WATER WITHDRAWAL REGISTRATION

In accordance with the provisions of Tennessee Code Annotated Section 69-8-301 et seq., the Water Resources Information Act; this registration is required for anyone withdrawing an average of 10,000 gallons or more of water per day.
See page 3-4 for instructions.

PART A. FACILITY & CONTACT INFORMATION

1. Withdrawal Registration No.: ____________ (For Official Use Only)

2. Water User: TVA – Watts Bar Nuclear Plant Type: Nuclear Plant
   Mailing Address: 1101 Market Street, LP 3K
   City: Chattanooga State: Tennessee Zip: 37402

3. Location (if different from mailing address): Rhea County
   Street Address: Highway 68; 1260 Nuclear Plant Road
   City: Spring City State: Tennessee Zip: 37381

4. Number of employees at location: 1049

5. Indicate the contact individual for water withdrawal information:
   Name: D.J. Hutchison Title: Chemistry/Environmental Technical Support Manager
   e-mail: djhuthchison@tva.gov Phone: 423.365.8016 Fax: 423.365.1904

PART B. WATER USE REPORTING PERIOD

6. Year: 2006 Seasonal Withdrawals Beginning (Month/Year): 01/01/2006 Ending (Month/Year): 12/31/2006

7. Water Registration: (Check One): ______ New Operation X Renewal

8. List any water problems you have experienced in the last reporting period: NA

9. Number of days ground water (springs and wells) has been withdrawn during the year: 0

10. Number of days surface water (streams) has been withdrawn during the year: 365

11. **Total number of days water has been withdrawn during the year:** 365

12. Classification of Water Use (Use all that Apply) and Percentage of Total use:

0 % a) Domestic water use (drinking, human consumption and general sanitation uses)
0 % b) Institutional or other general uses (lawn watering, laundry)
0 % c) Irrigation of crops, pastures and nursery stock
0 % d) livestock watering (includes feed lots, dairy sanitation and fish farming)
0 % e) navigation (lock usage and flow augmentation for navigation)
0 % f) thermoelectric power production, including cooling purposes (excludes hydroelectric)
0 % g) recreational use, park use, golf course irrigation, water park use
0 % h) industrial uses include manufacturing, food processing, washing, and cooling
0 % i) hydroelectric power generation (provided none of it is used consumptively)
0 % j) mining (milling or where water is used to wash or process an ore)
0 % k) dewatering (mining, quarry rock production, other operations where water is withdrawn)
100 % l) any other use not defined above. Describe: Nuclear power generation
100 % **Total (Must equal 100%)**

PART C. WATER WITHDRAWAL INFORMATION (Attach additional sheets if necessary)

Year	I.D. #	Source Name	G, S,P[1]	County	Latitude [2]	Longitude [2]	Method of Measure[3]	Million Gallons Withdrawn
2006	001	Tennessee River	S	Rhea	TRM 528		D	48857.18
2006	002	Tennessee River	S	Rhea	TRM 527		D	12072.82
2006	003							
	004							
13.	**Total Volume Withdrawn in Million Gallons=**							**60929.99**
14.	**Average Daily Water Withdrawal for year (Line 13 divided by Line 11)=**							**166.931**
15.	**Max. Daily Water Withdrawal (MG):** 219.289				**Month of Max. Withdrawal:** August			

[1] G=Ground water (well or spring);
S=Surface water (stream, river, holding pond, lake);
P=Purchased water

(Check One)
[2]Datum: ☐ NAD 27 ☐ NAD 83

[3]Method of Measurement Key:
A=Flow Meter
B=Calculated using pump capacity rating and duration of pumpage
C=Capacity of vessel holding water
D=Electronic flow measurement
E=Other (explain below:)

PART D. WATER DISCHARGE (Attach additional sheets if necessary)

Year	I.D. #	Discharge Site Name[4]	River Mile	County	NPDS Permit #	Lat.	Long.	Percent of effluent	Million Gallons Returned
2006	001	Tennessee River	529.2	Rhea	TN0020168	84 46 46.21W	35 36 39.07N	75%	3736.729
2006	002	Tennessee River	527.9	Rhea	TN0020168	84 47 11.95W	35 35 40.41 N	25%	1245.576
16.	**Total Volume of Water Returned (Effluent or Discharge) in Million Gallons equals:**								**55947.57**

[4]Examples of discharge sites: stream, well injection, spray, public sewer system, septic tank, field tile

PART E. SIGNATURE

I hereby certify that the information provided on this form is true to the best of my knowledge.

16. Print Name: Darrin Hutchison Date: 02/13/2008

17. Signature:

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Total of lines 12(a) through 12(l) must equal 100.

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Identify the source point and quantity of water withdrawn from each source point.

Indicate year of withdrawal, ID number (assigned by DWS), source name commonly used by withdrawer to refer to the source, i.e. Smith Spring, Big Creek intake, Collier Road Well. Withdrawals made from multiple wells that are measured at an entry point may be reported as a single figure and described as a well field, e.g. Thomson Well Field. If there are several source points, each metered separately, please report the withdrawal of each source point.
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Nashville, TN 37243-1549

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For assistance in completing Water Withdrawal Registration, contact:

Wayne Muirhead
Environmental Specialist
615-253-4067 FAX:615-532-0503
wayne.muirhead@state.tn.us

Phillips, Jerri L

From: Ballard, Nathan (GE Infra, Water) [Nathan.Ballard@ge.com]
Sent: Wednesday, October 07, 2009 1:15 PM
To: Phillips, Jerri L
Subject: Clarification

Jerri,

Bear in mind, that I took my sample at the intake of the water treatment plant from the fire protection system. That is AFTER it has been treated at the PLANT intake with various biocides (clamtrol, etc) and corrosion inhibitors for the plant piping. As a result, the water quality analysis I sent you isn't simply river water - but its relatively close.

Nathan Ballard
GE Infrastructure
Water & Process Technologies
Field Service Representative

T 423 365 8634
F 423 365 8364
C 865 806 5230
E nathan.ballard@ge.com
www.gewater.com

TVA Watts Bar
2170 Nuclear Plant Rd
Spring City, TN 37381, USA

WATER ANALYSIS REPORT

4000081280
TVA WATTS BAR NUCLEAR
2170 NUCLEAR PLANT ROAD
Spring City, TN
UNITED STATES 37381

Sampled: 30-OCT-2008
Reported: 12-NOV-2008
Field Rep: Overbeck, Susan
WDL0038

	RAW WATER S1031101
Ammonia, Free And Fixed, as N, ppm	F
pH	7.8
Specific Conductance, at 25°C, µmhos	214
Alkalinity, "P" as $CaCO_3$, ppm	0
Alkalinity, "M" as $CaCO_3$, ppm	71
Sulfur, Total, as SO_4, ppm	18.7
Chloride, as Cl, ppm	9.8
Hardness, Total, as $CaCO_3$, ppm	80
Calcium Hardness, Total, as $CaCO_3$, ppm	56
Magnesium Hardness, Total, as $CaCO_3$, ppm	24
Barium, Total, as Ba, ppm	0.03
Strontium, Total, as Sr, ppm	0.09
Copper, Total, as Cu, ppm	< 0.05
Iron, Total, as Fe, ppm	0.06
Sodium, as Na, ppm	9.3
Potassium, as K, ppm	1.9

WATER ANALYSIS REPORT

4000081280
TVA WATTS BAR NUCLEAR
2170 NUCLEAR PLANT ROAD
Spring City, TN
UNITED STATES 37381

Sampled: 30-OCT-2008
Reported: 12-NOV-2008
Field Rep: Overbeck, Susan
WDL0038

	RAW WATER S1031101
Aluminum, Total, as Al, ppm	< 0.1
Manganese, Total, as Mn, ppm	0.03
Nitrate, as NO_3, ppm	< 1
Phosphate, Total, as PO_4, ppm	< 0.4
Silica, Total, as SiO_2, ppm	4.6
Fluoride, as F, ppm	0.1
Lead, Total, as Pb, ppm	< 0.05
Mercury, Total, as Hg, ppb	< 0.2
Carbon, Total Organic, as C, ppm	2.1
Turbidity, NTU	1.8

December 2002

DETERRING TERRORISM:
Aircraft Crash Impact Analyses Demonstrate Nuclear Power Plant's Structural Strength

Purpose of the Study

The Sept. 11, 2001, terrorist attacks on the United States have drawn public attention to the potential for a crash of a large modern aircraft into structures that are part of our nation's critical infrastructure, including power plants.

Aircraft impact issues were addressed in the licensing process for all 103 U.S. nuclear power reactors; however the evaluations were based on the premise that such a crash would be accidental. On this basis, the potential for aircraft impact is small, and has been evaluated using probabilistic assessment methods. The results of these evaluations indicate that for all but a few nuclear power plant sites—those located near major airports—the probability of a crash is low and a resulting requirement for aircraft impact evaluation was not included in the licensing by the U.S. Nuclear Regulatory Commission.

Nonetheless, the nuclear power industry is confident that nuclear plant structures that house reactor fuel can withstand aircraft impacts, even though they were not specifically designed for such impacts. This confidence is predicated on the fact that nuclear plant structures have thick concrete walls with heavy reinforcing steel and are designed to withstand large earthquakes, extreme overpressures and hurricane force winds. The purpose of this study is to validate that confidence.

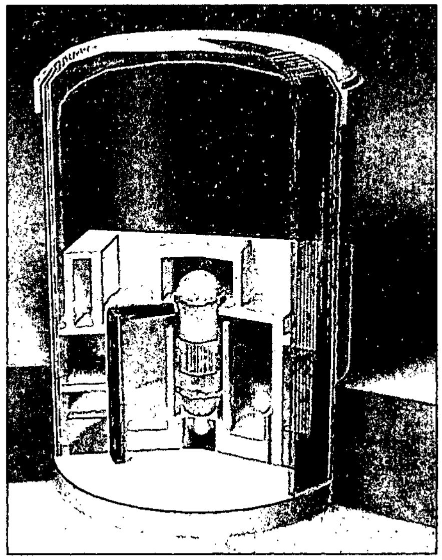
Results of the Analyses

Detailed results of the independent analyses will not be released to the public because of security considerations. However, the following are the general findings of the analyses:

Containment Buildings

Computer analyses of models representative of all U.S. nuclear power plant containment types have been completed.

The wing span of the Boeing 767-400 (170 feet)—the aircraft used in the analyses—is slightly longer than the diameter of a typical containment building (140 feet). The aircraft engines are physically separated by approximately 50 feet. This makes it impossible for both an engine and the fuselage to strike the centerline of the containment building. As a result, two analyses were performed. One analysis evaluated the "local" impact of an engine on the structure. The second analysis evaluated the "global" impact from the entire mass of the aircraft on the structure. In both cases, the analysis conservatively assumed that the engine and the fuselage strike perpendicular to the centerline of the structure. This results in the maximum force upon impact to the structure for each case.



Boiling Water Reactor Containment Structure

The analyses indicated that no parts of the engine, the fuselage or the wings—nor the jet fuel—entered the containment buildings. The robust containment structure was not breached, although there was some crushing and spalling (chipping of material at the impact point) of the concrete.

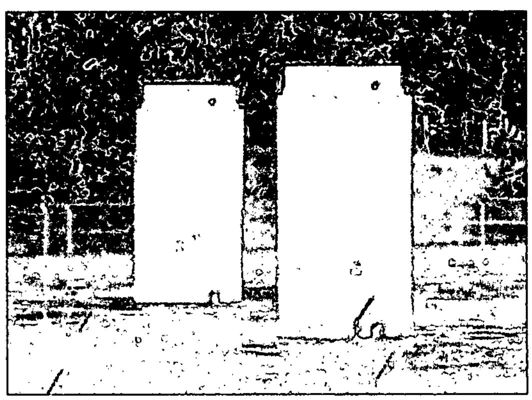
Used Fuel Storage Pools

The wing span of the Boeing 767-400 (170 feet) is substantially greater than the longest dimension of a typical used fuel pool wall (60 feet). The aircraft engines are physically separated by approximately 50 feet. This makes it impossible for both an engine and the fuselage to strike the mid-point of the pools. As a result, two analyses were performed for both a pressurized water reactor pool and a boiling water reactor pool. One analysis evaluated the "local" impact of an engine on the mid-point of the pool wall. The second analysis evaluated the "global" impact of the fuselage and the portion of the wings that could realistically hit the mid-point of the representative fuel pool wall. In both cases, the analysis conservatively assumed that the engine and the fuselage strike perpendicular to the mid-point of the pool wall. This results in the maximum impact force being applied directly to the structure for each case. The wall's mid-point would deflect (bend inward) more from this force than for an impact closer to the end of the wall.

The stainless steel pool liner ensures that, although the evaluations of the representative used fuel pools determined that there was localized crushing and cracking of the concrete wall, there was no loss of pool cooling water. Because the used fuel pools were not breached, the used fuel is protected and there would be no release of radionuclides to the environment.

Used Fuel "Dry" Storage Facilities

Due to the extremely small relative size of a dry fuel storage container compared to the Boeing 767-400, it is not possible for the entire mass of the aircraft to strike the container. Therefore, the analysis evaluated the worst case of a direct impact of an engine on the dry storage containers.



Used Nuclear Fuel Storage Containers

For the vertical concrete-encased steel containers, two impact points were evaluated. One evaluated a mid-plane impact to create maximum deflection.

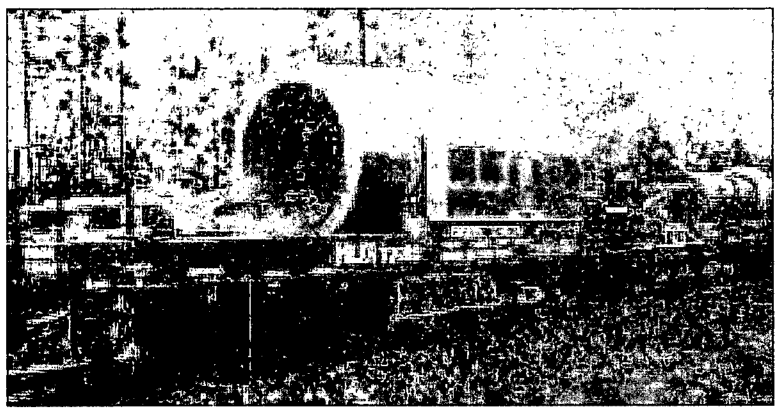
The other evaluated a strike near the top of the structure to create a maximum "tip-over" force on the structure. Based on results from the vertical steel, concrete encased container, the all-steel vertical container was only impacted at mid-plane. For the horizontal container, the evaluated impact point is the center of the concrete loading door.

For the concrete encased canisters, the steel canister containing the used fuel assemblies was not breached although there was crushing and cracking of the concrete enclosure at the area of impact. For the vertical steel container, the container was dented, but not breached. Because the dry storage structures were not breached, there would be no release of radionuclides to the environment.

Used Fuel Transportation Containers

Due to the extremely small relative size of a fuel transport container compared to the Boeing 767-400, it is impossible for the entire mass of the aircraft to strike the container. Therefore, the analysis evaluated the worst case of a direct impact of an engine on the representative fuel transport cask.

The analyses show the container body withstands the impact from the direct engine strike without breaching. The forces on the container are comparable to the forces used in tests containers must undergo before designs are approved by the NRC. Additionally, the container remains attached to the rail car and the rail car does not tip over. Because the fuel transport container is not breached, there would be no release of radionuclides to the environment.



Container for Transporting Used Nuclear Fuel

Analysts and Expert Peer Reviewer Qualifications

The Nuclear Energy Institute requested that EPRI perform this study for the nuclear industry. EPRI is a non-profit energy research consortium that provides science and technology-based solutions to global energy customers. The analysts were carefully selected by EPRI for their demonstrated capabilities in the dynamic analysis of heavily reinforced concrete structures, experience in impact analysis related to commercial and military applications, and experience in commercial nuclear power plant design. The analysts are employed by ABS Consulting and ANATECH Corporation. They include Dr. Joe Rashid, Dr. Randy James, Greg Hardy, Dr. Jorma Arros and Kelly Merz. The work was guided by Dr. Bob Kassawara, a licensed civil engineer who is a recognized expert in the area of dynamic response of nuclear power plant structures.

The results of the analysis were in-line peer reviewed by Drs. Bob Nickell and Bob Kennedy. Dr. Nickell is a world recognized expert in the dynamic analysis of structures and used fuel containers. Dr. Kennedy is a world renowned structural analyst.

Additional detail on the qualification of the analysts is contained in an appendix to this report.

General Approach

The impact of the selected commercial aircraft on containment buildings, used fuel pools, dry fuel storage facilities and used fuel transportation containers was analyzed using sophisticated computer models. The analysis codes employed are widely recognized as "state of the art" codes and have been benchmarked against empirical test data derived from the impact of various objects on concrete structures.

Because the design of U.S. nuclear plant structures varies, representative structures were analyzed that are typical of the structures that exist across the industry. The design parameters utilized in selecting the representative structures were biased to be conservative. For example, in analyzing the capacity of containment structures to withstand an aircraft impact, design parameters included rebar quantity, concrete thickness, concrete strength, steel containment liner existence and strength, and the height-to-width ratio of the containment building. The representative structures were selected on the basis of their conservative values for these parameters, i.e. below median values for the spectrum of plant designs. In this way, there is assurance that the structures analyzed represent actual plant structures.

The aircraft impact analysis of the representative nuclear plant structures incorporates best estimate calculation methods in order to provide results that are as realistic as possible.

Selection of Aircraft Analyzed

The reference aircraft chosen for this analysis is the Boeing 767-400. The maximum takeoff weight for this aircraft is 450,000 pounds, which includes 23,980 gallons of fuel. It has a wing span of 170 feet, an overall length of 201 feet, a fuselage diameter of 16.5 feet, and two engines weighing 9,500 pounds each.

This aircraft was selected for the following reasons:

- The weight of the Boeing 767-400 envelopes 88 percent of all commercial flights in the United States employing Boeing aircraft.
- It is the most widely used "wide body" aircraft in the U.S. commercial fleet.
- The weight of the engines on the Boeing 767-400 envelopes almost 90 percent of commercial aircraft engines, including wide body jets such as the Boeing 747,

Boeing 757, DC-10, MD-11, A-330, and the L-1011.

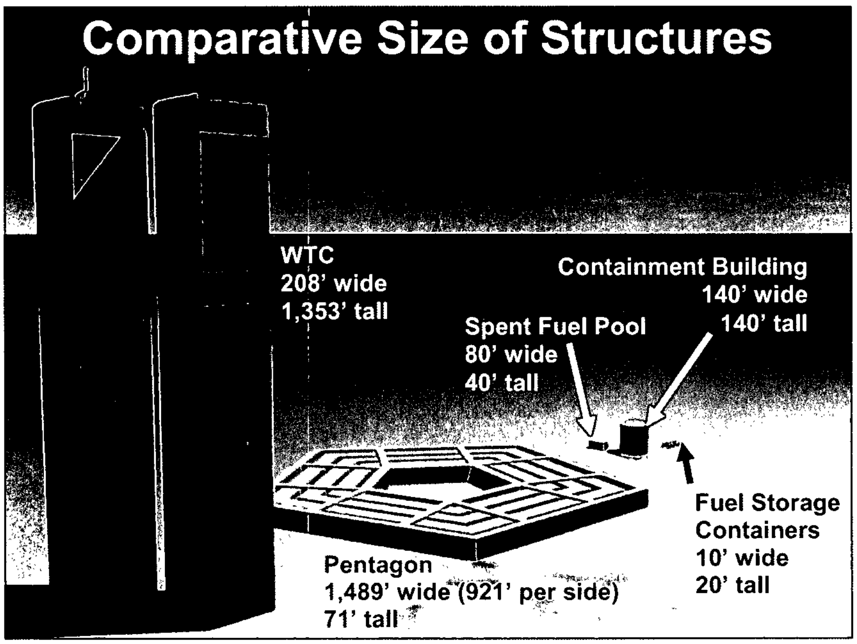
- The weight of the Boeing 767-400 is at the 85th percentile of Boeing commercial aircraft.

- Boeing aircraft account for almost two-thirds of the commercial aircraft registered in the United States.

The assumed speed of the aircraft is 350 miles per hour, which is approximately the speed at which a jetliner struck the Pentagon on Sept. 11, 2001, based on reported flight recorder data and analysis of security camera video that captured the impact. In addition, this speed is reasonable for this evaluation where it is assumed the pilot can maintain flight maneuverability and impact structures at the precise analyzed locations. Although there is sufficient available engine thrust on the 767-400 to increase the speed at the altitudes of the analyzed structures, precision flying close to the ground at speeds greater than 350 miles per hour is extremely difficult, according to experienced pilots. A less-experienced pilot would have great difficulty controlling the aircraft. Thus, the probability of the aircraft striking a specific point on a structure–particularly one of the small size of a nuclear plant–is significantly less as speed increases.

Typical Characteristics of Analyzed Structures

The structures that are the subject of this report are considerably smaller than the World Trade Center and Pentagon buildings that were attacked by terrorists on Sept. 11, 2001. Moreover, it is unlikely that a terrorist pilot could strike nuclear plant structures at the conservative impact points assumed in the analyses. The figure below provides a perspective of the size of nuclear power plant structures relative to the World Trade Center and Pentagon.



Containment Structures

Pressurized water reactor (PWR) containments typically consist of heavily steel-reinforced concrete cylinders ranging in thickness from 3.5 feet to 4.5 feet, capped by a hemispherical dome of steel-reinforced concrete. The cylinder is typically 140 feet high, with a 140-foot diameter.

Reinforcement bars that form a cage within the concrete are typically Grade 60 #18 steel bars on 12-inch to 15-inch centers. A #18 rebar is two and one-quarter inches in diameter – about the size of a man's forearm. The wing span of the 767-400 (170 feet) is greater than the diameter of the typical PWR containment, making it impossible to impact the entire aircraft mass on the containment structure even with a perpendicular strike on the building centerline. Pressurized water reactors constitute about two-thirds of the 103 reactors operating in the United States.

Boiling water reactor (BWR) containments typically consist of a steel containment vessel surrounded by a reinforced concrete shield that typically has a thickness of four feet or greater and is housed within the reactor building. The primary containment of a BWR is typically one-third the diameter of a PWR containment. The location and dimensions of the primary containment inside the reactor building make it an extremely difficult structure to hit with an aircraft.

Used Fuel Storage Pools

Used fuel pools that store fuel assemblies after they are removed from the reactor core are typically rectangular structures (40 feet by 60 feet) with a depth of at least 40 feet. The wall thicknesses are typically 4.5 feet to 6.5 feet of steel-reinforced concrete. The reinforcing bars typically are 1.25 inches in diameter. The interior of the concrete pool is covered with a stainless steel liner plate. Fuel assemblies are covered by a minimum of 25 feet of water within the pool.

Used fuel pools at PWRs are commonly located within an auxiliary building near the containment. Many of the PWR pools are located in the interior of the building, making it impossible for an aircraft to strike the pool at full force and thus providing considerable protection from an aircraft strike. For those PWR pools that are part of the exterior wall of an auxiliary building, most have a substantial portion of the pool below ground level, similarly providing considerable protection from an aircraft strike.

BWR fuel pools typically are located at an elevated position in the reactor building, outside of primary containment. For these reasons, a representative PWR spent fuel pool located at ground level with one wall of the pool forming part of an exterior wall and a representative elevated used fuel pool that forms part of an exterior wall for a BWR, were analyzed.

Used Fuel Dry Storage Facilities

The dry fuel storage facilities that have been built at 18 nuclear power plant sites permit storage of used fuel assemblies at a location on the site other than the used fuel pool. Used fuel must be cooled for at least five years in the fuel pool before being placed into dry storage containers. These dry storage systems utilize air and natural convection heat removal to provide cooling for the canister containing the used fuel.

Three types of dry fuel storage facilities were analyzed. The dimensions of all of the dry fuel storage facilities—small, low-profile structures—make them an extremely difficult target to strike.

1. A vertical stainless steel container (typically two inches thick with a four-inch thick cover) surrounded by steel-reinforced concrete (26 inches thick) within a steel shell. The structure is 18 feet tall and weighs 270,000 pounds.

2. A vertical stainless steel container approximately sixteen feet high, eight feet in diameter with a wall thickness of about 15 inches. The container weighs approximately 200,000 pounds to 300,000 pounds when loaded with fuel. The lid bolted to the top of the container, and the bottom which is welded on, are typically 10 inches to 12 inches thick.

3. A cylindrical stainless steel canister approximately 15 feet long, 4 feet in diameter and over one-half inch thick placed in a horizontal reinforced concrete container that weighs approximately 250,000 pounds.

Used Fuel Transportation Containers

Used fuel transportation containers are used to transport used fuel offsite to another nuclear power plant site for storage and, ultimately, to a permanent disposal facility. Used fuel must be cooled for at least eight to 10 years in the fuel pool before being transported. These transportation casks utilize natural convection heat removal to provide cooling for the canister containing the used fuel.

The analyzed transport container weighs 250,000 pounds and is mounted on a skid attached to a flatbed rail car. The rail car and skid weigh an additional 66,000 pounds. The cylindrical container is approximately eight feet in diameter and 17 feet long, making it a difficult target to strike with an aircraft.

Conservative Assumptions of the Analyses

The analyses of representative structures that house nuclear fuel included several conservative features that provide additional assurance that nuclear power plant structures housing nuclear fuel can withstand direct aircraft crashes

Containment Buildings

- For each analyzed structure, the aircraft and engine were assumed to strike perpendicular to the centerline of the structure, thereby subjecting the containment building to the maximum force of the aircraft. Because the containments are curved structures, missing the centerline reduces impact forces.

- The analysis assumed that the maximum takeoff weight of the Boeing 767-400 impacts the structure. In reality, fuel would be consumed during both takeoff and travel to the structure, reducing the overall weight of the aircraft.

Used Fuel Storage Pools

- Both the engine and the aircraft fuselage were assumed to strike at the mid-point of the pool wall, which is the area where the potential for inventory loss is greater. Impact at other locations would result in reduced consequences.

- Both the engine and the aircraft fuselage were assumed to strike perpendicular to the surface of the wall. Lesser impact angles would impart less force to the wall.

- The exact location of used fuel pools is not visible from a plant's exterior. It would therefore be extremely difficult for an attacker to identify and strike the pool.

- Intervening structures at many nuclear plants significantly inhibit the terrorists' ability to hit the used fuel pools.

Used Fuel Dry Storage Facilities

- The engine strikes perpendicular to the centerline of the vertically designed structures, thereby subjecting the structure to the maximum force of the engine. Because the dry storage facilities are curved structures, missing the centerline reduces impact forces.

- The engine strikes at mid-height of the vertically designed structures. Given that the fuselage of the Boeing 767-400 is approximately the same height as the dry storage facility, the probability that an engine could strike at the mid-height of the structure is extremely low.

- The engine strikes the exact center of the front concrete door plug of the horizontally designed structures. The center of the door is less than ten feet off the ground and is smaller in diameter than the engine itself, making such an impact point extremely unlikely.

Used Fuel Transportation Containers

- The engine strikes perpendicular to the centerline of the structure, thereby subjecting the structure to the maximum force of the engine. Because the transportation container is a curved structure, missing the centerline reduces impact forces.

- The engine strikes at mid-plane of the structure. Given the short length of the container relative to the wingspan of the aircraft, striking exactly at mid-plane has a very low probability.

Conclusion

The study determined that the structures that house reactor fuel are robust and protect the fuel from impacts of large commercial aircraft.

For more information on nuclear power plant security and other industry issues, contact the Nuclear Energy Institute at 202.739.8044 or www.nei.org.

Appendix

Analysts and Expert Peer Reviewer Qualifications

ABS Consulting

ABS Consulting is one of the leading risk consulting companies offering state-of-the-art engineering services to the highly protected industry sectors (nuclear, energy, chemical, offshore, marine, insurance, and government). ABS specializes in identifying risks and quantifying losses in the event of extreme man-made and natural hazards, including aircraft or missile impact, terrorist attack, toxic material releases, earthquakes, hurricanes, fires, explosions and human error.

ABS Consulting has experts in the fields of structural dynamics, sophisticated finite element analysis, probabilistic risk assessment, dispersion modeling, engineering mechanics, and explosion/blast analysis. ABS personnel participate in many technical standard committees including ANS, ASME, AISC, ASCE, API, and CMA. The three principal participants in this EPRI/NEI aircraft impact study (Greg Hardy, Jorma Arros and Kelly Merz) have authored over 40 technical papers in the subject areas.

ABS Consulting has 15 U.S. offices and 32 international offices, with over 900 employees.

ANATECH

ANATECH is a San Diego based firm of consulting engineers that has gained international recognition for the development and application of advanced engineering analysis methods for complex structural systems. ANATECH has extensive expertise in the use of non-linear analytical methods to establish structural capacities and failure modes for loadings that are beyond the conventional design basis of structures. A cornerstone for this work is the ANATECH concrete and steel material response model, ANACAP, which is widely recognized and extensively validated for advanced modeling of concrete structures. The key personnel at ANATECH involved with the security issues for aircraft crash impact are Y. R. (Joe) Rashid and Randy J. James.

9547

TENNESSEE VALLEY AUTHORITY

Office of Natural Resources
Division of Water Resources
Eastern Area, Field Operations

KINGSTON STEAM PLANT 316 PERMIT RENEWAL REPORT - 1980

Prepared by

Robert W. Schneider and Jack D. Tuberville

Norris, Tennessee

December 1980

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CHAPTER 1

INTRODUCTION

1.1 Background

The potential impacts of thermal discharges on aquatic ecosystems have been intensively investigated. Kennedy and Mihursky (1967), Raney and Menzel (1969), Coutant (1970), Coutant and Goodyear (1972), Coutant and Pfuderer (1973), and Coutant and Talmage (1975) have compiled extensive bibliographies on thermal effects, including direct and indirect effects of temperature on growth, survival, metabolism, behavior, and reproduction of fishes. Fish movement into thermally affected areas during cold seasons and their emigration during warm months have been documented by Epler and Bieniarz (1973), Jensen (1974), Storr and Schlenker (1974), and others. This movement of fish into discharge basins in winter has resulted in increased angler use and harvest in these areas (Hanson, 1973). Barkley and Perrin (1972) also noted an excellent winter fishery and reported availability of food and dissolved oxygen were major factors governing abundance of fishes in the receiving embayment.

According to Neill and Magnuson (1974), certain taxa are encountered more frequently in heated effluents because of a greater affinity and/or tolerance for higher temperatures. They reported attraction to warm water for longnose gar (*Lepisosteus osseus*), adult carp (*Cyprinus carpio*), adult yellow bass (*Morone mississippiensis*), young pumpkinseed (*Lepomis gibbosus*), bluegill (*L. macrochirus*), and largemouth bass (*Micropterus salmoides*), but avoidance by yellow perch (*Perca flavescens*), mottled sculpin (*Cottus bairdi*), subadult yellow bass, and black bullhead (*Ictalurus melas*). White crappie (*Poxomis annularis*) and channel catfish (*Ictalurus punctatus*) have also been shown to be attracted to higher water temperatures (McNeeley and Pearson, 1974; Stauffer, et al., 1974, respectively). Benda and Proffitt (1974) found centrarchids in a heated discharge fewer in number but with a higher condition factor than those in waters of ambient temperature. Jensen (1974) similarly reported a higher condition factor for fish resident in a heated discharge, but Stauffer, et al. (1974), found a significant reduction of the condition index. Reproductive responses to increased temperatures were either slight or not detectable in studies by Cragg-Hine (1971), Whitaker, et al. (1973), and Jensen (1974).

1.2 Scope/Objectives

Investigations reviewed above have shown general statements concerning effects of heated discharges on aquatic ecosystems are not possible. The influence of a particular thermal discharge is likely dependent upon the ecology of populations in the receiving water body as well as physical characteristics of the discharge. This report will specifically address the effect of the Kingston Steam Plant heated effluent on the local fish community of Watts Bar Reservoir.

The objectives of this study were to: (1) determine the influence of the thermal effluent on the distribution of Watts Bar Reservoir fish populations in the vicinity of Kingston Steam Plant, and (2) assess the impacts of thermal effluent on selected reservoir fish populations in terms of certain life history parameters.

1.3 Physical Description of Watts Bar Reservoir

Watts Bar is a Tennessee River mainstream reservoir impounded by Watts Bar Dam (TRM 529.9) in 1942. At normal pool elevation of 225.8

meters (m), the reservoir is 15,621 hectares (ha) and extends (Figure 1.1) to Melton Hill Dam on the Clinch River (CRM 23.1) and Fort Loudoun Dam on the Tennessee River (TRM 602.3).

The Clinch River arm of Watts Bar Reservoir has one major tributary, the Emory River, which centers 7.2 kilometers (km) above the confluence of the Clinch and Tennessee Rivers. This area of the reservoir along with the Tennessee River above this confluence is more riverine than the main body of Watts Bar Reservoir.

1.4 Physical and Operational Characteristics of Kingston Steam Plant

Kingston Steam Plant is located on the Clinch River (CRM 2.7), 3.2 km northeast of Kingston (Roane County), Tennessee, and 3.1 km below the confluence of the Emory and Clinch Rivers. The nine unit fossil-fueled steam plant occupies a peninsula formed by the Emory and Clinch Rivers. The total installed generating capacity of 1,700 megawatts (MW) was attained in 1955 with completion of units 5 through 9.

An underwater structure is located immediately below the confluence of the Clinch and Emory Rivers which deflects the cooler waters of the Clinch up the Emory beyond the plant intake (ERM 1.9). The intake channel extends 1,371.6 m from plant condenser cooling water pumps to the Emory River. A skimmer wall 12.4 m deep is located at the channel inlet parallel to the riverbank. Five bottom openings 4.6 m high by 14.5 m wide (334 m^2) admit cooler water from bottom strata of the Emory and Clinch Rivers to the intake canal.

A total of 65.4 m^3s^{-1} (2,310 cfs) of cooling water is heated approximately 8 C above ambient (at maximum boiler capacity) before discharge through plant substructure conduits. These empty into a

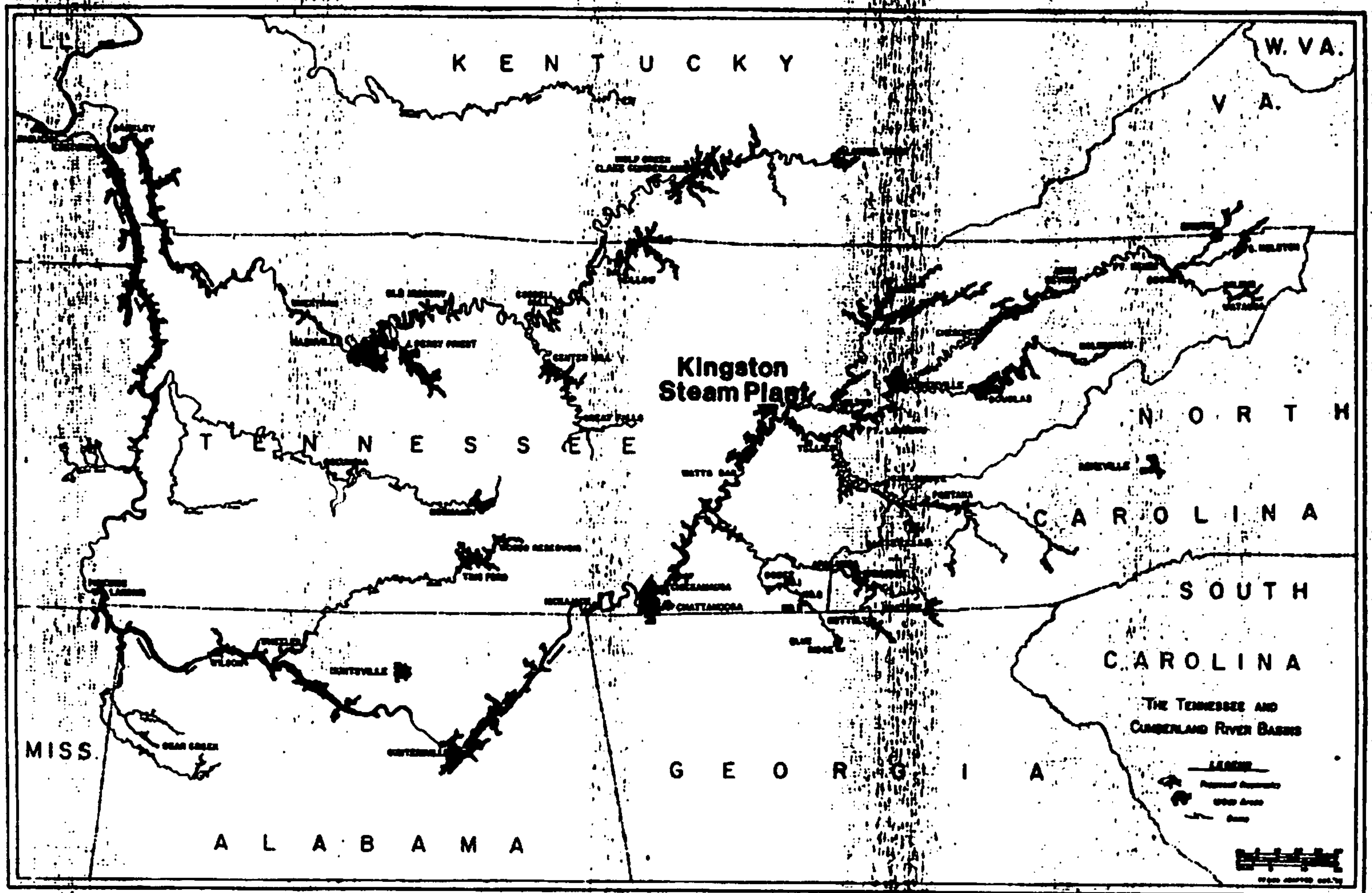


Figure 1.1 The location of the Kingston Steam Plant (Clinch River Mile 2.7) within the Tennessee River basin.

channel 182.9 m long which widens to a 3.2 ha discharge basin before joining the Clinch River arm of Watts Bar Reservoir at CRM 2.5.

CHAPTER 2

PROCEDURES

Data used to assess the impact of Kingston Steam Plant on adult fish populations in Watts Bar Reservoir were obtained using four sampling methods: gill netting, electrofishing, shoreline seining, and cove rotenone. Each of these sampling techniques yields biased results; therefore, comprehensive information on the fish community in the vicinity of Kingston Steam Plant was sought using all four methods. Deficiencies of individual sample methods were discussed in the initial Kingston fisheries report (TVA 1974) which included electrofishing, gill net, and seine data from April through October 1974 and rotenone data from 1949 through 1973. This report incorporates and updates those early data with electrofishing, gill netting, and seine collections from November 1974 through September 1975 and rotenone samples from 1975 through 1980. Three sample sites were established to provide data from areas of various impact from the thermal effluent at Kingston Steam Plant. Stations included an upstream thermally uninfluenced area, a maximum thermal effect area in the discharge channel, and a downstream station for mixed thermal effect.

2.1 Gill Netting

Standard sinking nylon gill nets measuring 30.5 m x 2.4 m with 38 millimeter (mm) bar mesh were used throughout the study. All were set perpendicular to the shoreline. Three stations were sampled for four consecutive nights each month (Figure 2.1). At both upstream and downstream stations gill nets were set at each of six substations during the first night, moved the second day to fish six different substations, and then alternated between these two sets of substations for the remainder of the

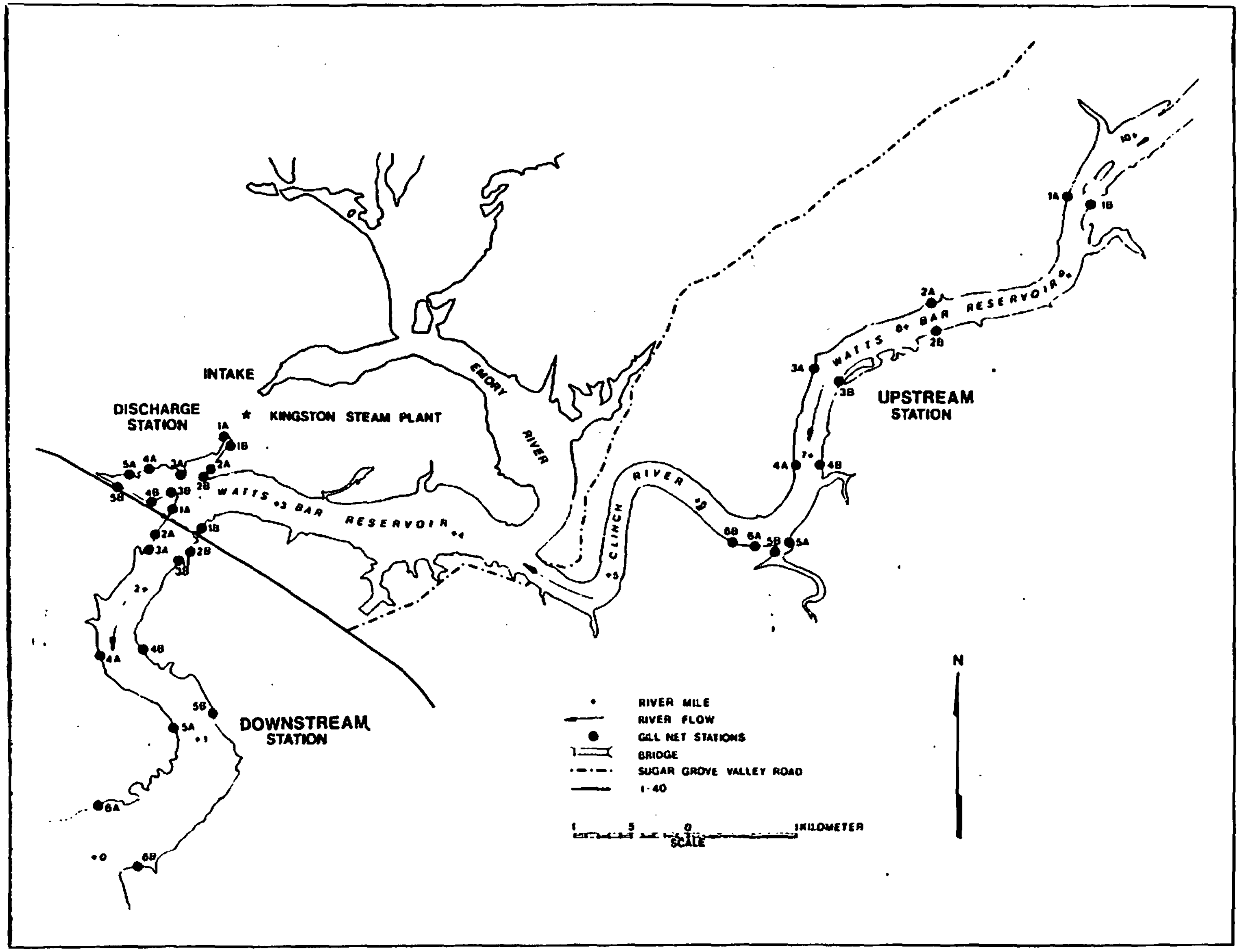


Figure 2.1. Location of gill net stations in the Clinch River (Watts Bar Reservoir) near Kingston Steam Plant.

week. Thus, 12 substations were sampled at each of these stations during a four-night period. Five gill nets were fished in a similar manner in the discharge station, resulting in 10 substations fished during a four-night period within that area (Figure 2.1).

2.2 Electrofishing

Electrofishing samples were collected biweekly from April 1974 through September 1975 two days a week. The electrofishing apparatus consisted of a portable 230 volt AC generator and a rectifier which converted the current to pulsed (180-360H_Z) DC.

Samples were collected from Watts Bar Reservoir in an area upstream of Kingston Steam Plant, within the discharge channel, and downstream from this discharge (Figure 2.2). The sequence in which stations were sampled was changed with each visit. Ten substations, five on each bank, were sampled at the upstream and downstream stations by shocking a designated section of shoreline for a three-minute period. Four substations were sampled in the discharge channel (two on each bank) and six in the discharge embayment with three stations on each bank.

The starting point of each substation was identified by existing landmarks or markers placed on the shoreline. During the three-minute sample period, the boat was operated at a constant speed, parallel to the shoreline applying continuous electrical current. Since river flow did not appear to greatly affect the boat speed except in the discharge, all substations on the left bank were sampled while moving upstream; those on the right bank, downstream. Since the velocity of water in the discharge basin was usually greater than the reservoir proper, the boat was operated to approximate the same distance traversed as at other stations.

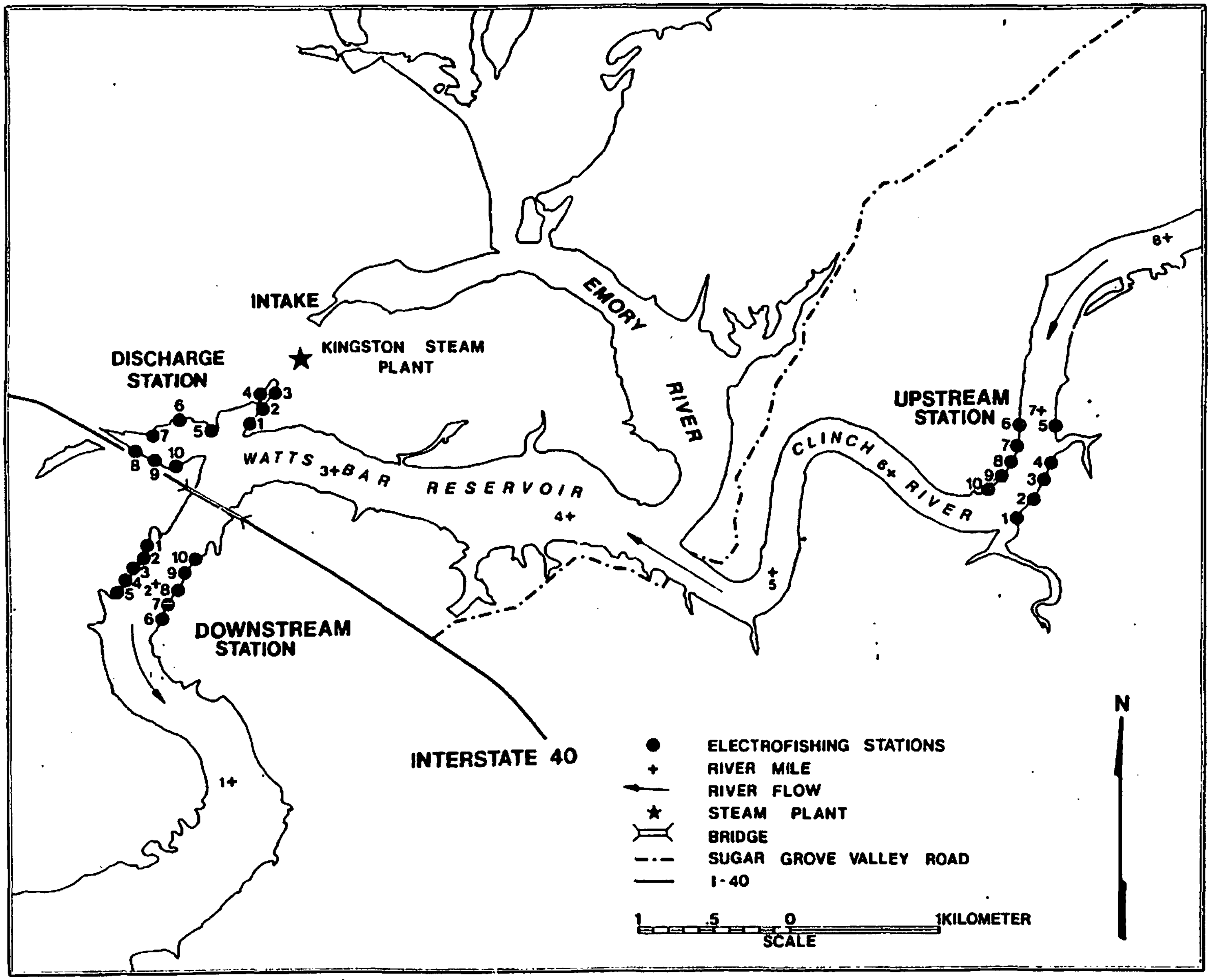


Figure 2.2. Location of electrofishing stations near Kingston Steam Plant.

Fish affected by the electrofishing unit were captured with long-handled dip nets (6.4 mm mesh), identified to species, and enumerated. Water temperatures at a depth of 1 m were recorded.

2.3 Seining

Seine samples were collected at upstream, discharge, and downstream stations using a seine measuring 6.1 m x 1.8 m with 6.4 mm bar mesh. Three shoreline seine hauls of approximately equal length were taken at each station once during September and October 1974 and September 1975. Minnows, darters, and small centrarchids were returned to the laboratory for identification. Larger species were identified in the field. Because of sparse samples seining data were used only to record species occurrence and supplement results from other gear types with respect to possible differences between stations.

2.4 Cove Rotenone

Since 1949, 69 cove rotenone samples have been taken at 27 sites in Watts Bar Reservoir (Appendix, Table 1). Samples were irregularly taken from 1949 through 1964 and then annually from 1975 through 1980. No samples were collected in the period 1965 to 1973.

Prior to 1960, rotenone sampling techniques varied from year to year and from reservoir to reservoir. For example, in Watts Bar Reservoir from 1949 through 1960 several techniques were used for determining area and volume of the sample sites, some studies were conducted without block nets. Samples beginning in 1960 (n = 61) followed methods accepted for cove rotenone surveys in the southeast (Hall 1975). Coves were surveyed, blocked with nets, and five percent emulsifiable rotenone applied at a concentration of 1 mg/l. Fish were collected for two days, grouped by species into 25 mm length groups, counted, and weighed (first day only). Weights of fish collected on the second day were estimated from those collected on the first day.

2.5 Data Presentation and Analysis

Total number, percentage composition, and mean monthly catch per unit effort (c/f) for each species collected by gill netting and electrofishing were examined to describe temporal and spatial distributions. A unit of effort for gill netting was defined as fishing one net for a 24-hour period. A unit of effort for electrofishing was defined as a shocking run at a constant speed along the shoreline for a duration of three minutes.

The influence of heated discharge on fish distributions was determined by comparing the pattern of monthly mean c/f for a particular taxon in the upstream station with patterns in discharge and downstream stations. For example, a large increase in mean monthly c/f in the discharge basin unmatched by a similar increase in the c/f in the upstream station was considered attraction to the thermal effluent, especially if this phenomenon occurred during winter. Conversely, a sharp decrease in monthly c/f for a particular species in the discharge basin not matched by a similar decrease at the upstream station was considered avoidance of the thermal effluent. Avoidance was considered likely if it occurred during the warmest months and significant if: (1) the c/f in the upstream station showed a sharp increase, and/or (2) the species was absent from the discharge basin during the same period, and/or (3) avoidance also occurred at the downstream station.

A species which occurred at all stations and constituted at least 1 percent of the total numbers of fish collected (all stations and sample periods combined) in either electrofishing or gill net samples was classified as "dominant." Spatial and temporal distribution of each dominant species were contrasted in relation to the thermal discharge of Kingston Steam Plant.

Species collected in cove rotenone samples were grouped into harvest categories and size classes for analysis (Appendix, Table 2). Rotenone samples are usually compared on the basis of standing stocks (both no./ha and kg/ha) of dominant species mainly for reservoir-wide differences through time (temporal). Species are considered dominant in rotenone samples if they meet the following criteria:

1. Must occur in at least 50 percent of all samples taken since 1960, and
2. Comprise 1 percent or more of the total number collected since 1960, or
3. Comprise 1 percent or more of the total biomass collected since 1960.

These species are discussed individually on the basis of young, intermediate, and adult sizes through time. In addition, certain species not "dominant" in rotenone samples are discussed because of sport and/or commercial fishing interests and were classified as "important." These species are flathead catfish, white bass, smallmouth bass, spotted bass, white crappie, and sauger.

Temporal changes in numbers and weight per hectare of fishes in Watts Bar Reservoir were examined using analysis of variance and Duncan's New Multiple Range Test. Since variances were found to increase as standing stock increased, a logarithmic transformation (base 10) was used to stabilize variances. Due to the presence of observations with values of zero, $\log_{10}(x + 1)$ was used to permit transformation of all data. Figures show geometric means while tables show arithmetic means and therefore different years may have the highest and/or lowest number and weight. These analyses included only data collected since sampling procedures became standardized in 1960. The 1978 samples (n = 2) were taken from the extreme lower end of the reservoir and are not considered to be representative of the fish community structure in the vicinity of Kingston Steam Plant; therefore, these samples were not included in the analyses.

CHAPTER 3

ADULT FISH RESULTS

3.1 Gill Netting Results

From April 1974 through September 1975, a total of 26,351 fish (49 species) was collected in gill nets set at the three sample areas (Table 3.1). The upstream station yielded 6,286 fish (43 species) with 11,087 (41 species) and 8,978 (43 species) collected at the discharge and downstream stations, respectively.

Seven species were designated as "dominant" in gill net samples. These were skipjack herring (*Alosa chrysochloris*), gizzard shad (*Dorosoma cepedianum*), mooneye (*Hiodon tergisus*), channel catfish, white bass (*Morone chrysops*), sauger (*Stizostedion canadense*), and freshwater drum (*Aplodinotus grunniens*). Gizzard shad were collected in greatest numbers (48 percent of total catch) followed by skipjack herring (22 percent). Sauger and white bass each comprised 5 percent of the total catch (Table 3.1).

Seasonal patterns of c/f for all species combined were usually similar at upstream and downstream stations (Figure 3.1). Discharge c/f trends were increasing from December to May and decreasing during summer. Catch rate at thermally affected stations was usually higher than the unaffected (upstream) station with the greatest difference in c/f in spring. This could be the result of attraction to the warmer water for spawning purposes.

Table 3.1. Total catch and percentage composition for species of fish collected with gill nets at three sampling stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Species	Upstream No.	Upstream Percent Comp.	Discharge No.	Discharge Percent Comp.	Downstream No.	Downstream Percent Comp.	Total No.	Total Percent Comp.
Unidentified lamprey	0	0.00	0	0.00	1	0.01	1	*
Paddlefish	14	0.22	22	0.20	13	0.14	49	0.19
Spotted gar	69	1.10	32	0.29	21	0.23	122	0.46
Longnose gar	18	0.29	57	0.91	28	0.31	103	0.39
Skipjack herring	1,138	18.10	3,230	29.13	1,480	16.48	5,848	22.19
Gizzard shad	2,675	42.55	5,448	49.13	4,750	52.91	12,873	48.85
Threadfin shad	38	0.60	70	0.63	10	0.11	118	0.48
Goldeye	1	0.02	0	0.00	0	0.00	1	*
Mooneye	664	10.56	53	0.48	332	3.70	1,049	3.98
Carp	67	1.07	11	0.10	62	0.69	140	0.53
River carpsucker	3	0.05	2	0.02	6	0.07	11	0.04
Quillback	19	0.30	30	0.27	19	0.21	68	0.26
Highfin carpsucker	1	0.02	0	0.00	1	0.01	2	*
Northern hog sucker	13	0.21	6	0.05	5	0.06	24	0.09
Smallmouth buffalo	12	0.19	25	0.23	13	0.14	50	0.19
Bigmouth buffalo	1	0.02	0	0.00	1	0.01	2	*
Black buffalo	0	0.00	1	0.01	0	0.00	1	*
White sucker	9	0.14	1	0.01	0	0.00	10	0.04
Blue sucker	0	0.00	0	0.00	1	0.01	1	*
Spotted sucker	5	0.08	1	0.01	2	0.02	8	0.03
Silver redhorse	39	0.62	5	0.05	4	0.04	48	0.18
River redhorse	9	0.14	3	0.03	5	0.06	17	0.06
Black redhorse	33	0.52	3	0.03	9	0.10	45	0.17
Golden redhorse	160	2.55	28	0.25	34	0.38	222	0.84
Shorthead redhorse	6	0.10	0	0.00	2	0.02	8	0.03
Unidentified redhorse	1	0.02	2	0.02	0	0.00	3	0.01
Blue catfish	6	0.10	48	0.43	50	0.56	104	0.39
Yellow bullhead	0	0.00	2	0.02	4	0.04	6	0.02
Channel catfish	199	3.17	426	3.84	461	5.13	1,086	4.12
Flathead catfish	9	0.14	20	0.18	36	0.40	65	0.25
White bass	216	3.44	790	7.12	344	3.83	1,350	5.12
Yellow bass	3	0.05	1	0.01	2	0.02	6	0.02
Striped bass	9	0.14	48	0.43	11	0.12	68	0.26
Hybrid white x striped bass	1	0.02	0	0.00	1	0.01	2	*
Rock bass	2	0.03	0	0.00	4	0.04	6	0.02
Redbreast sunfish	1	0.02	7	0.06	4	0.04	12	0.05
Warmouth	0	0.00	1	0.01	0	0.00	1	*
Bluegill	97	1.54	76	0.69	75	0.84	248	0.94

Table 3.1. Continued.

Species	Upstream No.	Upstream Percent Comp.	Discharge No.	Discharge Percent Comp.	Downstream No.	Downstream Percent Comp.	Total No.	Total Percent Comp.
Longear sunfish	1	0.02	1	0.00	0	0.00	2	*
Redear sunfish	1	0.02	0	0.00	2	0.02	3	0.01
Smallmouth bass	0	0.00	1	0.01	0	0.00	1	*
Spotted bass	3	0.05	4	0.04	2	0.02	9	0.03
Largemouth bass	10	0.16	15	0.14	12	0.13	37	0.14
Unidentified bass	0	0.00	0	0.00	1	0.01	1	*
White crappie	33	0.52	85	0.77	71	0.79	189	0.72
Black crappie	8	0.13	9	0.08	13	0.14	30	0.11
Unidentified crappie	0	0.00	2	0.02	0	0.00	2	*
Sauger	429	6.82	411	3.71	603	6.72	1,443	5.48
Walleye	1	0.02	3	0.03	4	0.04	8	0.03
Freshwater drum	262	4.17	107	0.96	479	5.33	848	3.22
Total	6,286		11,087		8,978		26,351	

*Less than 0.01%.

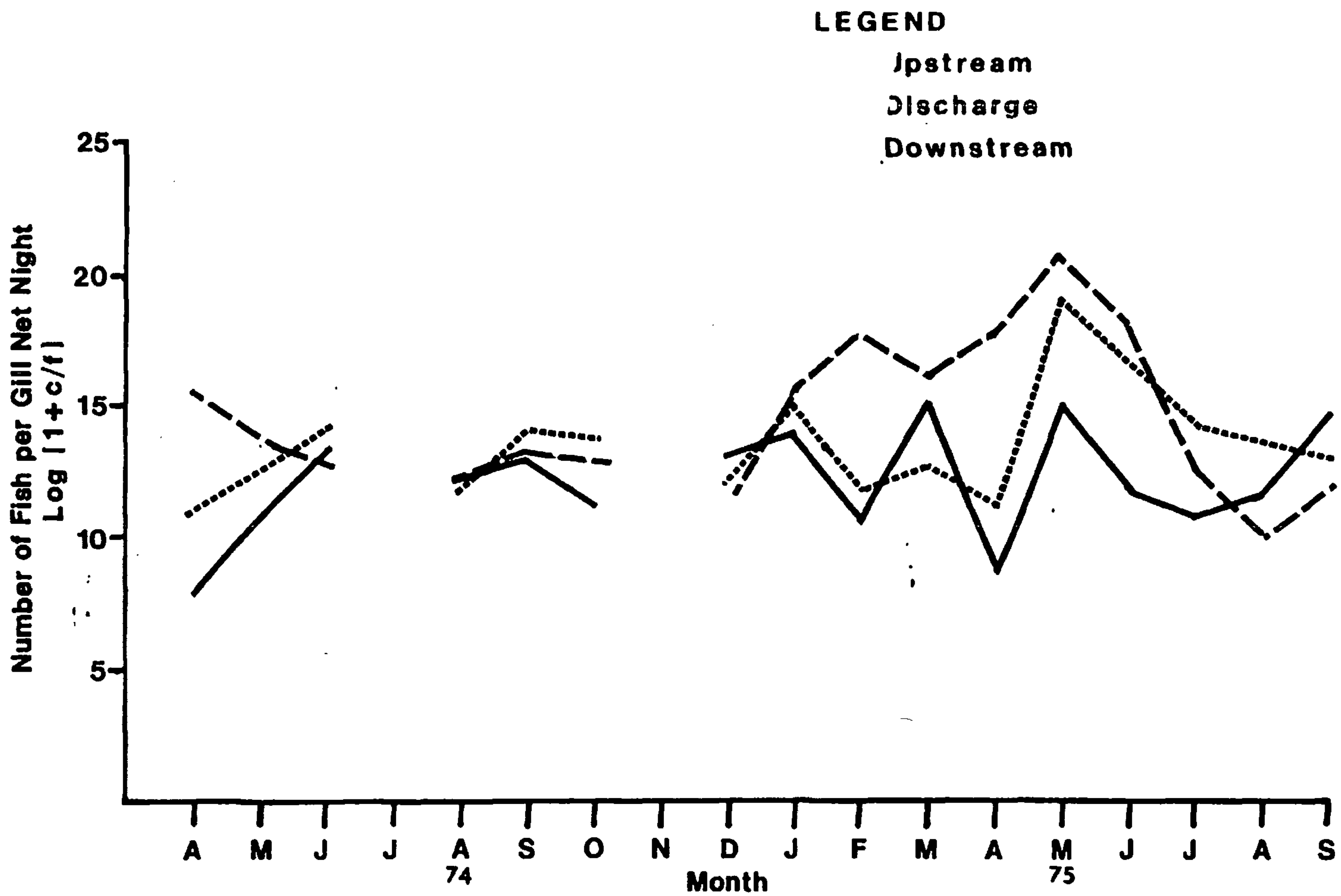


Figure 3.1 Mean monthly catch per gill net night for all species of fish collected at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

3.2 Electrofishing Results

From April 1974 through September 1975, 18,810 fishes encompassing 46 species were collected by electrofishing from three stations in Watts Bar Reservoir in the vicinity of Kingston Steam Plant (Table 3.2). In the upstream station, 5,885 fishes (38 species) were collected, while 8,064 (38 species) and 4,861 (35 species) were collected from the discharge and downstream stations, respectively.

Monthly average c/f for all species combined showed relatively similar seasonal patterns at the upstream and downstream stations (Figure 3.2). Low values occurred at both stations during June 1975 with increases at both during July and August 1975. Monthly c/f patterns in the discharge station were less in accord with the other two stations, especially the high c/f in April 1975 and low values in October 1974 and February 1975.

Seven species were designated "dominant" in electrofishing samples: gizzard shad, threadfin shad (*Dorosoma petenense*), carp, emerald shiner (*Notropis atherinoides*), bullhead minnow (*Pimephales vigilax*), bluegill, and largemouth bass. Shad comprised over 67 percent of the total number of fish collected (Table 3.2) with emerald shiner (11 percent) the next most abundant species followed by bluegill (4 percent) and largemouth bass (4 percent).

3.3 Seining Results

A total of 1,864 fish encompassing 20 species was collected by seining at the three stations near Kingston Steam Plant (Table 3.3). The distribution of numbers and species among stations was as follows: 427 fishes representing 13 species in the upstream station, 498 fishes encompassing 14 species in the discharge basin, and 939 fishes from 15 species in the downstream station.

Table 3.2. Total catch and percentage composition for species of fish collected by electrofishing in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

	Upstream		Discharge		Downstream		Total	
	No.	Percent Comp.	No.	Percent Comp.	No.	Percent Comp.	No.	Percent Comp.
Ohio lamprey	0	0.00	1	0.01	0	0.00	1	0.01
Spotted gar	1	0.01	0	0.00	1	0.02	2	0.01
Longnose gar	1	0.01	4	0.05	2	0.04	7	0.04
American eel	0	0.00	1	0.01	0	0.00	1	0.01
Skipjack herring	6	0.10	34	0.42	25	0.51	65	0.35
Gizzard shad	1,390	23.60	2,237	27.74	1,471	30.26	5,098	27.10
Threadfin shad	2,307	39.18	3,713	46.04	1,570	32.92	7,590	40.34
Mooneye	3	0.05	9	0.11	9	0.19	21	0.11
Carp	128	2.17	106	1.31	236	4.85	470	2.50
Silver chub	2	0.03	0	0.00	0	0.00	2	0.01
Golden shiner	3	0.05	0	0.00	0	0.00	3	0.02
Emerald shiner	555	9.43	887	11.00	600	12.34	2,042	10.85
Spotfin shiner	74	1.26	33	0.41	32	0.66	139	0.74
Mimic shiner	0	0.00	1	0.01	0	0.00	1	0.01
Steelcolor shiner	8	0.14	3	0.04	4	0.08	15	0.08
Pimephales sp.	519	8.81	60	0.74	105	2.16	684	3.64
River carpsucker	1	0.01	1	0.01	2	0.04	4	0.02
Quillback	2	0.03	1	0.01	1	0.02	4	0.02
Northern hog sucker	3	0.05	4	0.05	3	0.06	10	0.05
Smallmouth buffalo	10	0.16	10	0.12	13	0.27	33	0.18
Black buffalo	0	0.00	1	0.01	1	0.02	2	0.01
Black redhorse	1	0.01	0	0.00	0	0.00	1	0.01
Golden redhorse	101	1.71	10	0.12	9	0.19	120	0.64
Yellow bullhead	0	0.00	1	0.01	0	0.00	1	0.01
Channel catfish	1	0.01	5	0.06	3	0.06	9	0.05
Flathead catfish	1	0.01	9	0.11	6	0.12	16	0.09
Brook silverside	21	0.36	22	0.27	23	0.47	66	0.35
White bass	11	0.18	84	1.04	7	0.14	102	0.54
Yellow bass	0	0.00	0	0.00	3	0.06	3	0.02
Striped bass	0	0.00	1	0.01	1	0.02	2	0.01
Rock bass	1	0.01	0	0.00	0	0.00	1	0.01
Redbreast sunfish	28	0.47	65	0.81	71	1.46	164	0.87
Green sunfish	0	0.00	1	0.01	0	0.00	1	0.01
Warmouth	1	0.01	1	0.01	1	0.02	3	0.02
Bluegill	372	6.31	169	2.10	267	5.49	808	4.29
Longear sunfish	21	0.36	140	1.74	35	0.72	196	1.04
Redear sunfish	7	0.12	1	0.01	3	0.06	11	0.06
Smallmouth bass	19	0.32	29	0.36	20	0.41	68	0.36
Spotted bass	13	0.22	52	0.64	56	1.15	121	0.64
Largemouth bass	175	2.97	317	3.93	220	4.52	712	3.78
White crappie	13	0.22	14	0.17	35	0.72	62	0.32
Black crappie	1	0.01	0	0.00	0	0.00	1	0.01
Logperch	42	0.71	13	0.16	6	0.12	61	0.32

Table 3.2. Continued.

	Upstream		Discharge		Downstream		Total	
	No.	Percent Comp.	No.	Percent Comp.	No.	Percent Comp.	No.	Percent Comp.
Sauger	15	0.25	9	0.11	5	0.10	29	0.15
Freshwater drum	24	0.40	15	0.19	15	0.31	54	0.29
Banded sculpin	4	0.06	0	0.00	0	0.00	4	0.02
TOTALS	5,885		8,064		4,861		18,811	

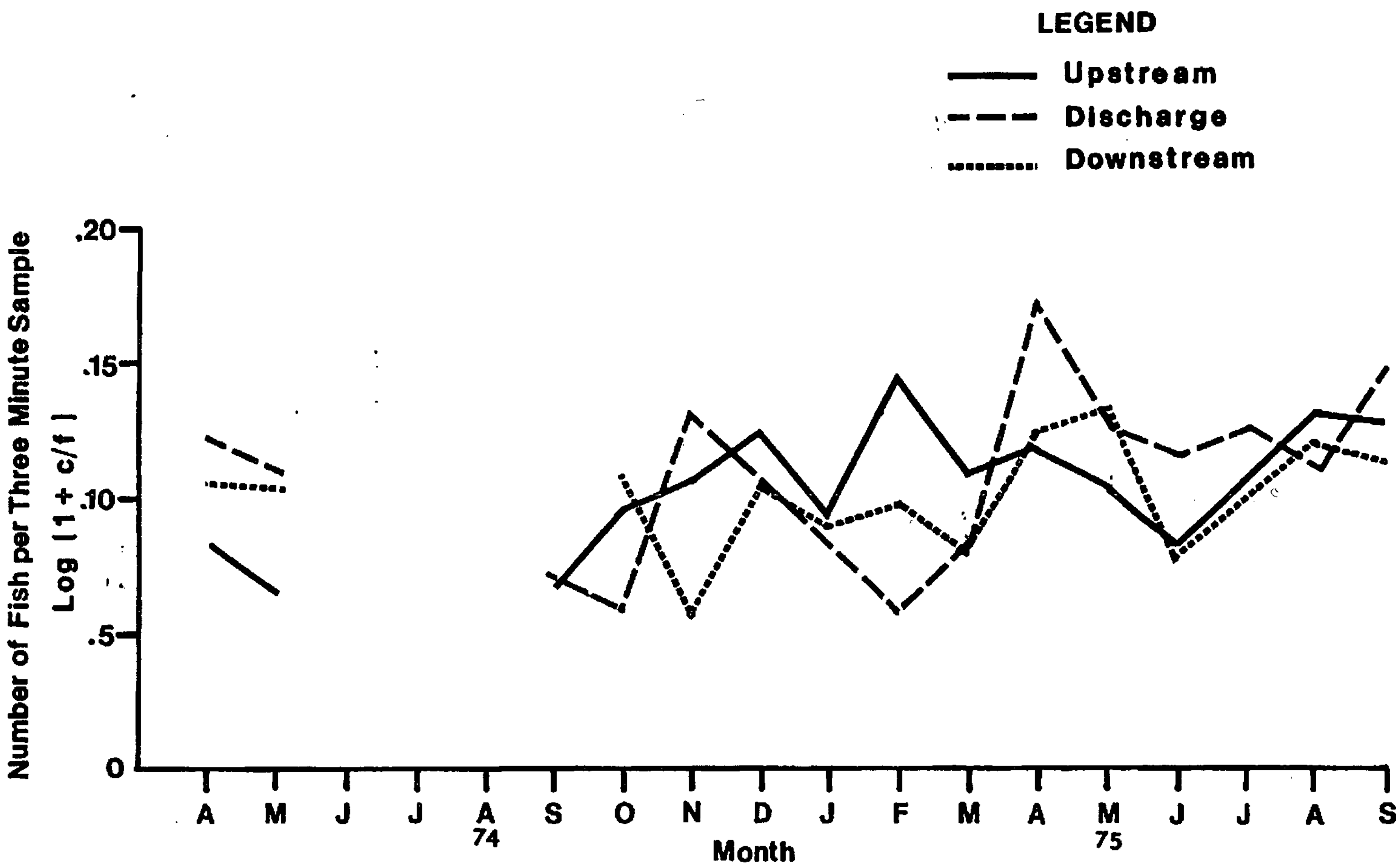


Figure 3.2 Mean monthly catch per three-minute electrofishing sample for all species of fish collected at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 3.3. Numbers and percentage composition of fish species collected by seining at three sampling stations in Watts Bar Reservoir near Kingston Steam Plant (September through October 1974 and September 1975).

Common Name	Upstream No.	Upstream Percent Composition	Discharge No.	Discharge Percent Composition	Downstream No.	Downstream Percent Composition	Total No.	Total Percent Composition
Threadfin shad	5	1.17	2	0.40	0	0.00	7	0.38
Stoneroller	0	0.00	0	0.00	1	0.10	1	0.05
Emerald shiner	36	8.43	237	47.59	177	18.85	450	24.14
Spotfin shiner	38	8.90	81	16.27	190	20.23	309	16.58
Steelcolor shiner	0	0.00	2	0.40	16	1.70	18	0.97
Pimephales sp.	139	32.55	62	12.45	437	46.54	638	34.23
Northern hog sucker	0	0.00	0	0.00	5	0.53	5	0.27
Mosquitofish	1	0.23	3	0.60	0	0.00	4	0.21
Brook silverside	41	9.60	18	3.61	74	7.88	133	7.14
Redbreast sunfish	0	0.00	25	5.02	3	0.32	28	1.50
Bluegill	136	31.85	51	10.24	11	1.17	198	10.62
Longear sunfish	0	0.00	10	2.00	1	0.10	11	0.59
Hybrid sunfish	0	0.00	1	0.20	0	0.00	1	0.05
Smallmouth bass	1	0.23	1	0.20	2	0.21	4	0.21
Spotted bass	2	0.47	0	0.00	1	0.10	3	0.16
Largemouth bass	8	1.87	4	0.80	1	0.10	13	0.70
Greenside darter	1	0.23	0	0.00	0	0.00	1	0.05
Tenn. snubnose darter	4	0.94	1	0.20	0	0.00	5	0.27
Logperch	15	3.51	0	0.00	19	2.02	34	1.84
Freshwater drum	0	0.00	0	0.00	1	0.10	1	0.05
TOTALS	427		498		939		1,864	

3.4 Species Occurrences Near Kingston Steam Plant

A total of 63 species was collected by electrofishing and netting during 1974 and 1975 studies (Table 3.4). Fifty species were collected in the thermally uninfluenced area upstream of Kingston Steam Plant, 52 species occurred in downstream samples and 54 species were found in the discharge basin. Twenty species were collected only at one or two sampling stations in small numbers.

Four species were collected exclusively at the upstream station, four only in the discharge, and two other species were taken only from the downstream station (Table 3.4). Only a few specimens of each species were collected and their absence at other sample stations indicates low abundance and/or specific habitat requirements rather than thermal effects.

Two closely related species, bullhead minnow and bluntnose minnow, were each solely recorded from different gear (seining and electrofishing, respectively) in similar abundance. Since it is unlikely that these two similar species would be sampled exclusively by different gear types, a taxonomic error is highly probable. Habitat in the study area is most like that described for the bullhead minnow (Pflieger 1975). These two species will be discussed as a single taxon (Pimephales sp.) in the discussion of "dominant" species.

3.5 Seasonal Distributions

Seasonal patterns were evident with respect to the number of species collected by gill netting and electrofishing. A lower number of species (less than 14) was usually found at the three gill netting stations during winter with increases at all stations in spring and summer 1975 (Figure 3.3). The number of species collected per month by electrofishing

Table 3.4. Numbers of fish collected by three gear types at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Common Name	Gear: Gill Net			Electrofishing			Seine		
Station:	U[1]	D[2]	DS[3]	U	D	DS	U	D	DS
Ohio lamprey*	0	0	0	0	1	0	0	0	0
Unidentified lamprey	0	0	1	0	0	0	0	0	0
Paddlefish	14	22	13	0	0	0	0	0	0
Spotted gar	9	32	21	1	0	1	0	0	0
Longnose gar	18	57	28	1	4	2	0	0	0
American eel*	0	0	0	0	1	0	0	0	0
Skipjack herring	1,138	3,230	1,480	6	34	25	0	0	0
Gizzard shad	2,675	5,448	4,750	1,390	2,237	1,471	0	0	0
Threadfin shad	38	70	10	2,307	3,713	1,570	5	2	0
Mooneye	5	53	332	3	9	9	0	0	0
Stoneroller*	0	0	0	0	0	0	0	0	1
Carp	67	11	62	128	106	236	0	0	0
Silver chub*	0	0	0	2	0	0	0	0	0
Golden shiner*	0	0	0	3	0	0	0	0	0
Emerald shiner	0	0	0	555	887	600	0	0	0
Spotfin shiner	0	0	0	74	33	32	38	81	190
Mimic shiner*	0	0	0	0	1	0	0	0	0
Steelcolor shiner	0	0	0	8	3	4	0	2	16

Table 3.4. Continued.

Common Name	Gear: Station:	Gill Net U[1]	D[2]	DS[3]	Electrofishing U	D	DS	Seine U	D	DS
Bluntnose minnow		0	0	0	0	0	0	139	62	437
Bullhead minnow		0	0	0	519	60	105	0	0	0
River carpsucker		3	2	6	1	1	2	0	0	0
Quillback		19	30	19	2	1	1	0	0	0
Unidentified carpsucker		1	0	1	0	0	0	0	0	0
White sucker*		9	1	0	0	0	0	0	0	0
Blue sucker*		0	0	1	0	0	0	0	0	0
Northern hog sucker		13	6	5	3	4	3	0	0	5
Smallmouth buffalo		12	25	13	10	10	13	0	0	0
Bigmouth buffalo*		1	0	1	0	0	0	0	0	0
Black buffalo*		0	1	0	0	1	1	0	0	0
Spotted sucker		5	1	2	0	0	0	0	0	0
Silver redhorse		39	5	4	0	0	0	0	0	0
River redhorse		9	3	5	0	0	0	0	0	0
Black redhorse		33	3	9	1	0	0	0	0	0
Golden redhorse		160	28	34	101	10	9	0	0	0
Shorthead redhorse*		6	0	2	0	0	0	0	0	0
Unidentified redhorse		1	2	0	0	0	0	0	0	0
Blue catfish		6	48	50	0	0	0	0	0	0
Yellow bullhead*		0	2	4	0	1	0	0	0	0
Channel catfish		199	426	461	1	5	3	0	0	0
Flathead catfish		9	20	36	1	9	6	0	0	0
Mosquitofish*		0	0	0	0	0	0	1	3	0
Brook silverside		0	0	0	21	22	23	41	18	74
White bass		216	790	344	11	84	7	0	0	0
Yellow bass		3	1	2	0	0	3	0	0	0

Table 3.4. Continued.

Common Name	Gear: Station:	Gill Net U[1]	Gill Net D[2]	Gill Net DS[3]	Electrofishing U	Electrofishing D	Electrofishing DS	Seine U	Seine D	Seine DS
Striped bass		9	48	11	0	1	1	0	0	0
White-striped hybrid*		1	0	1	0	0	0	0	0	0
Rock bass*		2	0	4	1	0	0	0	0	0
Redbreast sunfish		1	7	4	28	65	71	0	25	3
Green sunfish*		0	0	0	0	1	0	0	0	0
Warmouth		0	1	0	1	1	1	0	0	0
Bluegill		97	76	75	372	169	267	136	51	11
Longear sunfish		1	1	0	21	140	35	0	10	1
Redear sunfish		1	0	2	7	1	3	0	0	0
Hybrid sunfish*		0	0	0	0	0	0	0	1	0
Smallmouth bass		0	1	0	19	29	20	1	1	2
Spotted bass		3	4	2	13	52	56	2	0	1
Largemouth bass		10	15	12	175	317	220	8	4	1
Unidentified bass		0	0	1	0	0	0	0	0	0
White crappie		33	85	71	13	14	35	0	0	0
Black crappie		8	9	13	1	0	0	0	0	0
Unidentified crappie		0	2	0	0	0	0	0	0	0
Greenside darter*		0	0	0	0	0	0	1	0	0
Tenn. snubnose darter*		0	0	0	0	0	0	4	1	0
Logperch		0	0	0	42	13	6	15	0	19
Sauger		429	411	603	15	9	5	0	0	0
Walleye		1	3	4	0	0	0	0	0	0
Freshwater drum		262	107	479	24	15	15	0	0	1
Banded sculpin*		0	0	0	4	0	0	0	0	0

*Species which were not collected in all three stations (i.e. Control, Discharge, and Intermediate).
1. Upstream Station
2. Discharge
3. Downstream Station

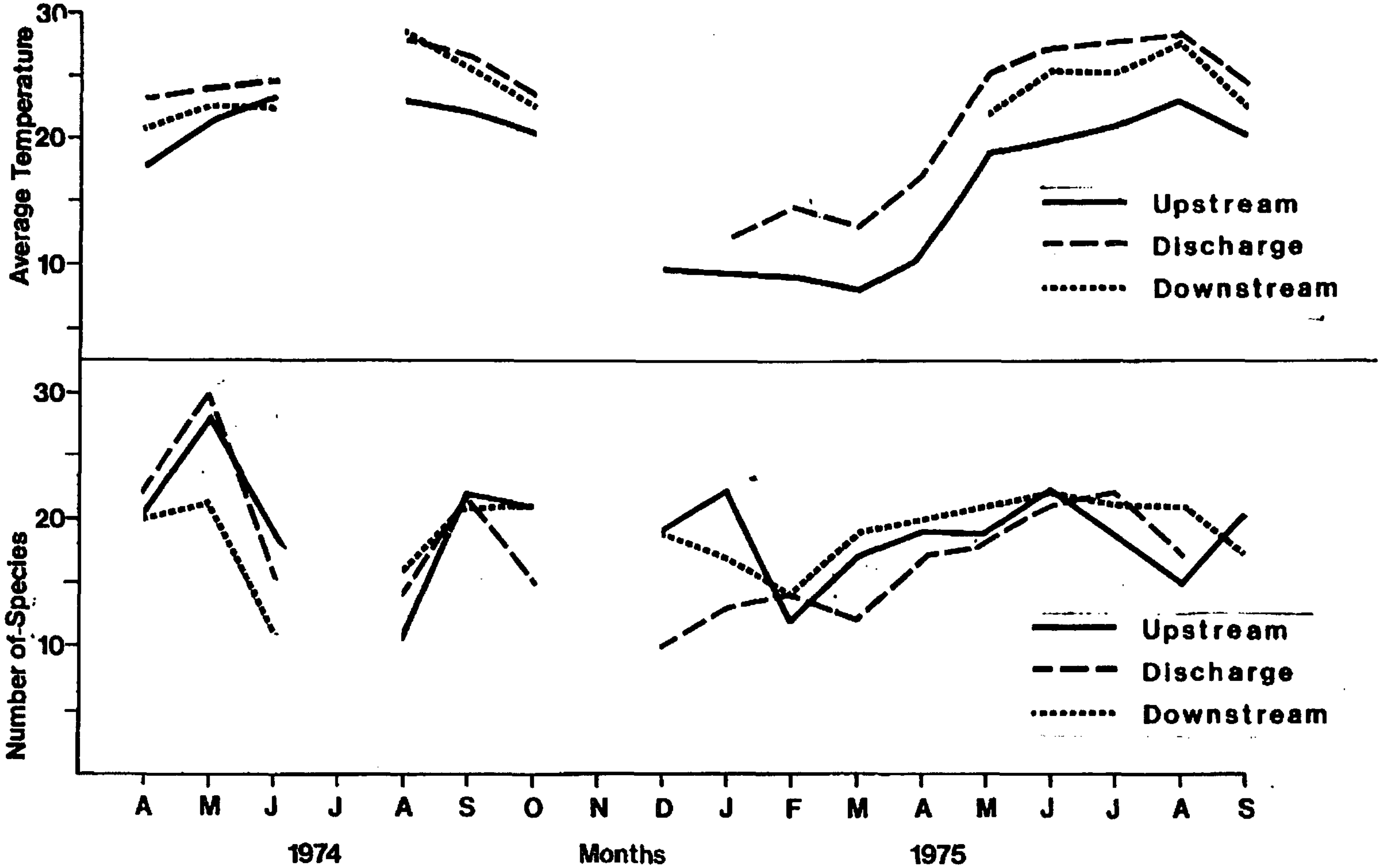


Figure 3.3. Mean monthly surface temperatures and total number of species collected each month with gill nets at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

showed a similar trend of low number of species caught during winter; however, substantial increases were observed from April through early summer of 1975 (Figure 3.4). Increases in the spring could possibly be attributed to migratory spawners such as sauger and white bass passing the plant vicinity in route to spawning areas. Increases during the summer were probably due to seasonal distribution patterns of most species resulting in high concentrations in the littoral zone during the summer and in the limnetic zone during the winter. Sampling during these investigations were restricted to the littoral or shoreline areas throughout the year.

A comparison of water temperature data (Figure 3.3) and the number of species collected by gill netting at the discharge station did not indicate any significant thermal effect; i.e., the number of species collected decreased but was not low during periods of maximum discharge temperature (June and July 1975). The number of species collected each month by electrofishing also showed little or no response to increased temperature during June and July 1975 (Figure 3.4).

3.6 Cove Rotenone Results

Sixty-three species from 14 families were collected in 59 cove rotenone samples in Watts Bar Reservoir, 1960 through 1980, with four species collected in all samples (Table 3.5). Species contributing greatest number and biomass to the total sample (all years) were gizzard and threadfin shad. Combined they contributed more than 54 percent by number and 35 percent by weight. Several commercial species (carp, smallmouth buffalo, and freshwater drum) comprised very low percentages by number but more than 10 percent by weight. Bluegill was the most abundant sport fish, followed by largemouth bass.

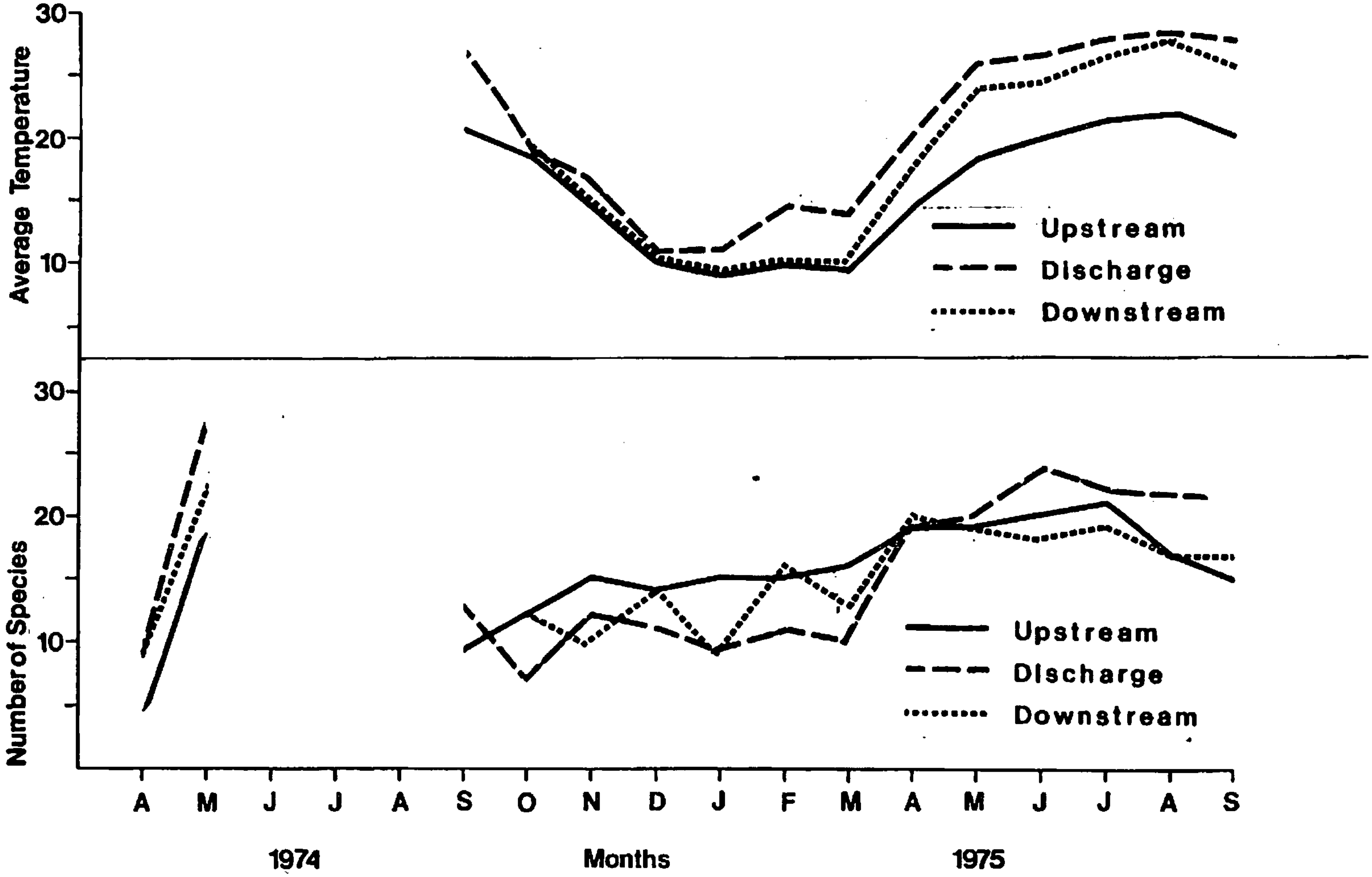


Figure 3.4. Mean monthly water temperatures recorded at one-meter depth and total number of species collected each month by electrofishing at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 3.5. List of fish species, frequency of occurrence in 59 samples and percent composition by number and weight from rotenone samples of Watts Bar Reservoir, 1960 through 1980.

Common Name	Scientific Name	Sample Occurrence	Percent by Number	Percent by Weight
	Sport Fish Species			
White bass[i]	*Morone chrysops*	51	0.3342	0.4477
Yellow bass	*Morone mississippiensis*	18	0.1842	0.1003
Striped bass	*Morone saxatilis*	2	0.0010	0.0005
Hybrid white x striped bass	*Morone* sp. (Hybrid)	1	0.0025	0.0023
Rock bass	*Ambloplites rupestris*	2	0.0010	0.0028
Unidentified sunfish	*Lepomis* sp.	10	0.2041	0.0023
Warmouth	*Lepomis gulosus*	55	0.6766	0.3132
Redbreast sunfish	*Lepomis auritus*	42	0.6766	0.5501
Green sunfish	*Lepomis cyanellus*	1	0.0010	0.0004
Bluegill[d]	*Lepomis macrochirus*	59	18.9931	6.3154
Longear sunfish	*Lepomis megalotis*	23	0.2369	0.1025
Redear sunfish	*Lepomis microlophus*	21	0.0204	0.0449
Hybrid sunfish	*Lepomis* sp. (Hybrid)	1	0.0021	0.0004
Unidentified bass	*Micropterus* sp.	1	0.0004	Trace
Smallmouth bass[i]	*Micropterus dolomieui*	44	0.3491	0.3699
Spotted bass[i]	*Micropterus punctulatus*	28	0.2435	0.1315
Largemouth bass[d]	*Micropterus salmoides*	59	1.5932	2.3851
Unidentified crappie	*Pomoxis* sp.	2	0.0008	Trace
White crappie[i]	*Pomoxis annularis*	48	0.4968	0.4009
Black crappie	*Pomoxis nigromaculatus*	22	0.0177	0.0535
Yellow perch	*Perca flavescens*	9	0.0190	0.0208
Sauger[i]	*Stizostedion canadense*	49	0.1230	0.4652
Walleye	*Stizostedion vitreum vitreum*	1	0.0009	0.0001

Table 3.5. Continued.

Common Name	Scientific Name	Sample Occurrence	Percent by Number	Percent by Weight
	Commercial Fish Species			
Chestnut lamprey	*Ichthyomyzon castaneus*	2	0.0019	0.0011
Spotted gar	*Lepisosteus oculatus*	9	0.0064	0.0724
Longnose gar	*Lepisosteus osseus*	22	0.0131	0.1169
Unidentified gar	*Lepisosteus* sp.	3	0.0022	0.0008
Skipjack herring	*Alosa chrysochloris*	44	0.1348	0.2619
Mooneye	*Hiodon tergisus*	10	0.0061	0.0236
Carp[d]	*Cyprinus carpio*	57	0.3927	19.0712
Unidentified carpsuckers	*Carpiodes* sp.	1	0.0003	0.0062
River carpsucker	*Carpiodes carpio*	12	0.0158	0.5203
Quillback	*Carpiodes cyprinus*	2	0.0012	0.0016
White sucker	*Catostomus commersoni*	3	0.0018	0.0455
Northern hog sucker	*Hypentelium nigricans*	17	0.0211	0.1179
Smallmouth buffalo[d]	*Ictiobus bubalus*	44	0.3152	15.1965
Bigmouth buffalo	*Ictiobus cyprinellus*	4	0.0197	0.9703
Black buffalo	*Ictiobus niger*	5	0.0032	0.3235
Spotted sucker	*Minytrema melanops*	19	0.0646	0.8178
Unidentified redhorse	*Moxostoma* sp.	3	0.0019	0.0142
Silver redhorse	*Moxostoma anisurum*	1	0.0005	0.0001
Shorthead redhorse	*Moxostoma macrolepidotum*	8	0.0036	0.0237
River redhorse	*Moxostoma carinatum*	2	0.0013	0.0306
Black redhorse	*Moxostoma duquesnei*	16	0.0271	0.4368
Golden redhorse[d]	*Moxostoma erythrurum*	44	0.1192	1.6094
Unidentified catfish	*Ictalurus* sp.	1	0.0006	0.0007
Blue catfish	*Ictalurus furcatus*	1	0.0016	0.0040
Black bullhead	*Ictalurus melas*	1	0.0004	0.0003
Yellow bullhead	*Ictalurus natalis*	8	0.0076	0.0093
Brown bullhead	*Ictalurus nebulosus*	1	0.0004	0.0004
Channel catfish[d]	*Ictalurus punctatus*	53	0.4001	1.9766
Flathead catfish[i]	*Pylodictis olivaris*	35	0.0384	0.3516
Freshwater drum[d]	*Aplodinotus grunniens*	59	3.5674	10.0244

Table 3.5. Continued.

Common Name	Scientific Name	Sample Occurrence	Percent by Number	Percent by Weight
	Prey Fish Species			
Gizzard shad[d]	Dorosoma cepedianum	59	15.7782	32.2312
Threadfin shad[d]	Dorosoma petenense	54	39.0223	3.2167
Hybrid shad	Dorosoma sp. (Hybrid)	4	0.0020	0.0024
Stoneroller	Campostoma anomalum	6	0.0044	0.0004
Silver chub	Hybopsis storeriana	4	0.0061	0.0028
Golden shiner	Notemigonus crysoleucas	5	0.0029	0.0040
Unidentified shiner	Notropis sp.	4	0.0494	0.0034
Emerald shiner	Notropis atherinoides	32	0.3097	0.0160
Common shiner	Notropis cornutus	1	0.0008	0.0000
Whitetail shiner	Notropis galacturus	9	0.0027	0.0001
Silver shiner	Notropis photogenis	5	0.0203	0.0021
Spotfin shiner	Notropis spilopterus	21	0.3365	0.0279
Steelcolor shiner	Notropis whipplei	21	0.1960	0.0207
Unidentified minnow	Pimephales sp.	5	0.1414	0.0085
Bluntnose minnow	Pimephales notatus	32	1.8219	0.0620
Fathead minnow	Pimephales promelas	28	0.0554	0.0109
Bullhead minnow	Pimephales vigilax	22	2.5383	0.1122
Unidentified madtom	Noturus sp.	1	0.0003	0.0000
Mosquitofish	Gambusia affinis	2	0.0016	0.0001
Greenside darter	Etheostoma blennioides	1	0.0003	0.0000
Logperch	Percina caprodes	52	0.3747	0.1260
Banded sculpin	Cottus carolinae	1	0.0004	0.0002
Brook silverside	Labidesthes sicculus	41	0.0910	0.0050

i = important species
d = dominant species

Among the prey group, gizzard shad was the only species to occur in every sample while threadfin shad were present in 54 of the 59 samples. Two game species (largemouth bass and bluegill) were collected in every sample, and white bass and warmouth were missing from only eight and four samples, respectively. Of the commercial fish species most frequently encountered, freshwater drum were present in all samples, carp in 57 and channel catfish in 53.

Evaluation of the presence of species in samples over the years showed that blue catfish have not been collected since 1964 and 11 species have appeared since 1973. Rock bass and walleye were collected only in 1973, the year stoneroller, white sucker, and yellow bass were first reported. Mosquitofish and black bullhead were first collected in 1975, brown bullhead, chestnut lamprey, and yellow perch in 1976, quillback and silver redhorse in 1977, and green sunfish in 1979.

Total fish numbers fluctuated considerably but biomass remained relatively stable throughout the sample period (Table 3.6). There was no significant difference ($\alpha = 0.05$) in total numbers of fish/ha from 1960 to 1980 possibly because of high within year variation in the young fish group (Table 3.7). The largest number of fish per ha (24,346) were collected in 1960. Standing stocks from all other samples averaged less than 8,503 fish per ha. Lowest numbers of fish per ha occurred in 1975 and 1979. The 1979 lows probably resulted from two consecutive very cold winters which considerably reduced the number of threadfin shad in the 1979 samples.

Analysis of variance showed a highly significant difference ($\alpha = 0.01$) in total biomass from 1960 to 1980 with highest biomass per ha in 1973, 1975, and 1980 (Tables 3.6 and 3.7). The 1980 biomass was much

Table 3.6. Number of samples and mean annual standing stock (no/ha and kg/ha) for young, intermediate, and adult fish collected from cove rotenone samples in Watts Bar Reservoir 1960 through 1980.

Year	Number of Samples	Young-of-year		Intermediate		Adult		Total	
		Number	Biomass	Number	Biomass	Number	Biomass	Number	Biomass
1960	3	23,626.78	32.01	304.12	16.27	414.73	161.23	24,345.62	209.51
1964	20	5,199.76	11.75	398.64	19.53	508.68	174.23	6,107.08	205.51
1973	10	13,236.87	29.72	854.46	30.18	1,237.82	286.64	15,329.16	346.54
1975	6	1,873.22	5.05	574.21	23.64	1,112.00	317.50	3,559.43	346.19
1976	8	3,222.65	10.15	809.62	23.29	843.27	224.89	4,875.54	258.33
1977	8	8,849.50	22.01	445.67	14.93	877.27	189.75	10,172.44	226.69
1979	2	1,999.34	14.22	469.18	16.38	910.28	176.89	3,378.80	207.49
1980	2	11,629.65	12.52	523.81	23.63	3,947.03	411.92	16,100.49	448.07
All Years	59	7,496.93	16.43	557.68	21.51	914.36	224.31	8,968.97	262.25
Percentage		83.60	6.30	6.20	8.20	10.20	85.50		

Table 3.7. Analysis of variance and Duncan's New Multiple Range Test for differences in numbers and weights per hectare of fish groups collected in cove rotenone samples in Watts Bar Reservoir, 1960 through 1980. Ranking is from highest abundance to lowest (left to right). Years that do not differ significantly (α = 0.05) are connected by the same line. Degrees of freedom were 7 for treatments and 51 for error.

Group	Anova F. Value	Years							
		Numbers							
Young	0.75	77	80	73	64	76	60	79	75
Intermediate	4.16**	73	76	75	80	79	77	64	60
Adult	6.99**	80	73	79	75	76	77	64	60
Sport	1.87	80	73	77	76	75	79	64	60
Commercial	1.00	73	60	75	64	76	80	77	79
Prey	1.27	80	73	77	60	64	76	79	75
Total	1.25	80	73	77	60	64	76	79	75
		Years							
		Biomass							
Young	0.89	73	79	77	60	76	80	64	75
Intermediate	2.05	73	76	80	75	64	79	60	77
Adult	1.95	80	73	75	76	64	79	77	60
Sport	9.83**	73	79	76	75	77	80	64	60
Commercial	1.39	75	60	64	73	76	80	79	77
Prey	3.25**	80	73	77	75	79	76	64	60
Total	2.14	80	73	75	76	60	64	77	79

*Significant at α = 0.05. **Significant at α = 0.01.

greater than any other because of large numbers of adult gizzard shad in samples. Biomass estimates decreased from 1975 through 1979. In 1980 the fish community apparently made a significant recovery with biomass estimates being the highest ever found in Watts Bar Reservoir.

The total sample (all years) was divided into sport, commercial, and prey categories. Sport fishes ranked as the intermediate group in terms of numbers (24.2 percent) and low group in composition by biomass (11.7 percent; Table 3.8). Both parameters exhibited no distinct trends through time, but numbers were highest in 1980 while biomass peaked in 1973. Analysis of variance for the 1960 to 1980 period showed significant differences (α = 0.05) in sport fish biomass between some years (Table 3.7).

Commercial fishes made up only 5.2 percent of the total number but over 50 percent of the total biomass (Table 3.8). Commercial fish numbers and biomass per ha were low in 1977 and 1979 and peaked in 1973 and 1975, respectively. Mean numbers showed a declining trend from 1973 to 1979 while biomass was relatively stable. Unusually cold winters may have been the cause for reductions in biomass in 1977. Analysis of variance showed no differences between years (Table 3.7).

Prey fishes were numerically the largest group with 70.7 percent of mean total numbers for all samples (Table 3.8). Mean annual numbers fluctuated through time but there was no significant difference (α = 0.05) over years (Table 3.7). Prey species biomass accounted for 36.3 percent of the total. Highest biomass values occurred every three years and there was a significant difference between some years (Table 3.7).

Evaluation by year and by size group showed that young-of-year comprised 83.6 percent of the total number and 6.3 percent of the total

Table 3.8. Mean annual standing stock estimates (no./ha and kg/ha) of sport, commercial, and prey fish collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Sport Fishes		Commercial Fishes		Prey Fishes	
	Number	kg	Number	kg	Number	kg
1960	580.39	11.98	525.14	142.63	23,240.09	4.89
1964	2,089.78	18.62	445.43	128.24	3,571.87	64.52
1973	2,717.38	50.23	606.84	142.85	12,004.94	153.46
1975	1,633.14	32.18	546.55	223.53	1,379.75	90.48
1976	2,054.27	39.43	421.04	151.89	2,400.22	67.01
1977	2,260.27	31.43	364.70	75.74	7,547.47	119.52
1979	1,378.85	40.61	224.27	104.15	1,775.69	62.72
1980	5,079.83	30.04	391.31	128.20	10,629.35	289.82
All Years	2,168.53	30.71	463.54	136.41	6,336.90	95.13
Percentage	24.2	11.70	5.20	52.00	70.70	36.30

biomass (Table 3.6). Analysis of variance and Duncan's New Multiple Range Test indicated no significant differences between sample mean numbers and biomass of young fishes since 1960 (Table 3.7) and no general trends were evident.

The intermediate group comprised 5.8 percent by number and 8.6 percent by weight of the total. Analysis of variance showed a significant difference ($\alpha = 0.01$) for intermediate mean numbers between years but no significant difference for biomass (Table 3.7). No distinct overall trends were observed.

Adult fishes made up 10.2 percent and 85.5 percent by number and biomass, respectively (Table 3.6), and only numbers showed a significant difference between years ($\alpha = 0.01$, Table 3.7). Samples collected in 1980 were the highest ever recorded and resulted from the exceptionally large sample of adult gizzard shad.

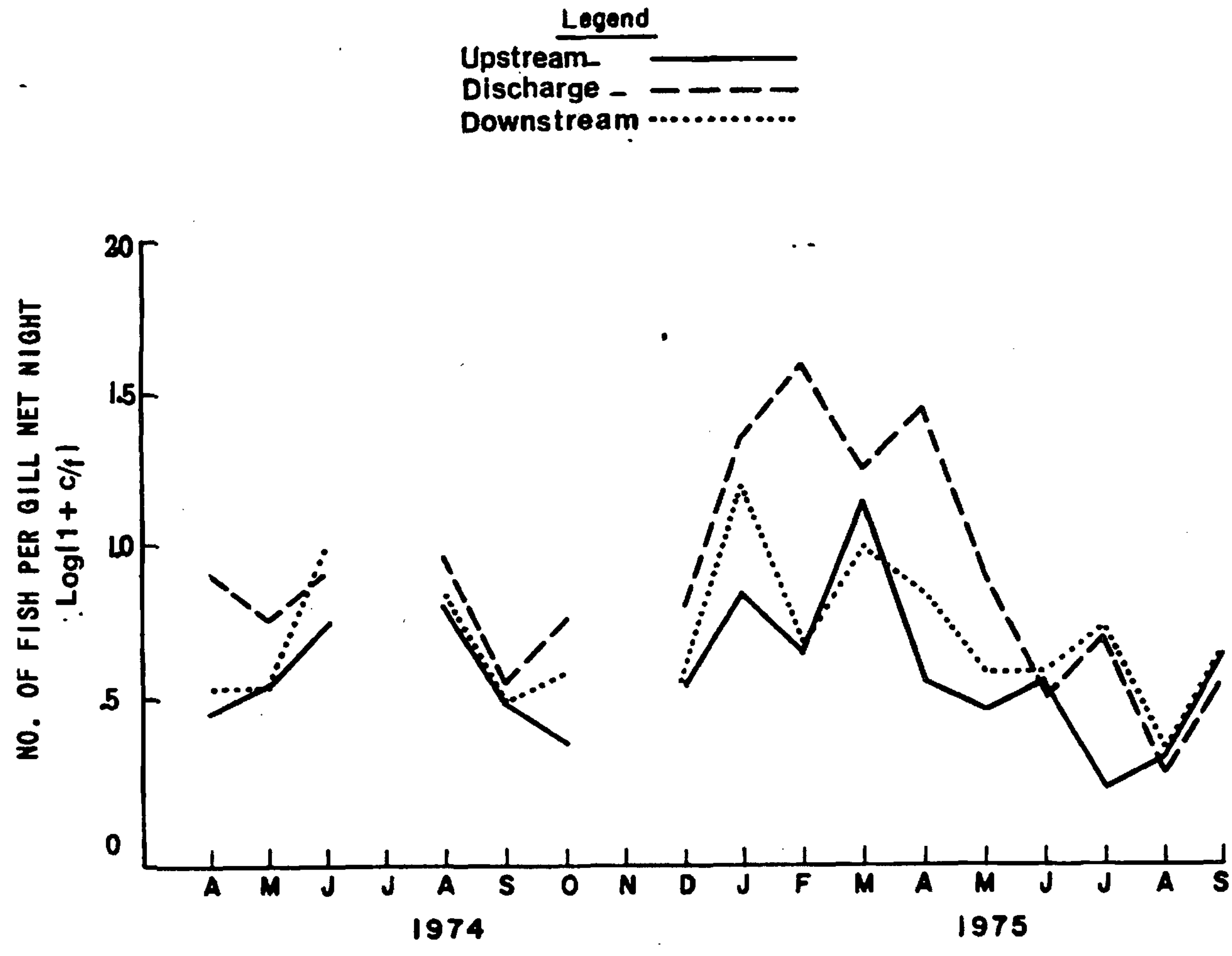


Figure 4.1. Mean monthly catch per gill net night for skipjack herring (*Alosa chrysochloris*) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

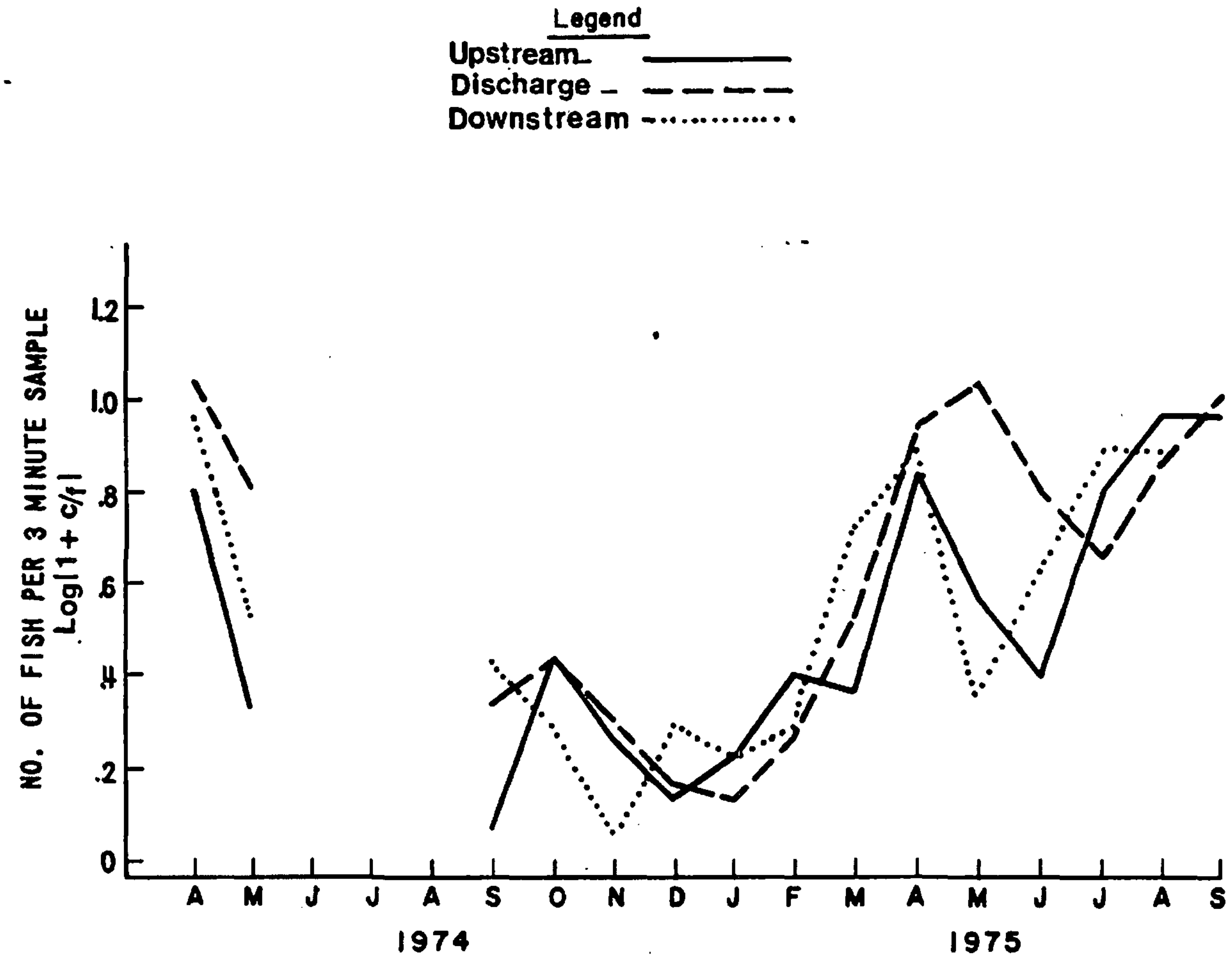


Figure 4.2. Mean monthly catch per three minute electrofishing sample for gizzard shad (Dorosoma cepedianum) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

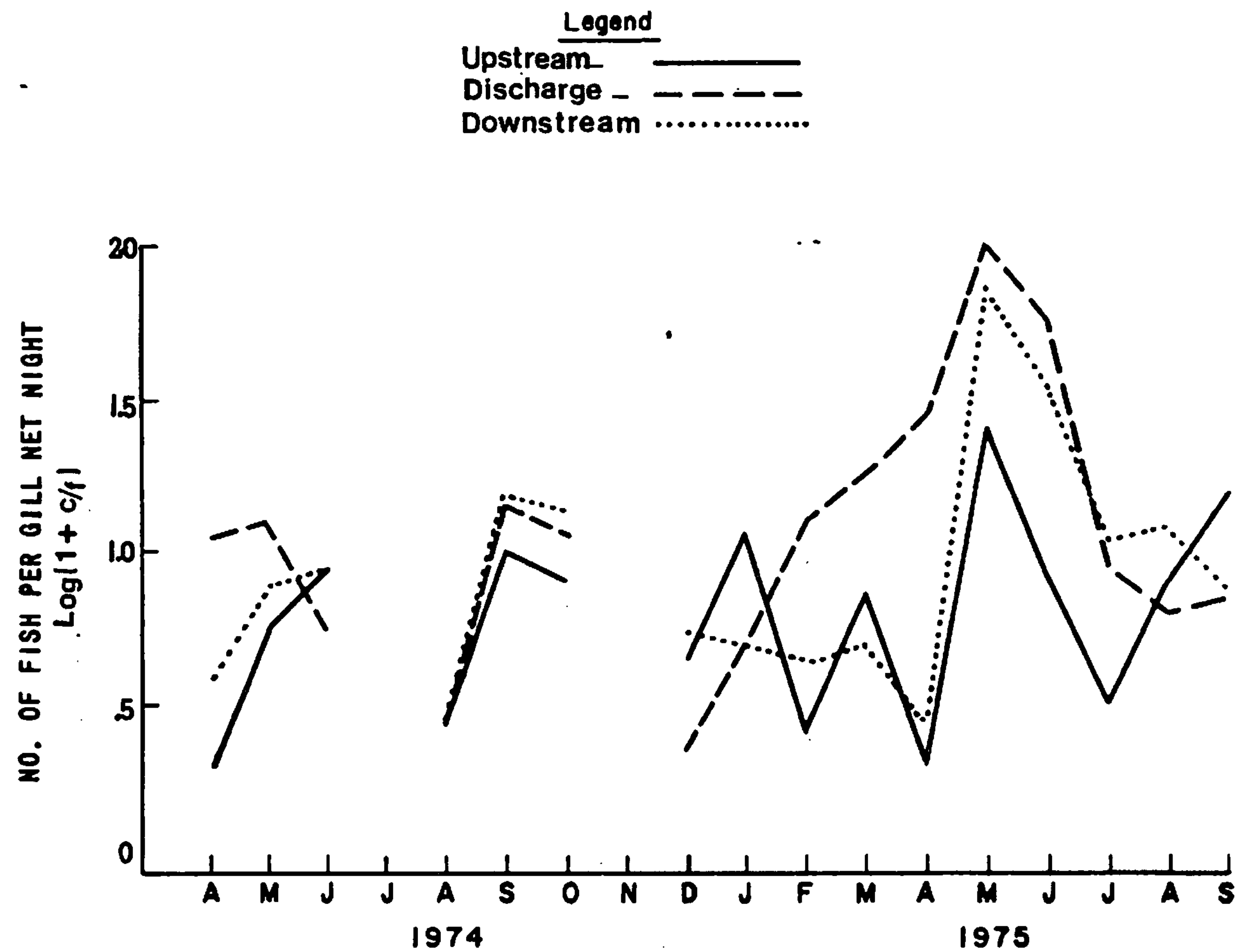


Figure 4.3. Mean monthly catch per gill net night for gizzard shad (Dorosoma cepedianum) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Long-term trends in abundance and biomass estimates were evaluated using results of cove rotenone samples. Adult gizzard shad had higher numbers and weights in samples after 1960 with the 1980 samples much higher in numbers and biomass than any others (Table 4.1); however, no discernible trends were apparent. Mean annual numbers and biomass were relatively high with an average of 2,005 fish/ha weighing 81 kg. Both mean numbers and biomass have shown significant differences between years (α = 0.01; Tables 4.2 and 4.3).

4.3 Threadfin Shad

Threadfin shad was a dominant species in electrofishing and rotenone samples. Electrofishing c/f patterns were erratic with little similarity among areas (Figure 4.4). There was no distinct period of high abundance, but common periods of low c/f were October 1974 and May through June 1975. Maximum peaks for each station occurred February to April and all were slightly greater than highs at other times of the year. There was no evidence heated effluent from Kingston Steam Plant adversely affected spatial distribution of this species in Watts Bar Reservoir.

Cove rotenone samples showed large year to year fluctuations in mean numbers and biomass of threadfin shad largely due to numbers of young-of-year (Table 4.4). Threadfin shad annual mean numbers showed significant differences between years (Tables 4.2 and 4.3). Numbers and to a lesser extent biomass were low in 1975, 1977, and 1978, probably due to extremely cold winters during the mid-1970's. In 1980 the threadfin population rebounded to earlier levels.

4.4 Mooneye

This species was dominant only in gill net samples. Except for April 1974, mooneye were most common in samples from upstream and downstream

Table 4.1. Mean annual standing stock estimates (no./ha and kg/ha) of young and adult gizzard shad collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Adult		Total	
	Number	kg	Number	kg	Number	kg
1960	31.55	0.21	88.42	24.46	119.96	24.66
1964	67.56	0.21	250.10	50.27	317.66	50.48
1973	323.69	0.75	761.46	130.57	1,085.15	131.32
1975	13.93	0.03	504.96	85.40	518.89	85.42
1976	3.07	0.01	324.43	57.62	327.50	57.64
1977	5,676.01	14.27	609.92	102.18	6,285.93	116.45
1979	749.91	5.93	538.55	53.11	1,288.46	59.04
1980	18.67	0.06	3,646.76	283.38	3,665.42	283.44

Table 4.2. Analysis of variance and Duncan's New Multiple Range Test for differences in the logarithm of numbers/ha of dominant and important species from cove rotenone samples in Watts Bar Reservoir, 1960 through 1980. Ranking is from highest to lowest (left to right). Years that do not differ significantly (α = 0.05) are connected by the same line. Degrees of freedom were 7 for treatments and 51 for error.

Species	Anova F. Value	Years							
Whitebass	2.80*	64	73	76	60	77	75	79	80
Bluegill	1.67	80	73	77	76	75	79	64	60
Smallmouth bass	1.95	73	80	75	77	64	76	79	60
Spotted bass	2.08	75	60	76	64	77	80	73	79
Largemouth bass	4.12**	80	76	77	75	64	73	79	60
White crappie	1.44	80	77	60	73	75	64	79	76
Sauger	3.52**	64	79	80	75	76	60	77	73
Carp	1.10	75	73	76	64	80	60	79	77
Smallmouth buffalo	6.12**	60	64	73	80	75	79	76	77
Golden redhorse	3.31**	76	80	75	73	64	79	77	60
Channel catfish	1.17	73	80	79	77	64	76	75	60
Flathead catfish	1.12	73	80	77	75	64	76	79	60
Freshwater drum	1.18	60	73	75	64	76	80	77	79
Gizzard shad	5.66**	80	77	79	73	75	76	64	60
Threadfin shad	2.20*	60	80	73	64	76	75	77	79

*Significant at α = 0.05. **Significant at α = 0.01.

Table 4.3. Analysis of variance and Duncan's New Multiple Range Test for differences in the logarithm of weights (kg/ha) of dominant and important species from cove rotenone samples in Watts Bar Reservoir, 1960 through 1980. Ranking is from highest to lowest (left to right). Years that do not differ significantly (α = 0.05) are connected by the same line. Degrees of freedom for treatment were 7 and 51 for error, respectively.

Species	Anova F. Value	Years							
White bass	1.07	73	64	76	77	75	60	79	80
Bluegill	9.92**	73	79	76	80	75	77	64	60
Smallmouth bass	1.19	73	64	80	75	76	77	79	60
Spotted bass	2.74*	64	60	75	76	80	77	73	79
Largemouth bass	5.54**	77	76	75	79	73	60	64	80
White crappie	1.35	80	73	64	79	60	75	77	76
Sauger	1.34	79	77	76	64	80	75	60	73
Carp	1.74	75	73	76	80	79	64	77	60
Smallmouth buffalo	4.79**	60	64	80	73	75	79	76	77
Golden redhorse	2.49*	78	80	75	79	73	64	77	60
Channel catfish	0.69	79	80	73	76	77	64	75	60
Flathead catfish	0.73	73	75	64	80	76	79	77	60
Freshwater drum	1.11	60	73	76	64	75	80	79	77
Gizzard shad	4.17**	80	73	77	75	79	76	64	60
Threadfin shad	1.07	60	76	73	64	80	75	79	77

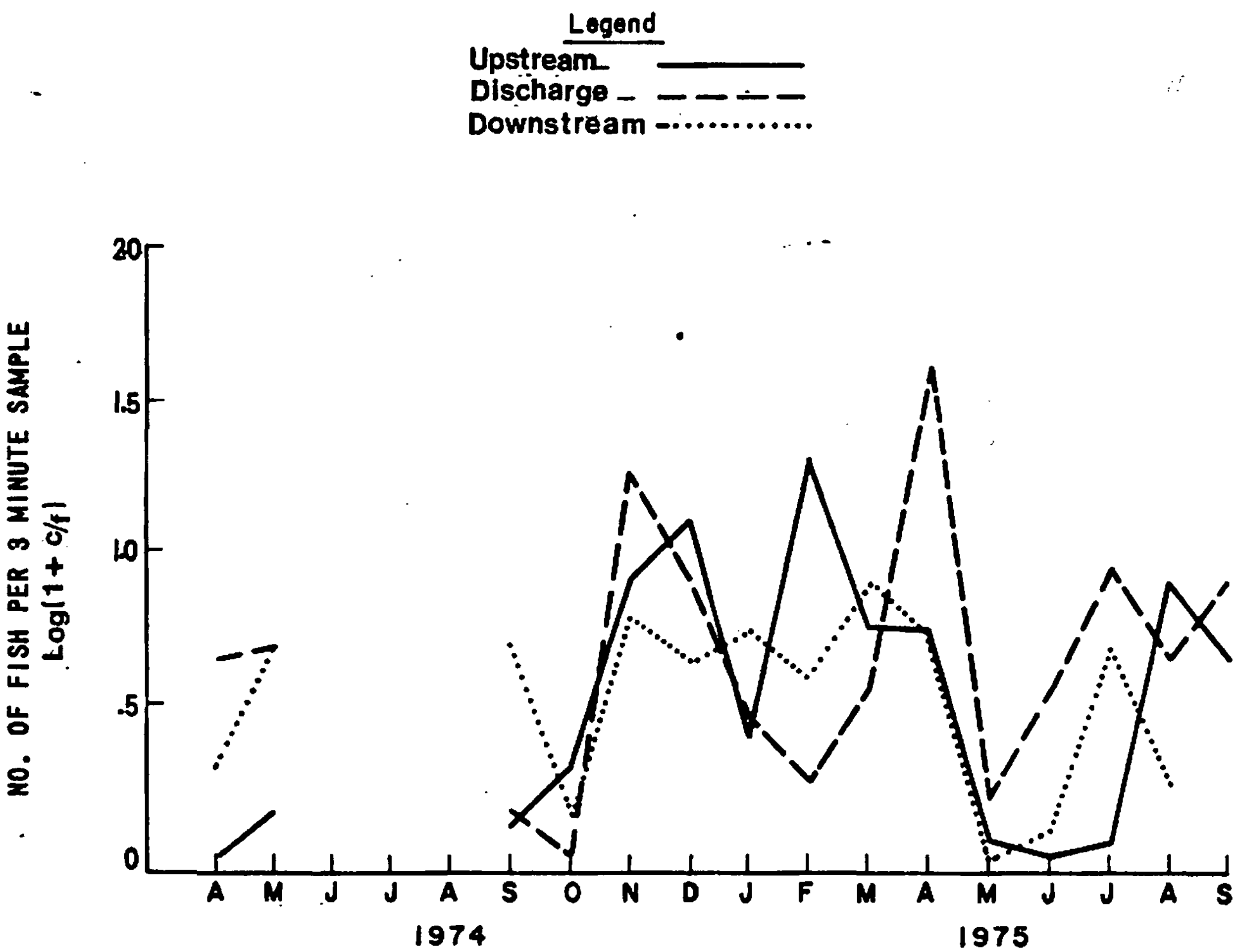


Figure 4.4. Mean monthly catch per three minute electrofishing sample for threadfin shad (Dorosoma petenense) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 4.4. Mean annual standing stock estimates (no./ha and kg/ha) of young and adult threadfin shad collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Adult		Total	
	Number	kg	Number	kg	Number	kg
1960	23,045.94	30.04	0.00	0.00	23,045.94	30.04
1964	2,539.85	6.82	2.71	0.10	2,542.56	6.92
1973	5,997.43	16.02	8.92	0.27	6,006.34	16.29
1975	205.52	0.48	101.97	2.82	307.49	3.29
1976	1,231.76	4.51	103.49	2.97	1,335.25	7.48
1977	241.52	1.42	0.52	0.02	242.04	1.43
1979	153.85	2.24	5.13	0.14	158.97	2.38
1980	5,830.20	5.19	0.00	0.00	5,830.20	5.19

stations (Figure 4.5). Avoidance of the discharge at all times, but April 1974, was indicated by a consistently lower c/f than other stations. Mooneye were low in abundance at all stations during late winter-spring (except April 1974), a period coincident with spawning activity which probably occurs in areas upstream from the plant vicinity.

4.5 Carp

Carp were dominant only from electrofishing and rotenone samples. Patterns of average monthly electrofishing c/f of carp were dissimilar between stations (Figure 4.6). The downstream station usually had greater c/f values than the other two stations. Abundance at the upstream station was consistently greater than the discharge except for June, July, and September of 1975. Peak c/f occurred in April at upstream and downstream stations, but not until July at the discharge station. Carp c/f was frequently low at the discharge station, but not during periods of high effluent temperature (May-August).

Rotenone samples revealed peak numbers and biomass of carp in 1975 (Table 4.5), with both parameters showing significant differences between years (Tables 4.2 and 4.3). Young and intermediate carp were usually not collected, probably due to their preference for habitat other than coves. From 1975 through 1977 both mean numbers and biomass of carp declined, but this trend was reversed in 1979 and 1980.

4.6 Emerald Shiner

Electrofishing was the only sample method in which emerald shiner was a dominant species. Monthly average c/f values were similar at all stations and no distinctive seasonal trends were evident (Figure 4.7). No avoidance of heated effluent was evident for emerald shiners. Seining

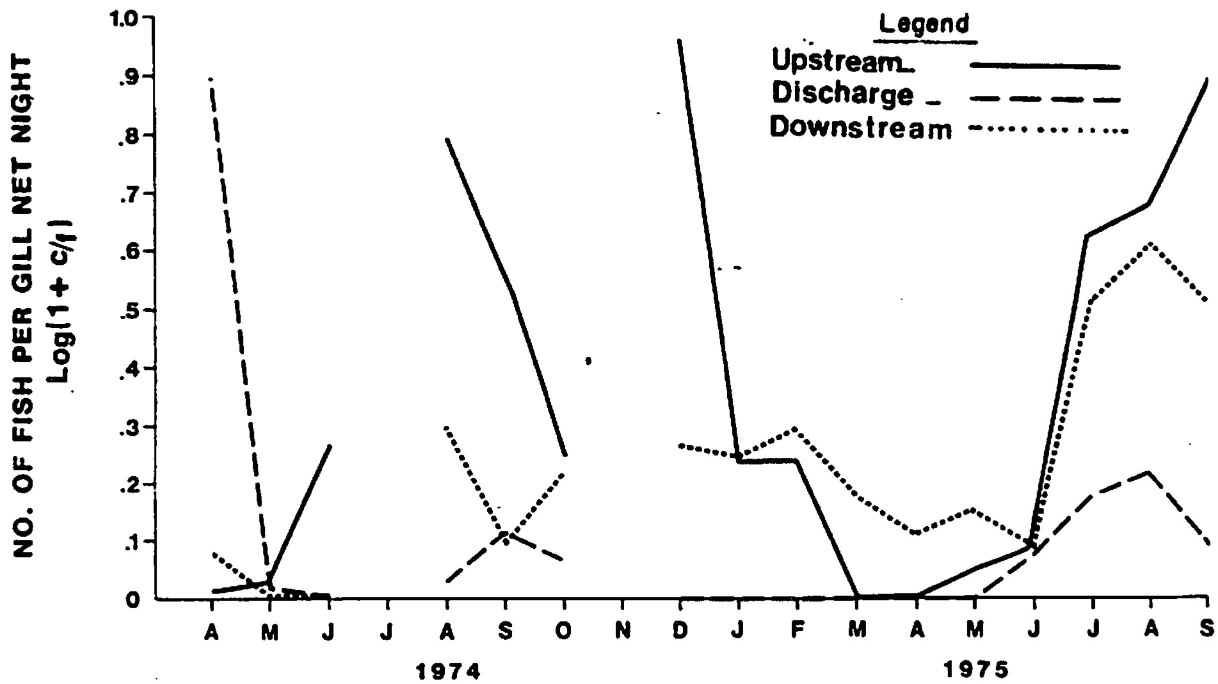


Figure 4.5. Mean monthly catch per gill net night for mooneye (*Hiodon tergisus*) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

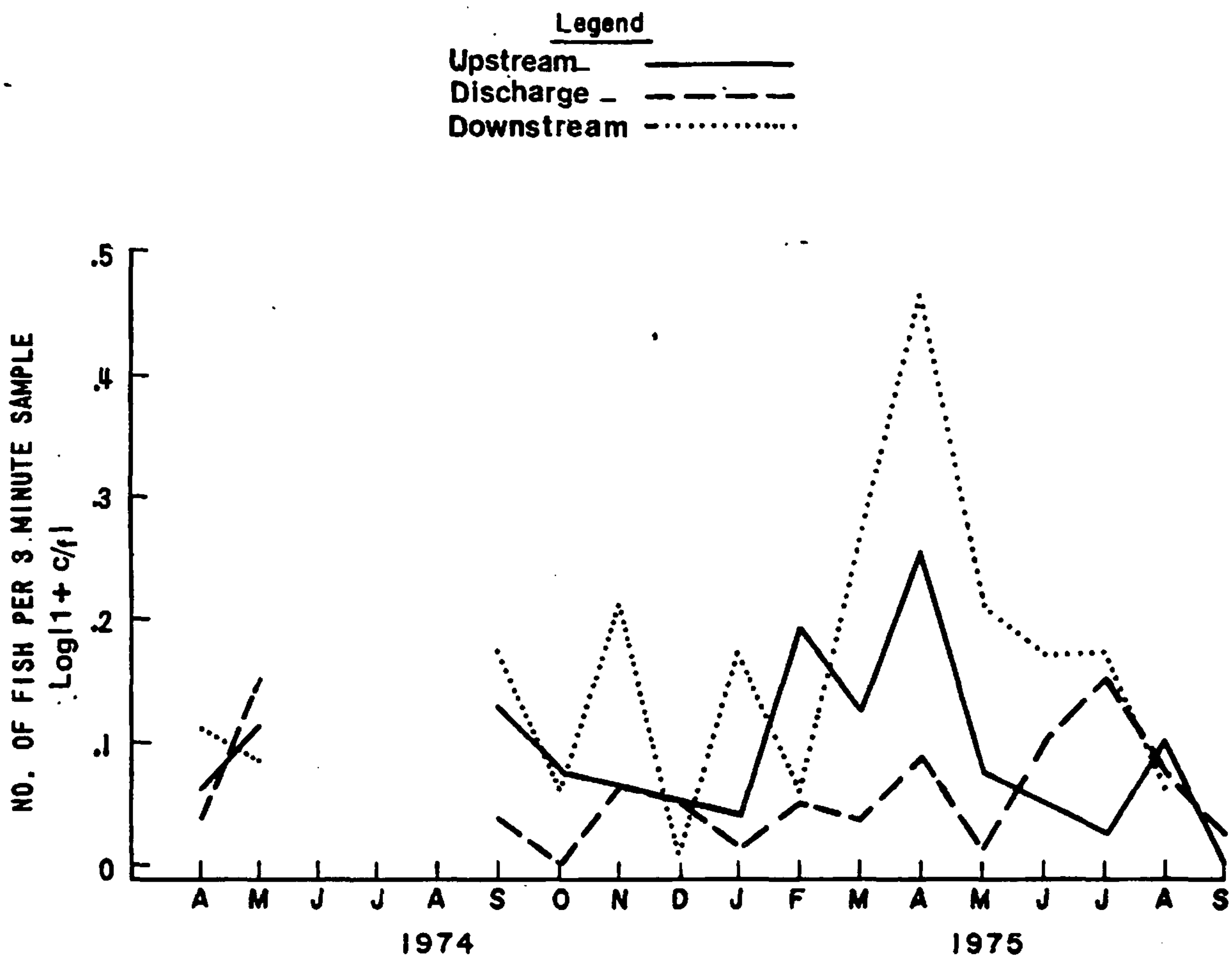


Figure 4.6 Mean monthly catch per three minute electrofishing sample for carp (Cyprinus carpio) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 4.5. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult carp collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	0.00	0.00	0.00	0.00	38.42	35.30	38.42	35.30
1964	7.00	0.60	0.86	0.24	19.04	20.01	26.90	20.85
1973	0.00	0.00	1.65	0.53	31.53	51.62	33.18	52.16
1975	0.00	0.00	0.00	0.00	88.20	134.17	88.20	134.17
1976	0.25	Trace	0.00	0.00	42.80	82.12	43.04	82.12
1977	0.00	0.00	0.00	0.00	16.99	33.12	16.99	33.12
1979	0.00	0.00	0.00	0.00	18.06	34.02	18.06	34.02
1980	0.00	0.00	0.00	0.00	23.71	55.67	23.71	55.67

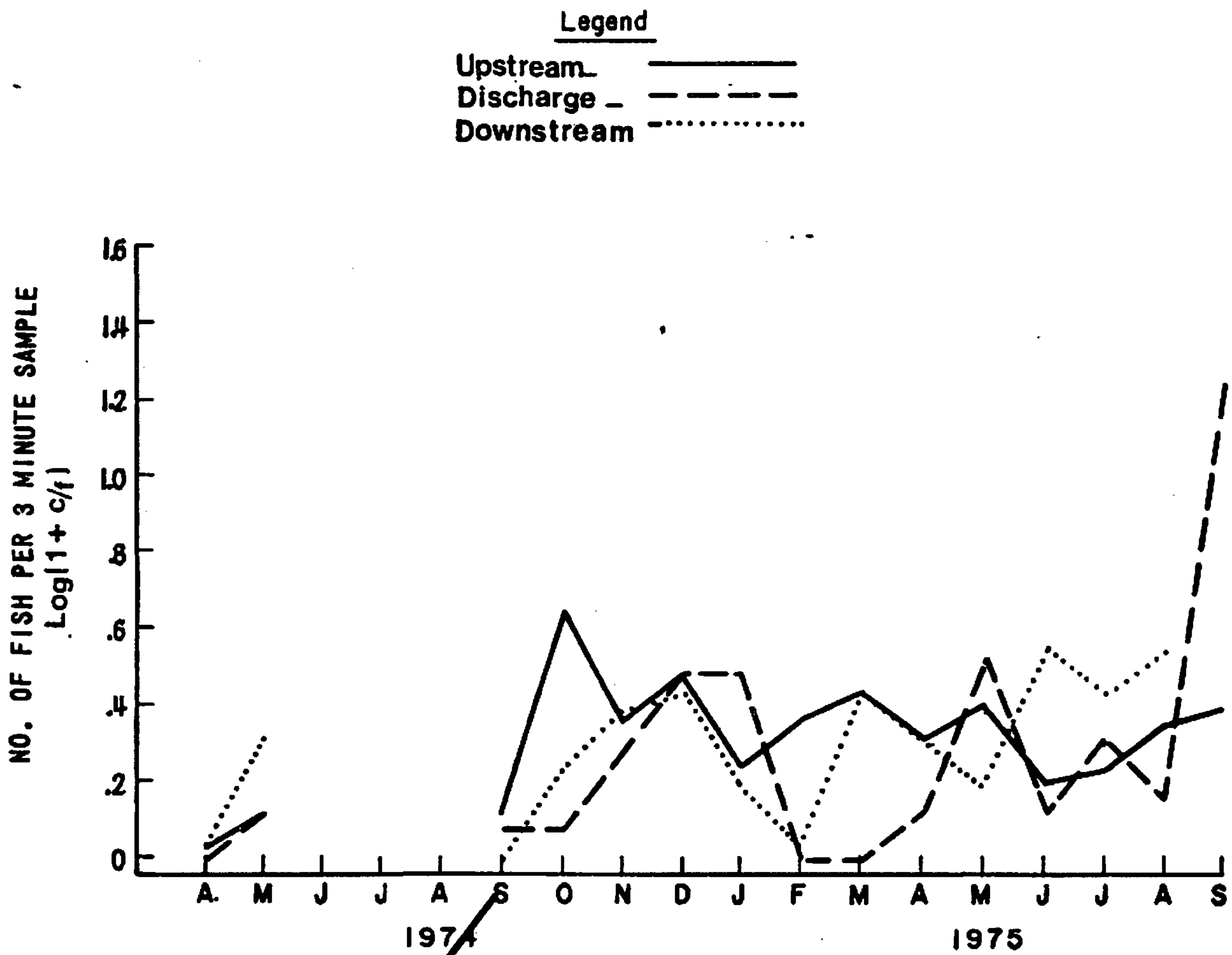


Figure 4.7. Mean monthly catch per three minute electrofishing sample for emerald shiner (Notropis atherinoides) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through August 1975).

data supports this conclusion with highest numbers collected from the discharge station (Table 3.3).

4.7 Pimephales sp.

Electrofishing and seining data showed this genus was most numerous at upstream and downstream stations (Figure 4.8, Table 3.4). Thus, while a general avoidance of the discharge area was evident, data did not reveal this response to be temperature dependent. Low abundance in the discharge coincided with periods of high piscivorous abundance, suggesting an influence of this group on Pimephales sp.

4.8 Channel Catfish

Channel catfish was a dominant species only in gill net and rotenone samples. Generally, over the study period, gill net c/f values were lowest at the upstream station with apparent attraction to discharge and downstream areas from April through July 1975 (Figure 4.9).

Channel catfish total mean numbers in rotenone samples oscillated over the years of record (Table 4.6), with a general increasing trend in both numbers and biomass. Largest sample biomass occurred in 1973. Neither numbers nor biomass showed a significant difference between years (Tables 4.2 and 4.3).

4.9 Flathead Catfish

Flathead catfish were considered an important species in rotenone samples. Standing stocks were relatively small in cove samples of Watts Bar Reservoir with highest densities found in 1973 (Table 4.7). Abundance estimates were usually about four fish/ha weighing about one kg. There were no significant differences between mean annual numbers or biomass (Tables 4.2 and 4.3).

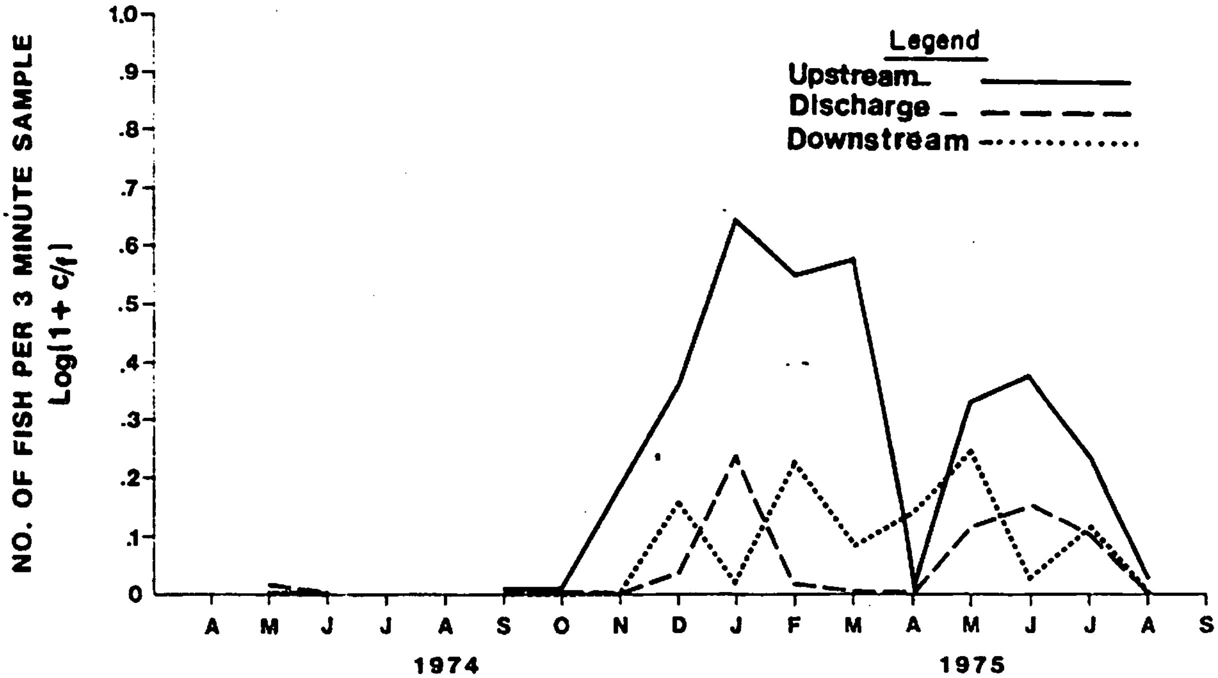


Figure 4.8. Mean monthly catch per three minute electrofishing sample for Pimephales sp. at three stations in Watts Bar Reservoir near Kingston Steam Plant.

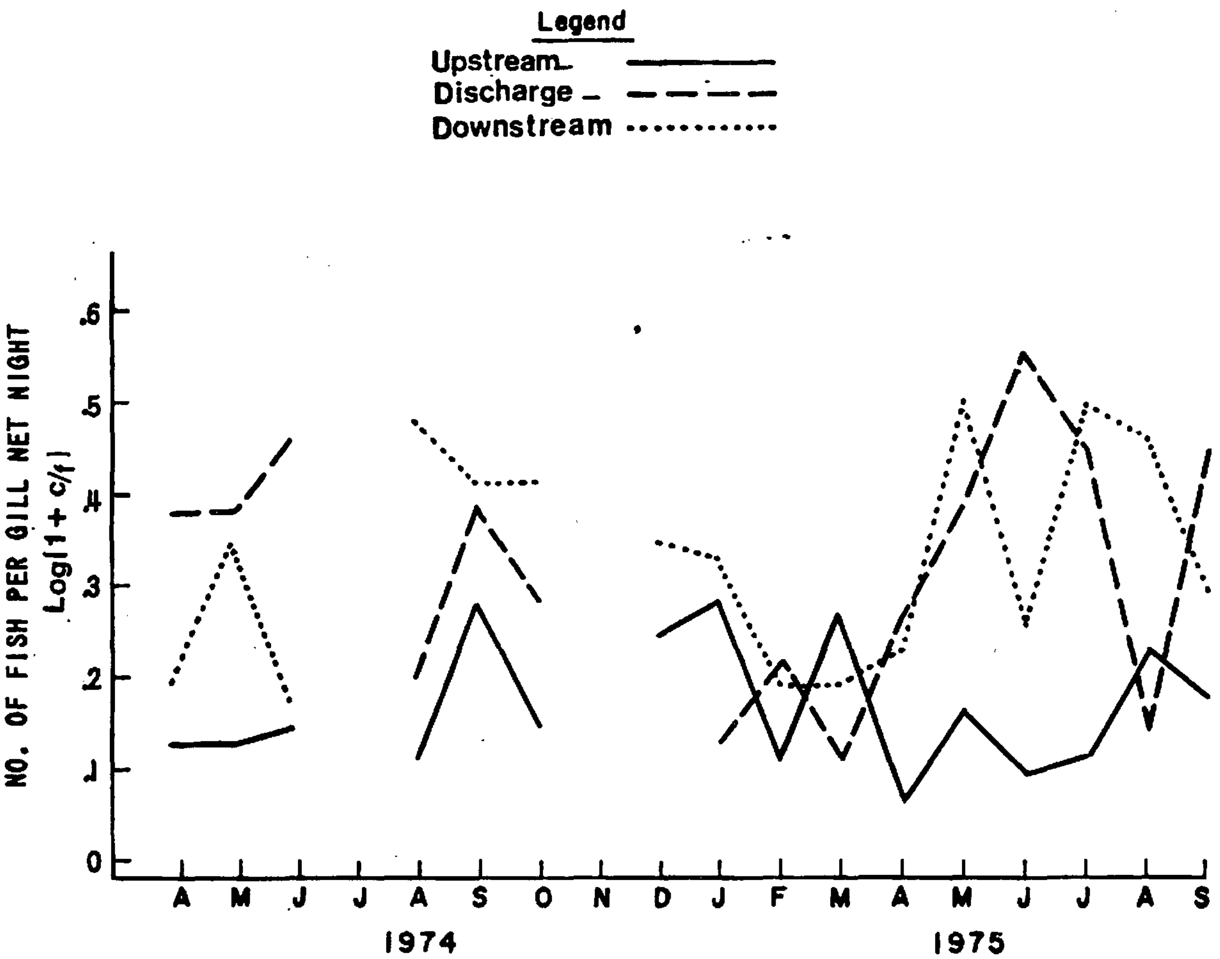


Figure 4.9. Mean monthly catch per gill net night for channel catfish (*Ictalurus punctatus*) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 4.6. Mean annual standing stock (no/ha and kg/ha) of young, intermediate, and adult channel catfish collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	3.69	0.03	2.12	0.14	3.94	1.39	9.75	1.56
1964	3.84	0.05	14.52	0.64	8.34	2.86	26.70	3.56
1973	29.92	0.31	44.32	2.34	10.14	3.18	84.38	5.83
1975	0.00	0.00	4.58	0.25	6.86	2.66	11.44	2.90
1976	0.37	0.00	7.68	0.44	10.73	5.62	18.77	6.07
1977	8.14	0.06	17.18	1.08	16.78	7.27	42.09	8.41
1979	0.00	0.00	2.17	0.12	14.33	11.11	16.51	11.22
1980	5.81	0.06	32.56	1.63	22.40	6.33	60.77	8.01

Table 4.7. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult flathead catfish collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	0.00	0.00	0.48	0.03	0.25	0.14	0.73	0.16
1964	0.40	0.01	0.62	0.13	1.21	1.11	2.23	1.25
1973	2.66	0.03	1.90	0.19	2.34	1.15	6.89	1.36
1975	1.57	Trace	0.98	0.15	1.37	0.90	3.93	1.05
1976	0.95	Trace	1.02	0.08	1.04	0.57	3.01	0.66
1977	2.49	0.01	0.23	0.01	0.76	0.20	3.47	0.22
1979	0.00	0.00	1.28	0.32	0.00	0.00	1.28	0.32
1980	1.16	Trace	2.33	0.32	1.16	0.32	4.65	0.64

4.10 White Bass

White bass were dominant in gill net samples and considered important in rotenone sample analysis. Monthly average c/f from gill netting was usually higher in the discharge and downstream station than at the upstream station (Figure 4.10). There was a strong suggestion of attraction to the discharge during winter and late spring with abundances similar to the other two stations during the remainder of the year.

Rotenone data showed mean numbers of white bass to be significantly different (α = 0.05) over the years, but no significant differences were found for mean biomass (Tables 4.2 and 4.3). Except for 1977, white bass showed a general declining trend in both numbers and biomass since 1973. Standing stocks during the 20-year sample period were lowest in 1979 with no white bass collected in 1980. Highest numbers/ha and biomass/ha occurred in 1975 and 1977 (Table 4.8). Young white bass numbers and biomass estimates remained relatively stable except for the last two years when none were collected. Intermediate and adult groups exhibited no distinct trends and usually contributed very low numbers and biomass to the sample.

4.11 Bluegill

Bluegill were dominant only in electrofishing and rotenone samples. Electrofishing c/f showed low numbers at all stations October to December 1974 with an increasing trend at all stations after that period (Figure 4.11). Lowest values were found in April, November, and December 1974 at upstream and downstream stations while the discharge remained low from fall to spring. Upstream and downstream stations generally had higher c/f values than the discharge station, but seasonal increases were usually parallel at all three areas.

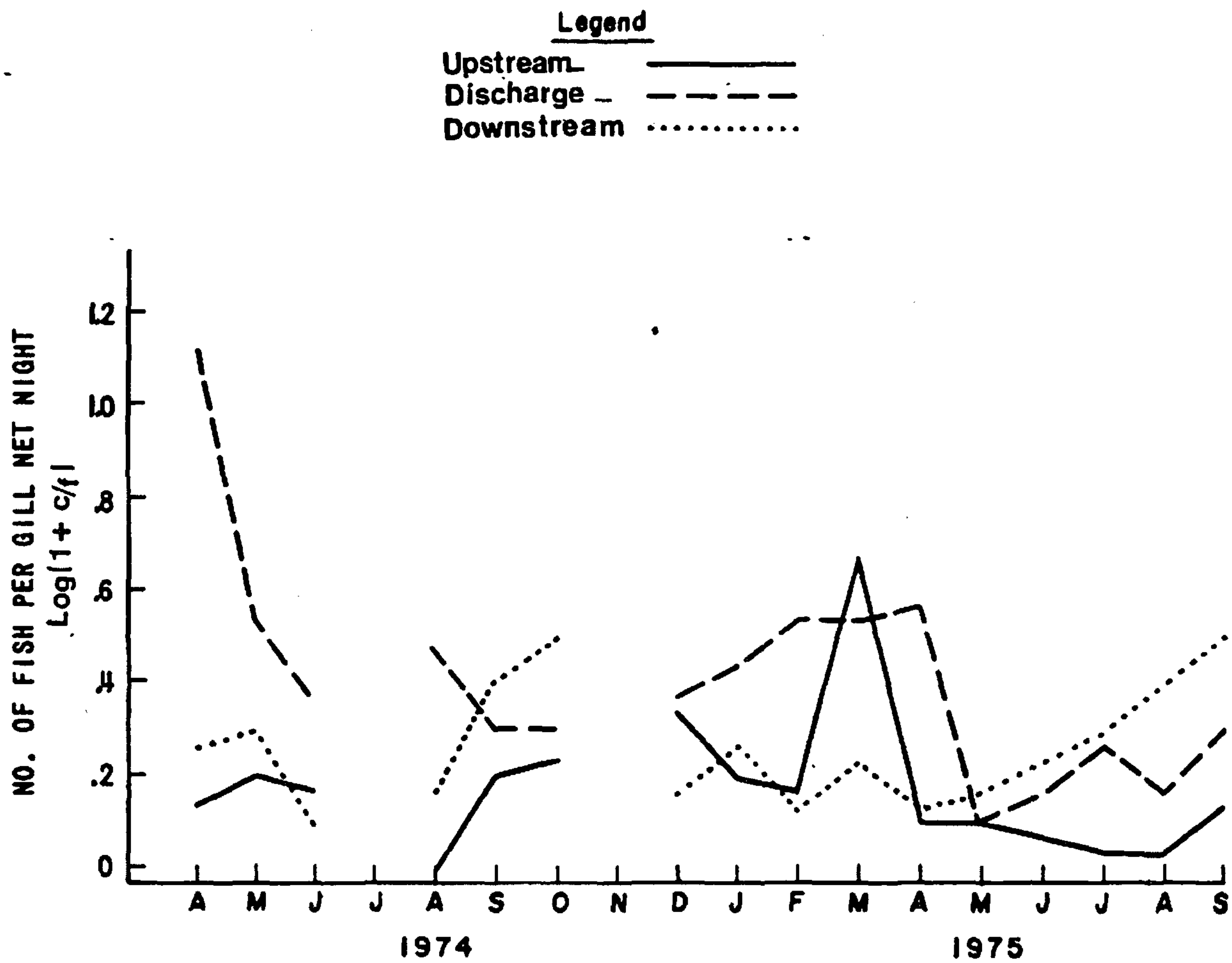


Figure 4.10 Mean monthly catch per gill net night for white bass (Morone chrysops) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 4.8. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult white bass collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	8.11	0.07	1.45	0.15	0.00	0.00	9.56	0.22
1964	25.79	0.14	3.54	0.31	3.98	0.87	33.32	1.33
1973	33.36	0.29	6.53	0.63	7.05	1.13	46.94	2.05
1975	8.15	0.02	3.69	0.23	0.63	0.08	12.46	0.33
1976	7.47	0.14	9.02	0.54	1.80	0.22	18.29	0.90
1977	34.52	0.14	6.97	0.53	6.16	0.86	47.66	1.53
1979	0.00	0.00	0.89	0.08	0.00	0.00	0.89	0.08
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

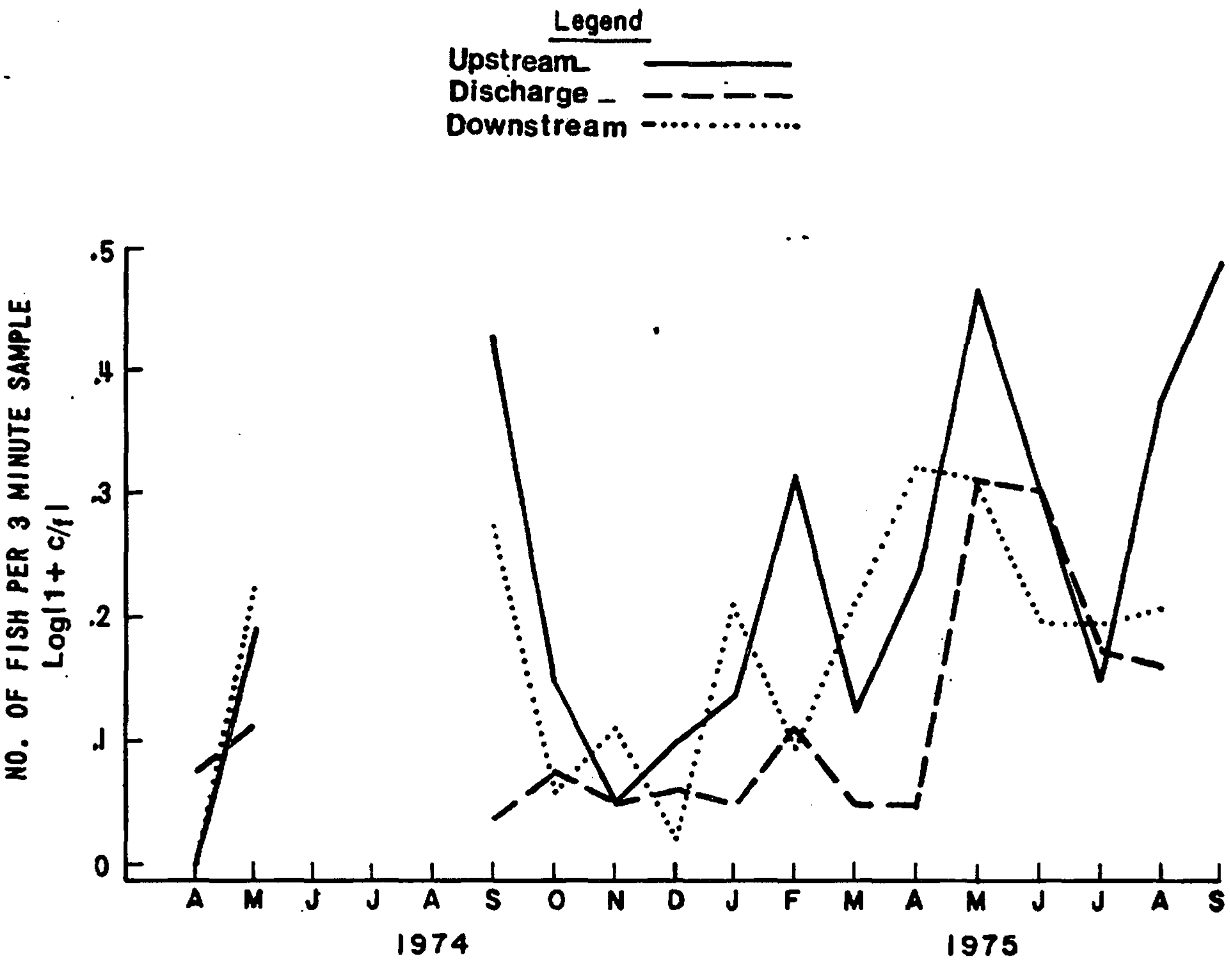


Figure 4.11. Mean monthly catch per three minute electrofishing sample for bluegill (Lepomis macrochirus) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Analysis of variance of bluegill numbers from rotenone samples showed no significant difference ($\alpha = 0.05$), but there were significant differences among yearly mean biomass ($\alpha = 0.01$; Tables 4.2 and 4.3). Because of a very large year class, the largest number of bluegill were collected in the 1980 sample (Table 4.9). Numbers and biomass of intermediate and adult bluegill in 1973 were highest for the 20-year period of record. Total numbers and biomass showed no distinct trends although biomass was usually much lower in pre-1973 samples. Bluegill mean numbers/ha have been consistently above 1,000 since 1964.

4.12 Smallmouth Bass

This desirable sport fish was the least abundant species of the genus *Micropterus* collected near Kingston Steam Plant (Table 3.4). Specimens collected by electrofishing were about equal in number at all stations, slightly more abundant at the discharge. Relatively small numbers collected prevent determination of effects of heated effluent from Kingston Steam Plant on the spatial distribution of this species in Watts Bar Reservoir.

Mean numbers and biomass of all groups increased through time to a peak in 1973 (Table 4.10). The next sample, abundance and biomass estimates, decreased and maintained that level until 1979. Numbers and biomass of young and intermediate smallmouth bass in 1979 were considerably lower than during the 1973 to 1977 period, but increased to normal levels in 1980. Neither smallmouth bass mean numbers or biomass showed significant differences between years (Tables 4.2 and 4.3).

4.13 Spotted Bass

Spotted bass were important from rotenone samples with highest abundance and biomass estimates occurring in 1975 and 1964, respectively

Table 4.9. Mean annual standing stock estimates (no/ha and kg/ha) of young, intermediate, and adult bluegill collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	285.37	0.53	54.46	1.46	45.94	3.64	385.78	5.63
1964	1,607.84	1.22	119.88	2.90	49.34	4.29	1,777.06	8.41
1973	1,542.38	4.01	506.71	12.57	223.29	16.12	2,272.38	32.70
1975	730.43	1.23	222.30	4.32	184.28	12.66	1,137.01	18.22
1976	802.57	1.69	450.48	7.28	170.33	12.70	1,423.38	21.67
1977	1,329.43	2.63	194.79	3.13	92.76	5.98	1,616.98	11.74
1979	548.15	2.70	292.72	6.89	178.94	15.17	1,019.80	24.76
1980	3,605.39	3.40	217.20	6.28	126.74	9.81	3,949.33	19.49

Table 4.10. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult smallmouth bass collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	2.65	0.01	0.50	0.05	0.75	0.13	3.90	0.19
1964	9.93	0.09	6.90	0.58	2.49	0.54	19.32	1.21
1973	67.20	0.42	12.69	0.50	3.73	1.01	83.61	1.93
1975	23.29	0.06	1.90	0.10	0.63	0.64	25.82	0.80
1976	16.41	0.07	3.02	0.19	1.64	0.24	21.07	0.51
1977	22.07	0.06	3.35	0.16	0.76	0.08	26.18	0.29
1979	0.89	0.01	0.89	0.02	1.28	0.25	3.07	0.28
1980	29.99	0.12	5.81	0.34	1.16	0.22	36.96	0.69

(Table 4.11). Intermediate spotted bass were absent in samples from 1977 and 1979 while adults have not been collected since 1964. There was no discernible trend as standing stock estimates varied considerably. Only mean biomass showed a significant difference between years ($\alpha = 0.05$; Tables 4.2 and 4.3).

4.14 Largemouth Bass

Largemouth bass were classified as a dominant species in both electrofishing and cove rotenone samples. Patterns of monthly electrofishing c/f were similar at discharge and downstream stations and were usually higher than values from the upstream area (Figure 4.12). High c/f values occurred April to July, especially at the discharge, suggesting attraction to this area during this period. Monthly average c/f at the upstream station was low at the beginning of the study and gradually increased to its highest level at the end of the study (September 1975).

Statistical examination of rotenone mean data through time showed there were significant differences among years for both numbers/ha and biomass/ha ($\alpha = 0.01$; Tables 4.2 and 4.3). Mean annual standing stocks for intermediate and adult size groups were largest in 1977 while young were most abundant in 1980 (Table 4.12). All size groups showed increasing trends from 1960 through 1977, but sharp decreases were found in the following sample (1979). In 1980, young largemouth bass increased and even exceeded pre-1979 estimates; however, intermediate and adult estimates continued to decline. Other black bass species and white bass stocks were also low in 1979, possibly a result of low stocks of prey species.

4.15 White Crappie

White crappie were considered as an important species in rotenone samples. Mean total numbers and biomass fluctuated through time and no

Table 4.11. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult spotted bass collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	32.54	0.16	3.94	0.28	2.28	0.32	38.77	0.75
1964	25.45	0.11	5.47	0.47	1.58	0.24	32.50	0.82
1973	0.00	0.00	0.15	0.01	0.00	0.00	0.15	0.01
1975	57.71	0.13	0.41	0.01	0.00	0.00	58.12	0.14
1976	16.49	0.05	0.25	0.01	0.00	0.00	16.74	0.06
1977	4.47	0.01	0.00	0.00	0.00	0.00	4.47	0.01
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	1.16	0.04	0.00	0.00	1.16	0.04

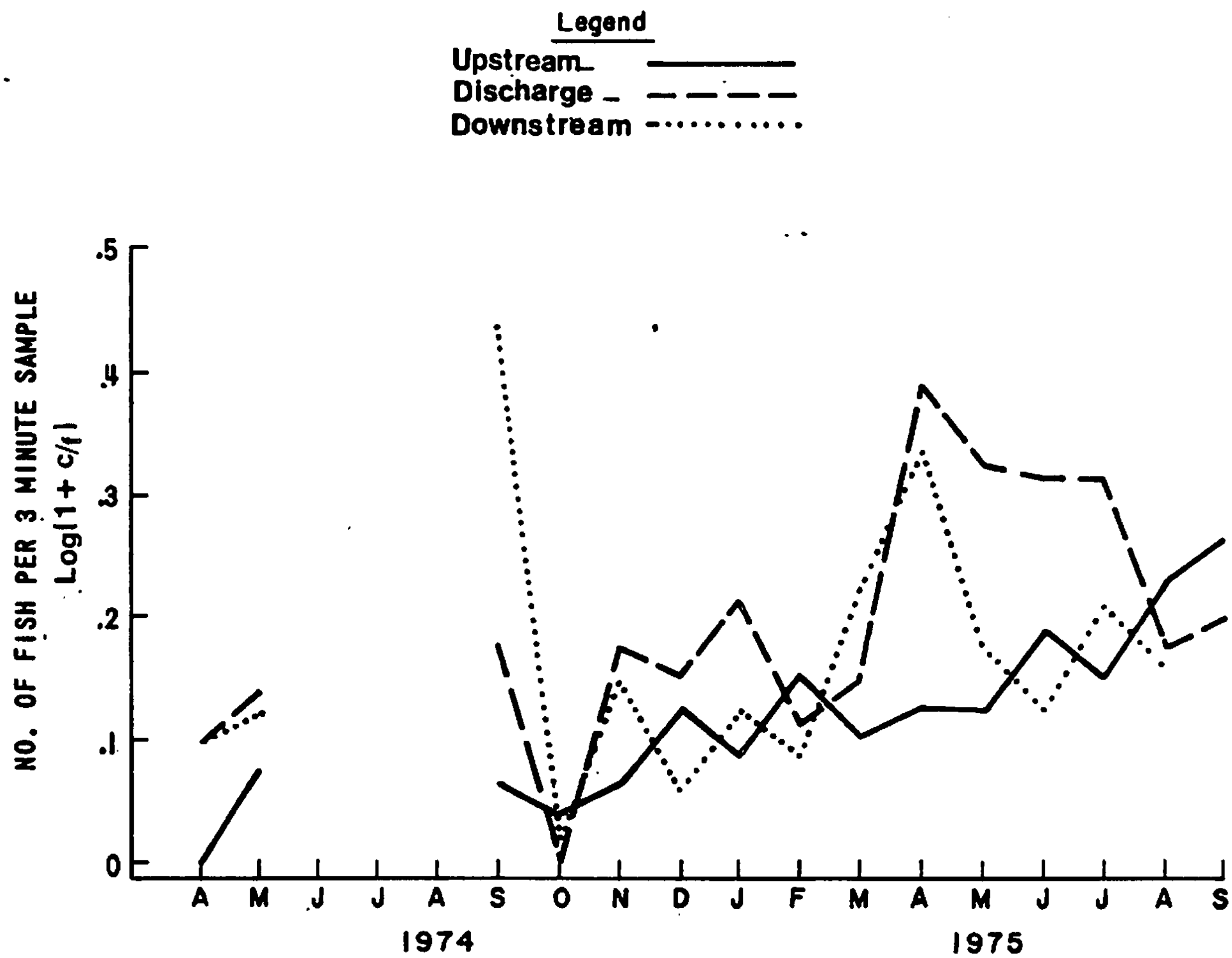


Figure 4.12. Mean monthly catch per three minute electrofishing sample for largemouth bass (Micropterus salmoides) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 4.12. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult largemouth bass collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	30.30	0.19	7.09	0.71	6.91	2.54	44.30	3.45
1964	66.39	0.41	13.53	1.39	5.70	1.67	85.62	3.47
1973	68.74	0.42	11.43	0.99	7.78	4.24	87.94	5.65
1975	99.35	0.27	33.23	2.17	13.61	4.92	146.19	7.36
1976	195.53	0.38	29.38	1.78	14.75	7.58	239.65	9.73
1977	201.33	0.60	42.95	2.66	23.73	8.65	268.02	11.90
1979	43.54	0.12	9.48	0.63	14.33	4.98	67.35	5.73
1980	310.16	0.91	3.79	0.21	2.48	0.87	316.43	1.99

significant difference between years was found (Tables 4.2 and 4.3).

Young-of-year standing stocks appeared to be decreasing in number and biomass over the years while intermediate and adult groups exhibited no consistent pattern (Table 4.13). Large numbers of intermediate white crappie were collected in 1980 while young and adult groups peaked in 1973.

4.16 Sauger

Sauger was a dominant species in gill netting samples and important in rotenone collections. The c/f patterns at the three gill net stations showed nearly parallel and equal fluctuations in 1975 (Figure 4.13). High c/f values were first observed in December in all areas and peaked at the discharge and downstream stations in January. Increases at the upstream station occurred later with peak abundance not reached until March, possibly reflecting upstream spawning migration which occurs about this time. Following these peaks, c/f at all stations fell sharply to low levels in August. Temperature related distributional trends appeared entirely absent with the possible exception of minor avoidance of the heated discharge in summer and early fall.

Rotenone samples revealed standing stocks of sauger in Watts Bar Reservoir have been relatively small except in 1964 when larger numbers of young were collected (Table 4.14). Young sauger have been absent since 1977. The only trend was a progressive increase in mean total biomass from 1973 through 1979. Only mean numbers exhibited significant differences between years ($\alpha = 0.01$; Tables 4.2 and 4.3).

Table 4.13. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult white crappie collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	59.18	0.18	2.42	0.14	3.38	0.50	64.98	0.82
1964	42.30	0.07	11.48	0.52	2.62	0.51	56.40	1.09
1973	66.59	0.07	3.96	0.15	10.30	1.59	80.85	1.81
1975	9.79	0.01	16.58	0.42	5.53	0.57	31.91	1.00
1976	0.57	Trace	1.62	0.05	1.11	0.15	3.30	0.20
1977	11.09	0.02	4.74	0.05	4.29	0.64	20.13	0.17
1979	0.00	0.00	11.10	0.40	2.68	0.51	13.78	0.91
1980	1.16	Trace	43.08	2.17	1.16	0.13	45.41	2.30

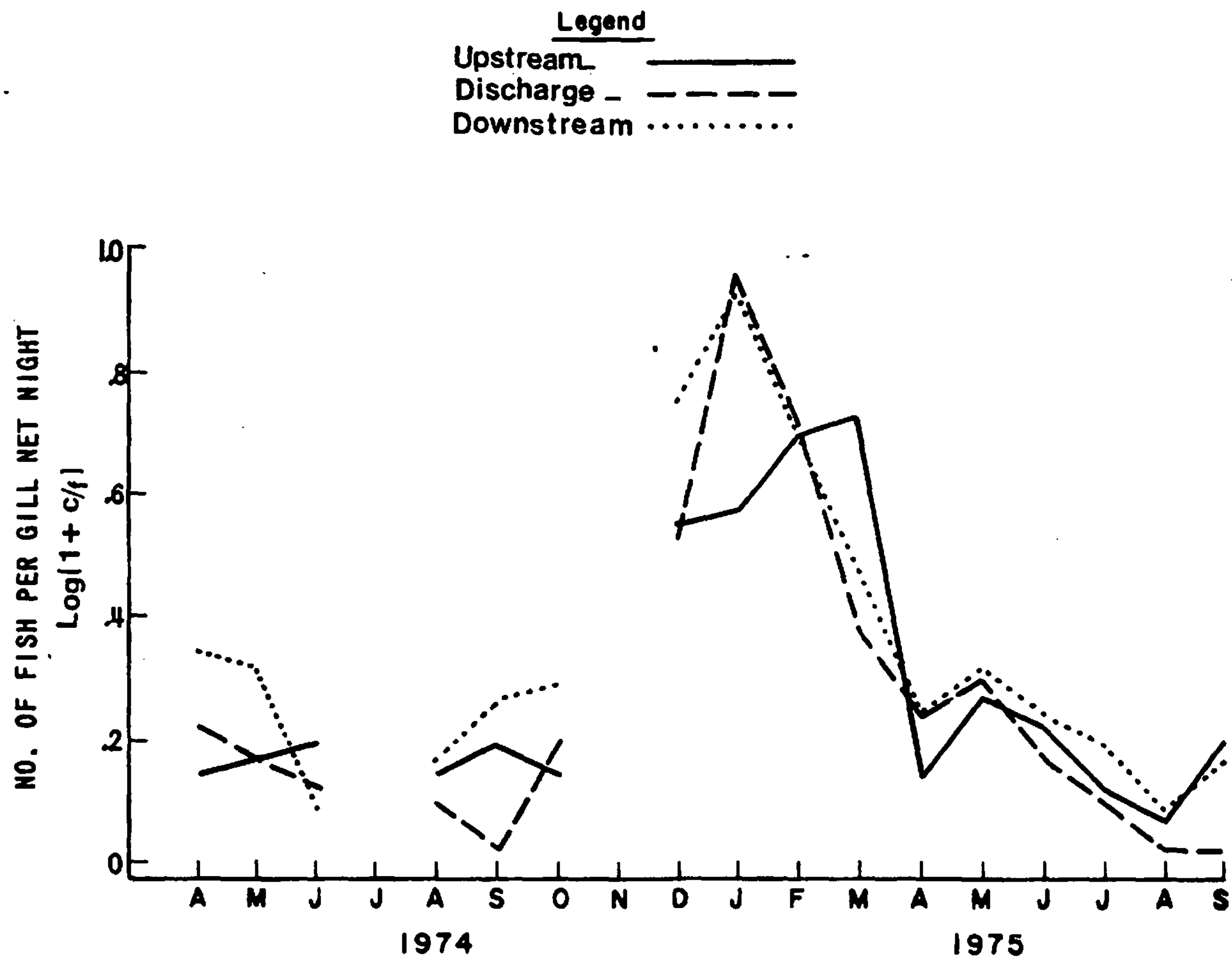


Figure 4.13. Mean monthly catch per gill net night for sauger (Stizostedion canadense) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Table 4.14. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult sauger collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	2.28	0.03	1.45	0.23	0.73	0.17	4.47	0.43
1964	12.94	0.37	7.65	0.68	0.60	0.18	21.19	1.22
1973	0.20	0.01	1.03	0.14	1.43	0.33	2.65	0.48
1975	1.94	0.09	8.12	0.83	0.31	0.06	10.37	0.98
1976	0.26	Trace	1.87	0.24	5.06	1.24	7.18	1.47
1977	0.00	0.00	0.98	0.12	4.52	2.03	5.51	2.15
1979	0.00	0.00	0.89	0.08	6.02	2.39	6.91	2.47
1980	0.00	0.00	2.48	0.38	2.48	0.50	4.96	0.88

4.17 Smallmouth Buffalo

Smallmouth buffalo were dominant in rotenone samples. Young and intermediates were only collected in two and three sample years, respectively (Table 4.15). This suggests only adult smallmouth buffalo usually inhabit cove environments. Adult numbers and weights were greater in years prior to 1973. A declining trend was evident for both biomass and numbers from the peak in 1964 until 1979 when a slight increase occurred. Significant differences between years were observed for both mean numbers and biomass ($\alpha = 0.01$; Tables 4.2 and 4.3).

4.18 Golden Redhorse

Dominant in rotenone samples, golden redhorse standing stocks through time were relatively low with an overall mean of about nine fish/ha weighing about four kg/ha. All size groups increased in mean numbers and biomass to a peak in 1976 when subsequent decreases occurred (Table 4.16). There were significant differences among mean annual numbers and biomass ($\alpha = 0.05$; Tables 4.2 and 4.3).

4.19 Walleye

This species was dominant only in gill netting and was much less numerous than sauger. Only eight walleye were collected near Kingston Steam Plant, seven of which were caught at discharge and downstream stations (Table 3.4). Low numbers precluded any determination of distributional effects resulting from heated effluent.

4.20 Freshwater Drum

This species was dominant in gill net and rotenone samples. Gill net c/f data revealed freshwater drum to be most numerous at downstream and upstream stations (Figure 4.14). Lowest densities were found in the

Table 4.15. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult smallmouth buffalo collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

	Young-of-Year		Intermediate		Adult		Total	
Year	Number	kg	Number	kg	Number	kg	Number	kg
1960	0.00	0.00	0.25	0.10	47.24	58.53	47.49	58.63
1964	0.17	0.03	1.52	0.38	50.83	64.89	52.51	65.30
1973	0.87	0.03	1.12	0.24	18.69	36.92	20.67	37.18
1975	0.00	0.00	0.00	0.00	21.15	36.41	21.15	36.41
1976	0.00	0.00	0.00	0.00	6.28	12.27	6.28	12.27
1977	0.00	0.00	0.00	0.00	5.19	9.46	5.19	9.46
1979	0.00	0.00	0.00	0.00	15.38	29.77	15.38	29.77
1980	0.00	0.00	0.00	0.00	9.46	22.89	9.46	22.89

Table 4.16. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult golden redhorse collected with rotenone in Watts Bar Reservoir from 1960 to 1980

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	0.00	0.00	0.97	0.17	0.98	0.47	1.95	0.64
1964	0.11	Trace	2.31	0.39	4.11	2.05	6.53	2.45
1973	0.57	0.02	0.39	0.04	4.07	3.18	5.03	3.25
1975	4.50	0.19	2.54	0.34	11.46	6.92	18.51	7.45
1976	8.94	0.53	8.06	0.90	16.10	8.96	33.10	10.39
1977	0.75	0.03	0.00	0.00	3.24	2.00	4.00	2.02
1979	0.89	0.06	0.00	0.00	4.46	3.43	5.36	3.49
1980	1.32	0.02	0.00	0.00	11.38	7.28	12.70	7.31

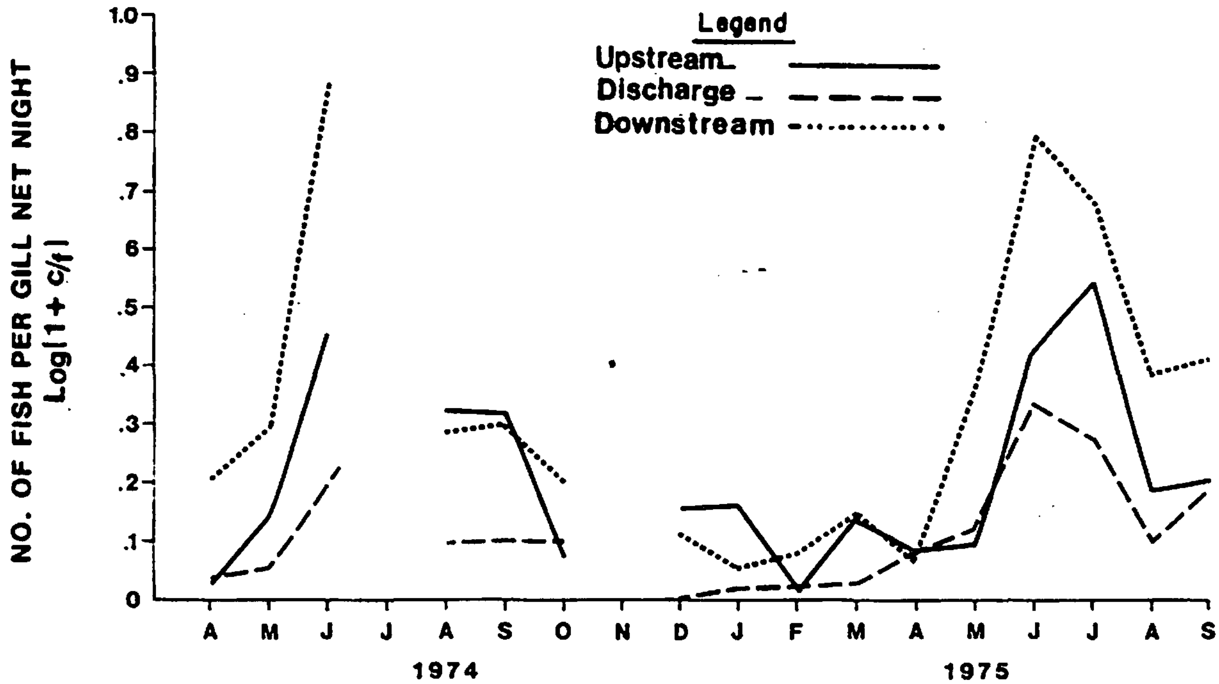


Figure 4.14. Mean monthly catch per gill net night for freshwater drum (Aplodinotus grunniens) at three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

discharge area and may represent a temperature-induced distributional pattern. However, a seasonal avoidance pattern was not evident.

Although rotenone number and biomass estimates did not differ significantly between years (Tables 4.2 and 4.3), both parameters tended to decrease from 1973 until 1980 when a sharp increase occurred (Table 4.17). Young-of-year drum were most abundant in 1973 which may have caused the high numbers and biomass observed for the intermediate group in 1975. Intermediate and adult drum exhibited decreasing trends from 1975 through 1979 and 1975 through 1980, respectively.

4.21 Summary

The spatial-temporal distributions of 20 species collected with four gear types were examined in this study. From gill net and electrofishing collections, several of these species exhibited higher c/f in downstream and upstream stations than in the discharge station unrelated to periods of high effluent temperature. These species included: mooneye, carp, Pimephales sp., bluegill, and freshwater drum. Emerald shiner seemed to be most numerous in the discharge while freshwater drum were most abundant in the more lacustrine habitat of the downstream station. Mooneye, Pimephales sp., and to a lesser extent bluegill, were highest in abundance in samples from the upstream station. Other species showed no consistently high c/f for any one sample area. Data for most species showed high c/f in spring and low values in winter. Two species (skipjack herring and sauger) showed highest c/f in winter with lowest values in summer. Strong thermal avoidance patterns were not indicated for any species, however, four species did appear to be seasonally attracted to the discharge area (gizzard shad, largemouth bass, skipjack herring, and channel catfish). These data indicate that, although there seemed to be some thermally

Table 4.17. Mean annual standing stock estimates (no./ha and kg/ha) of young, intermediate, and adult freshwater drum collected with rotenone in Watts Bar Reservoir from 1960 to 1980.

Year	Young-of-Year		Intermediate		Adult		Total	
	Number	kg	Number	kg	Number	kg	Number	kg
1960	33.50	0.32	219.89	12.46	167.06	30.50	420.45	43.27
1964	35.90	0.20	188.75	10.02	90.90	15.44	315.55	25.66
1973	120.99	1.10	208.37	10.47	95.31	18.18	424.66	29.74
1975	9.15	0.15	222.75	12.44	126.51	16.81	358.41	29.39
1976	21.61	0.31	159.34	8.10	96.84	19.20	277.80	27.61
1977	63.75	0.39	111.05	5.57	63.91	10.87	238.70	16.83
1979	0.89	0.02	79.65	4.66	54.44	11.30	134.98	15.98
1980	20.93	0.38	180.08	10.84	52.14	12.11	253.15	23.34

influenced distributional patterns in the discharge basin, Kingston Steam Plant has little if any effect on the distribution of adult fish in Watts Bar Reservoir proper.

Numbers and biomass of dominant and important species collected in cove rotenone samples since 1960 (59) were examined for long-term trends. Several species exhibited short-term decreases and others short-term increases, but these trends were considered normal population fluctuations. In no case was there a consecutive decrease in mean numbers or biomass over the study period, therefore it appears that discharge of heated effluent by Kingston Steam Plant has not had an adverse effect on fish populations of Watts Bar Reservoir.

CHAPTER 5

LIFE HISTORY ASPECTS OF DOMINANT AND IMPORTANT FISH SPECIES

The discharge of heated water from Kingston Steam Plant could influence the reproductive development, condition (i.e., length-weight relationships), and age and growth characteristics of fishes which inhabit waters in the vicinity of the plant. Fishes collected by gill netting and electrofishing methods described earlier were used to examine these life history parameters and to make comparisons among stations (i.e., upstream, discharge, and downstream). These data were also compared with results of other studies in the literature.

5.1 Reproductive Development

Ricker (1968) discussed the need for maturity stage classifications and James (1946) ascribed variations in gross anatomical and histological structures of gonads to changes in nutrition, age, water temperature, and spawning habits. Sexual development and maturity stages of fishes have been described by various authors. Bennett, Thompson, and Pan (1940) developed a field classification system for recording the macroscopic condition of bluegill and largemouth bass gonads. This system classifies gonads as immature, poorly developed, enlarged in spawning condition, partly spent, or completely spent. James (1946) developed a gonad maturity classification system for bluegill and largemouth bass based on histological characteristics of the testes or ovaries. This classification system can be readily correlated with the gross stages recognized by Bennett, et al. (1940). Kelly (1962) described ovaries of largemouth bass as immature, mature, or spent depending upon presence or absence of "mature ova" as defined by James (1946). Newton and Kilambi (1969) used season of capture, color, size, or opacity to classify white bass ovaries as immature, maturing, mature, or spent. These classification systems are similar to the one developed by Kestoven (1960) which was chosen for this study (Appendix, Table 3).

5.1.1 Procedures

Gonads were examined from bluegill, sauger, and freshwater drum. Developmental stage of gonads from bluegill and freshwater drum was classified according to Kestoven's system. For sauger, an abbreviated classification was used in which the gonads were recorded as immature (I; equivalent to Kestoven's classes 1-3), mature (M; equivalent to classes 4-5), ripe (R; equivalent to class 6), and spent (S; equivalent to class 7-9).

Minimum total lengths at which gonadal development began were recorded. Based on these measurements, comparisons were made to see if there were differences in size at maturity between stations. Distribution of maturity stages within specific months was compared among stations to determine if seasonal development of gonads was influenced by thermal discharge. These data were also used to infer when spawning activity began for each of these species in the vicinity of Kingston Steam Plant.

5.1.2 Results and Discussion

A total of 580 fishes was examined to determine maturity stages, including over 200 specimens each of sauger and freshwater drum. Generally, maturity stage information was collected from January through August; however, for sauger, an early spring spawner, specimens were examined only through May.

Bluegill--During the study period a total of 125 bluegill was examined for maturity stages: 37 from the upstream station, 27 from the discharge basin, and 61 from the downstream station. Bluegill reached spawning condition in all areas during May, indicating little if any thermal influence on gonadal development (Table 5.1).

Sauger--A total of 211 sauger was examined for maturity stages: 71 specimens from the upstream station, 79 from the discharge basin, and 61 from the downstream station (Table 5.2). High numbers of sauger captured in February were probably indicative of their migration past Kingston Steam Plant to upstream spawning sites. The few ripe fish collected in the vicinity of the steam plant in succeeding months suggest the study area was probably not an important spawning location for sauger.

Freshwater Drum--During the study period, 245 freshwater drum were examined for maturity stages: 60 from the upstream station, 22 from the discharge basin, and 162 from the downstream station. The major spawning period for drum was June with highest numbers of stage V and VI fish collected from the downstream station (Table 5.3). However, since spawning fish were collected at all stations during this period, adverse effects on gonadal development attributable to thermal effluent from Kingston Steam Plant were not evident.

5.2 Length-Weight Relationship

The relationship of weight to length can be used to establish an index of robustness or condition of a fish; i.e., at a given length,

Table 5.1 Numbers of bluegill by maturity stage and month collected from three stations in Watts Bar Reservoir near Kingston Steam Plant during 1975 and 1976.

MATURITY STAGE		MONTH 1	2	3	4	5	6	7	8	9	10
						(Downstream Station)					
IX											
VIII						1		1	1		
VII							2	3			
VI	spawning					15	6				
V	gravid		1			8	5				
IV					1	8	1				
III					5	2					
II					1						
I											
						(Discharge Station)					
IX						1					
VIII								1			
VII							1				
VI	spawning					5	7	1			
V	gravid					3	1	1			
IV						2					
III						1	1				
II					2						
I											
						(Upstream Station)					
IX											
VIII											
VII								3			
VI	spawning					6	2				
V	gravid					5					
IV						14					
III					1	1					
II			1		1						
I			3								

Table 5.2 Numbers of sauger by maturity stage and month collected from three stations in Watts Bar Reservoir near Kingston Steam Plant during 1975 and 1976.

MATURITY	MONTH 1	2	3	4	5	6	7	8	9	10
(Downstream Station)										
Spent		1		6	5					
Ripe		5		1	13					
Mature	6	15		2						
Immature	4	1			2					
(Discharge Station)										
Spent					5					
Ripe			1	1						
Mature		45	2	4						
Immature		15	5	1						
(Upstream Station)										
Spent		1		2	11					
Ripe		10	9	2	5					
Mature		24	3							
Immature		2	2							

Table 5.3 Numbers of freshwater drum by maturity stage and month collected from three stations in Watts Bar Reservoir near Kingston Steam Plant during 1975 and 1976.

MATURITY STAGE	MONTH 1	2	3	4	5	6	7	8	9	10
(Downstream Station)										
IX										
VIII					1	1				
VII						10	4			
VI spawning					11	89	2			
V gravid					6	13	2			
IV				1	8	2				
III					5					
II					3	1	2			
I			1		1					
(Discharge Station)										
IX										
VIII										
VII						1	2			
VI spawning						10	1			
V gravid						1				
IV				2		2	1			
III				1						
II				1						
I						1				
(Upstream Station)										
IX										
VIII						1	5			
VII						5	6			
VI spawning					3	27	6			
V gravid						1				
IV					2					
III				1						
II			1	1						
I			1							

a heavier fish is considered to be in better physical condition than a fish weighing less. This "relative condition" may be compared among fish of the same species from different areas to indicate the suitability of an environment for a species (Lagler 1956). The influence of a heated discharge upon the condition of fish may be demonstrated by a measurable difference in the relative condition of fish collected in thermally influenced areas and those taken from an uninfluenced area.

5.2.1 Procedures

Total length (mm) and weight (g) were taken as soon as possible after capture. For purposes of calculation, the length-weight relationship, $W = aL^b$ (Lagler 1956) was expressed in the log form: $W = \log a + b \log L$ where W is weight in grams, a is the Y intercept, b is the slope coefficient, and L is the total length in millimeters.

The slope coefficient (b) measures the rate of increase in weight for a given unit increase in length. Thus, this parameter can be used as an indication of the relative robustness of a sample of fish.

Comparisons of length-weight relationships were made for eight species of fish common in the vicinity of Kingston Steam Plant including: skipjack herring, gizzard shad, carp, channel catfish, bluegill, largemouth bass, sauger, and freshwater drum.

5.2.2 Results and Discussion

Low length-weight slope coefficients associated with occurrence in the discharge station did not exist for any of the eight species evaluated (Table 5.4). Highest slope values for all species, except channel catfish, were calculated for fish collected from a heated station. Channel catfish

Table 5.4. Length-weight regression statistics by station (sexes combined) for selected species in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

Species and Station	n	Intercept (a)	Slope (b)
Skipjack herring			
Upstream	110	-5.3084	3.1116
Discharge	239	-5.8367	3.3092
Downstream	226	-6.3060	3.4981
Gizzard shad			
Upstream	50	-3.5994	2.4307
Discharge	200	-5.4890	3.1990
Downstream	140	-4.3418	2.7327
Carp			
Upstream	31	-4.3587	2.8038
Discharge	10	-4.4126	2.8275
Downstream	47	-3.0705	2.3199
Channel catfish			
Upstream	42	-6.3531	3.4970
Discharge	84	-5.3593	3.1110
Downstream	126	-5.3366	3.0987
Bluegill			
Upstream	68	-5.0203	3.1443
Discharge	51	-5.2051	3.2212
Downstream	76	-4.8427	3.0671
Largemouth bass			
Upstream	35	-5.5537	3.2662
Discharge	98	-5.5675	3.2822
Downstream	51	-5.5259	3.2633
Sauger			
Upstream	154	-4.8773	2.9402
Discharge	235	-5.5234	3.1963
Downstream	230	-4.6669	2.8589

Table 5.4. (Continued)

Species and Station	n	Intercept (a)	Slope (b)
Freshwater drum			
Upstream	74	-1.1898	1.4248
Discharge	33	-4.7253	2.8872
Downstream	186	-3.7340	2.4798

at the upstream station had a high slope value, but the slope value at the discharge station was slightly higher than the downstream station. Carp and sauger exhibited lowest slope values from the downstream station, but values at the discharge basin for both of these species were higher than from the upstream station. Therefore, these lower slope values from the downstream samples do not appear to be due to thermal effects since any such effects should be more pronounced in the discharge sample. These results do not indicate adverse thermal effects and with some species may indicate positive effects resulting from Kingston Steam Plant effluent.

5.3 Age and Growth

The relationship of age to size of fish is an indicator of the suitability of an environment for a particular fish population (Lagler 1956). Therefore, age and growth studies can be designed and conducted to determine the influence of heated discharges on fish populations (Serns 1972). Numerous laboratory studies have shown a positive relationship between increasing temperature and the growth rate of fishes up to an optimum temperature. Above this optimum temperature, growth rates decline with increasing temperature until zero growth is observed (Duodoroff 1969). However, field studies of fish populations have not always shown strong correlation with laboratory results (Snyder and Blahm 1971). Specific minimum, optimum, and maximum temperatures have been shown to vary with species and acclimation of individual fish (Brown 1957). Roush (1968), O'Rear (1969), and Neill (1971) have indicated that average growth rates of fish populations living in waters influenced by heated power plant discharges show little or no acceleration if the fish have cooler water available. Certain species, however, appear to select waters with temperatues warmer than their optima and show a reduced condition index (Merriman 1970).

This study was undertaken to determine if the thermal effluent from Kingston Steam Plant has an adverse effect on age and growth characteristics of gizzard shad, channel catfish, bluegill, largemouth bass, sauger, and freshwater drum. Results of these investigations were compared with those from other populations in the Tennessee Valley region and other areas.

5.3.1 Procedures

Fishes used for the length-weight analysis were also utilized for the age and growth study. Scale samples were obtained from either side of the fish, just posterior to the distal end of the pectoral fin, and anterior to the dorsal fin. Samples were taken from above the lateral line in spiny-rayed fish and below the lateral line in soft-rayed fish (Lagler 1956). Scale impressions were made on acetate slides using a roller laboratory press. Scales were read at 40X to identify and measure annuli.

The dorsal spines from catfish were used to determine age and growth following the method described by Sneed (1951). Cross sections of the spines were cut with a saw as described by Leonard and Sneed (1951) at the distal end of the basal recess using a microscope equipped with an ocular micrometer. Annuli were identified and the distance between them measured along the lateral axis from center of the lumen to outer margin.

To determine the best relationship of body length to scale length, analysis of length versus mean scale radius was conducted utilizing the formula: length = a + bx, where a and b are slope coefficients. Because samples were obtained at various times throughout 1974 and 1975, growth increments were calculated on the basis of the last complete year of growth and represent growth during earlier years.

5.3.2 Results and Discussion

Gizzard Shad--Scale samples of 328 gizzard shad were examined to determine age and growth characteristics. The maximum number of annuli was five (five specimens). Gizzard shad from Watts Bar Reservoir attained a total length of 84 mm at age I and 275 mm at age V. Comparison of growth increments during the last full year of life for age groups one to three shows the largest increment of growth from the downstream station (Figure 5.1). For the fourth and fifth age groups the largest increment was in fish from the discharge station. These data indicate a slightly higher overall rate of growth during the last full year of life from thermally influenced areas for gizzard shad in Watts Bar Reservoir.

Channel Catfish--Age and growth characteristics of channel catfish in Watts Bar Reservoir were determined for 247 fish. The maximum number of annuli found was seven (two specimens). Channel catfish attained a total length of 124 mm in one year, 404 mm in six years, and 369 mm in seven years. This decrease in total length from the sixth to seventh annulus is probably due to sample size. A comparison of growth increments during the last full year of life shows no trend which would indicate thermal effects on growth (Figure 5.2). Increments of growth were not consistently large or small at any station.

Bluegill--Scales of 189 bluegill were examined to determine age and growth characteristics. The maximum number of annuli found was five

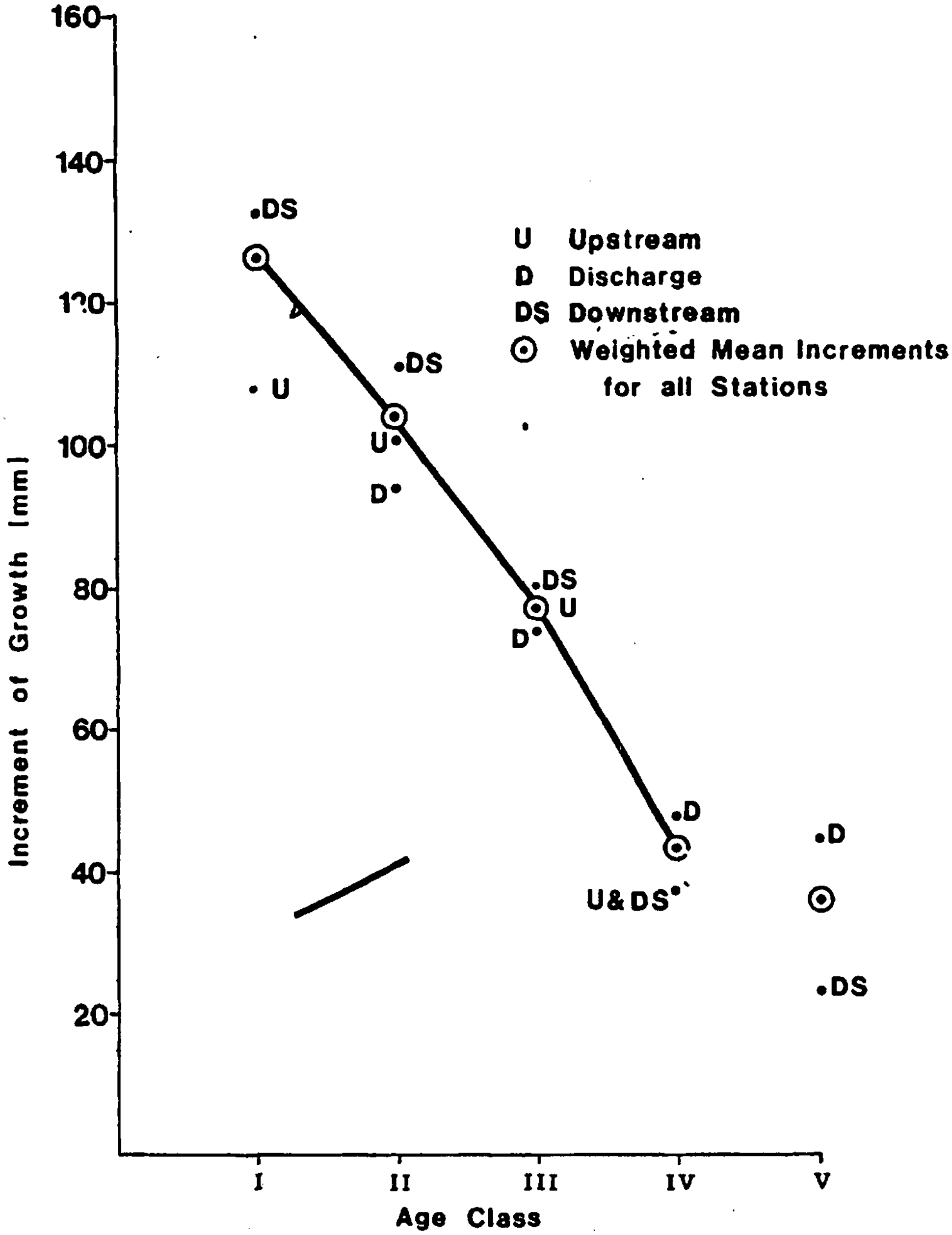


Figure 5.1. Increments of growth during the last full year of growth for five age groups of gizzard shad (Dorosoma cepedianum) from three areas in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

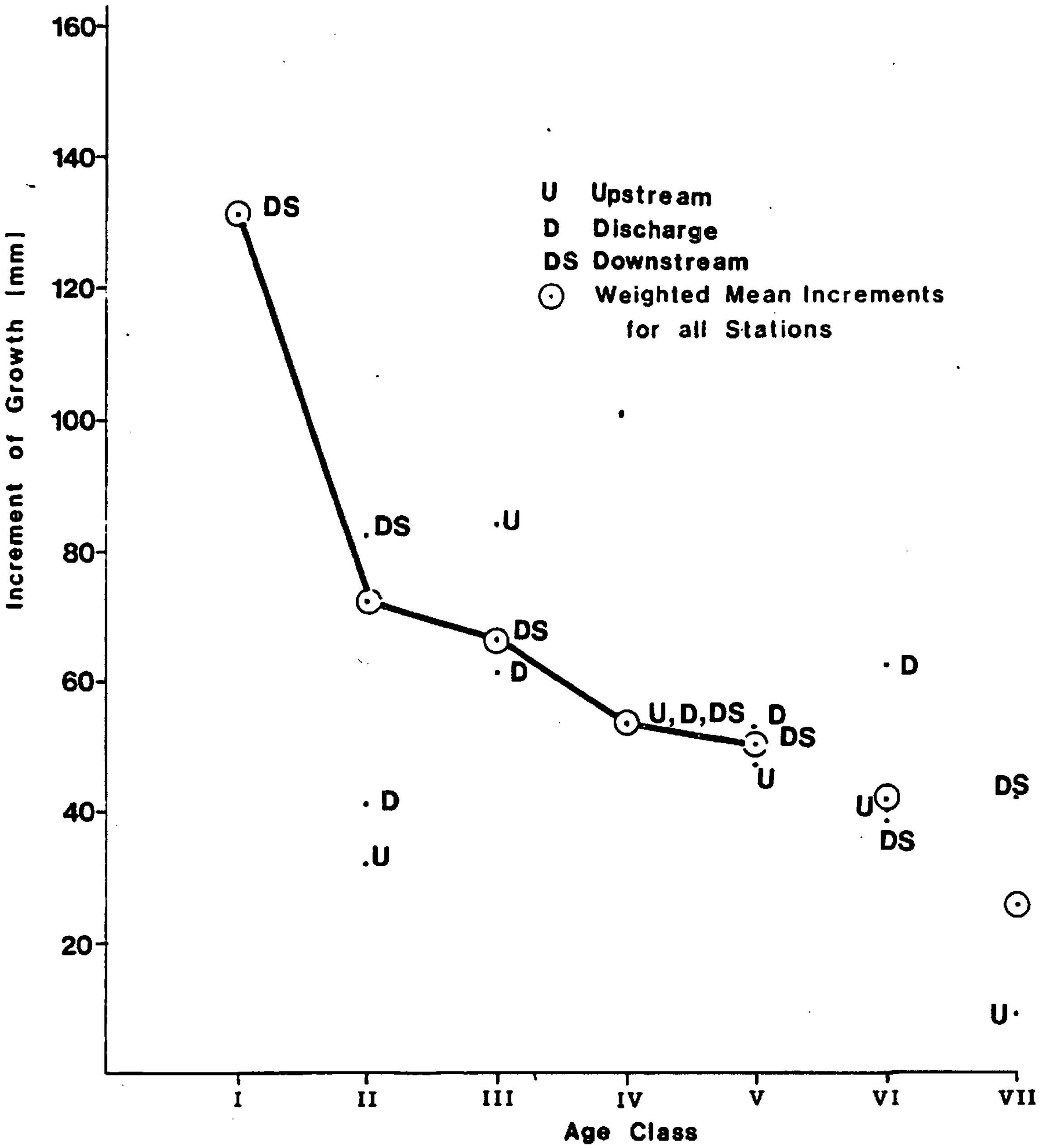


Figure 5.2. Increments of growth during the last full year of growth for seven age groups of channel catfish (Ictalurus punctatus) from three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

(four specimens). Bluegill attained a mean total length of 45 mm at the first annulus and 184 mm at the fifth annulus. Comparison of growth increments during the last full year of life showed no consistent trend but growth increments for fish from the downstream station were generally larger than those from upstream or discharge stations (Figure 5.3).

Largemouth Bass--Age and growth characteristics of largemouth bass were determined by examining scales of 155 fish. The maximum number of annuli found was six (one individual). Largemouth bass attained a mean total length of 118 mm at the first annulus and 405 mm at annulus six. Comparison of growth increments during the last full year of life again showed the largest increment occurred among fish from the downstream station (Figure 5.4). This larger increment was not apparent for fish from the discharge station.

Sauger--Scales of 528 sauger from Watts Bar Reservoir were examined to determine age and growth characteristics. The maximum number of annuli found was five (two specimens). Sauger attained a total length of 223 mm at the first annulus and 465 at the fifth annulus. Growth increments during the last full year of life (Figure 5.5) showed no trend indicative of an influence of thermal discharges. This would be expected for a migratory species such as sauger.

Freshwater Drum--Age and growth characteristics of freshwater drum from Watts Bar Reservoir were determined by examining scales of 289 fish. The maximum number of annuli found was six (one specimen). Drum attained a mean total length of 93 mm in one year and 351 mm in six years. Growth increments during the last full year of life (Figure 5.6) were largest at the discharge station.

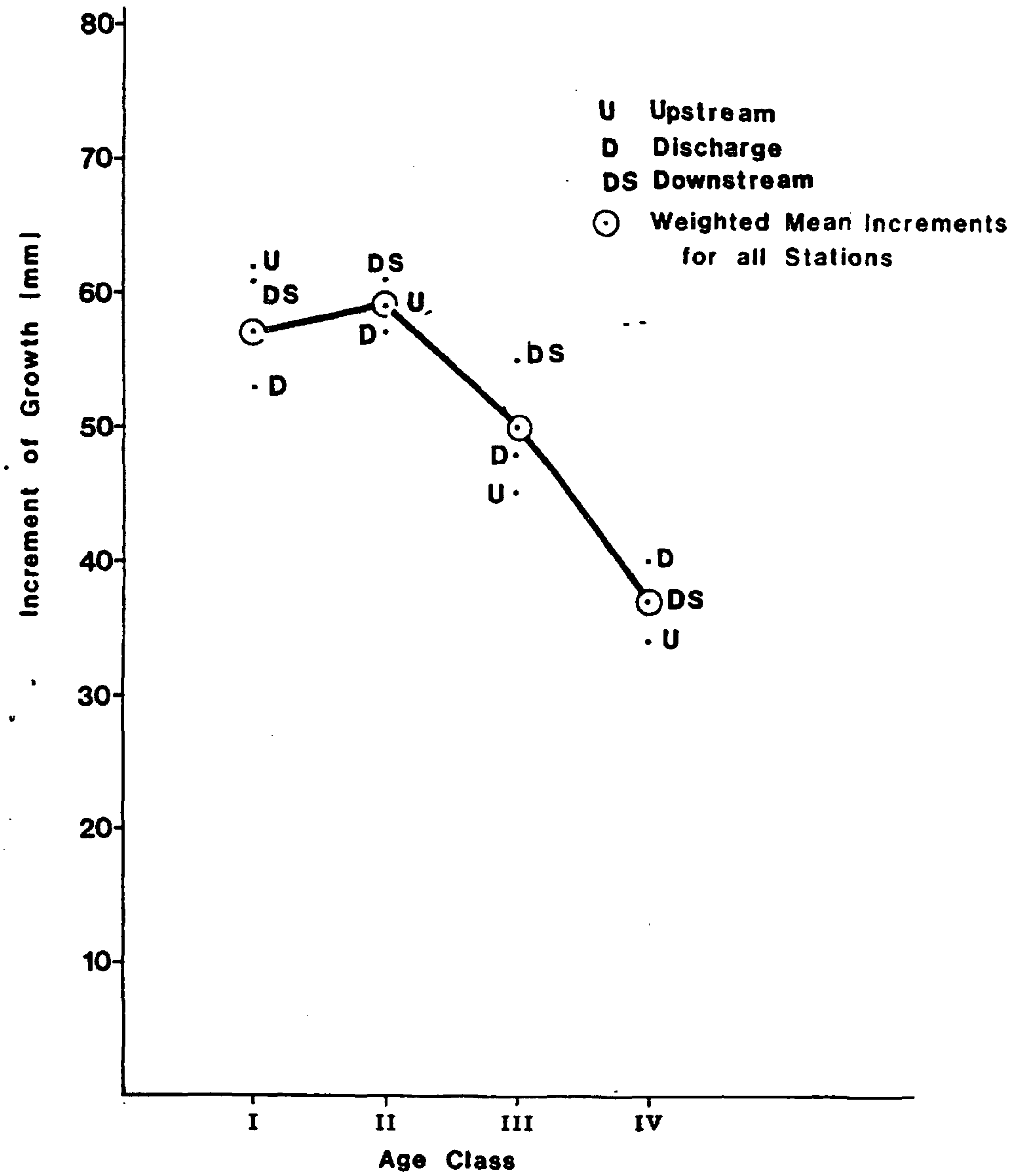


Figure 5.3. Increments of growth during the last full year of life for four age groups of bluegill (Lepomis macrochirus) from three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

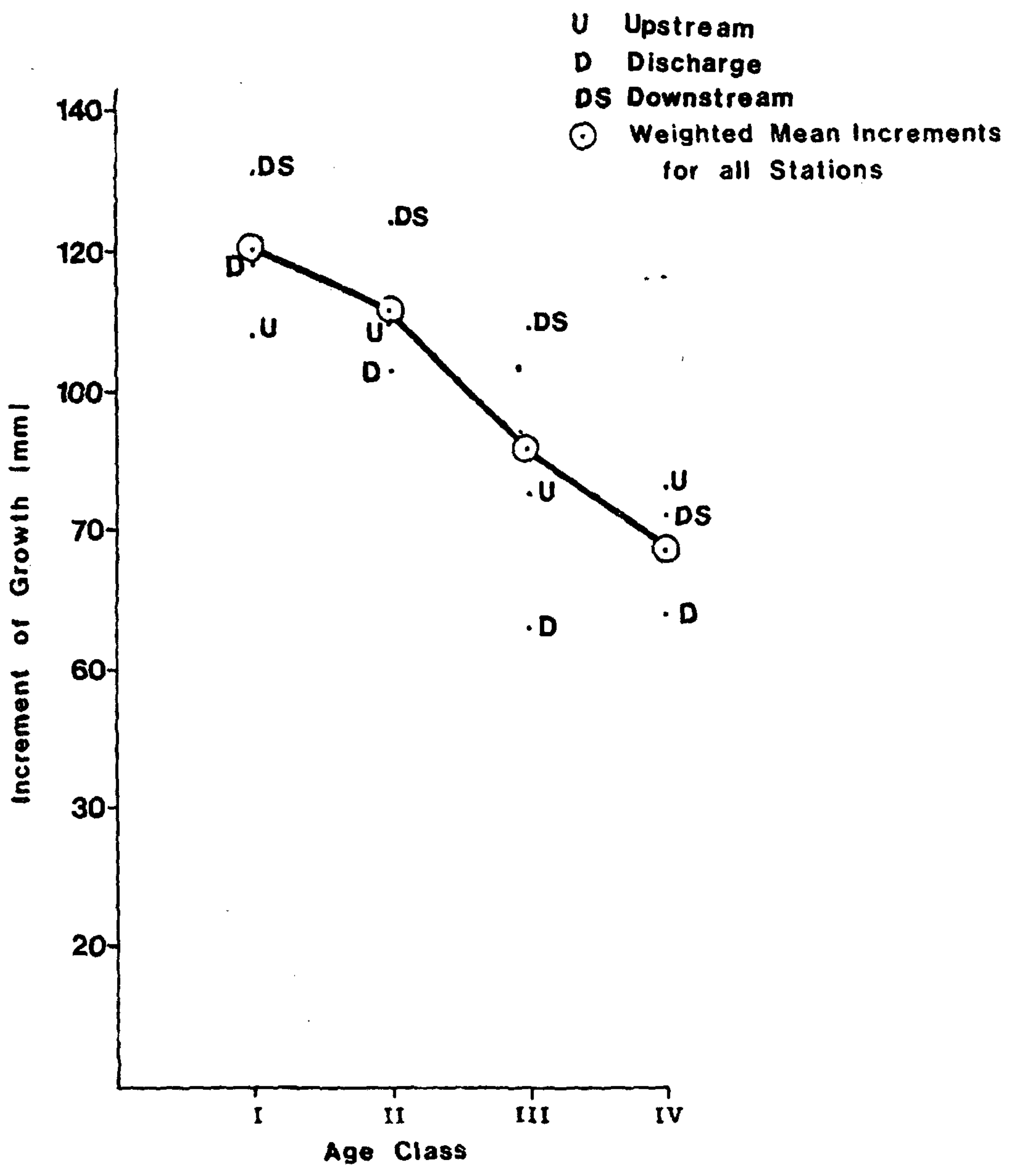


Figure 5.4. Increments of growth during the last full year of life for four age groups of largemouth bass (Micropterus salmoides) from three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

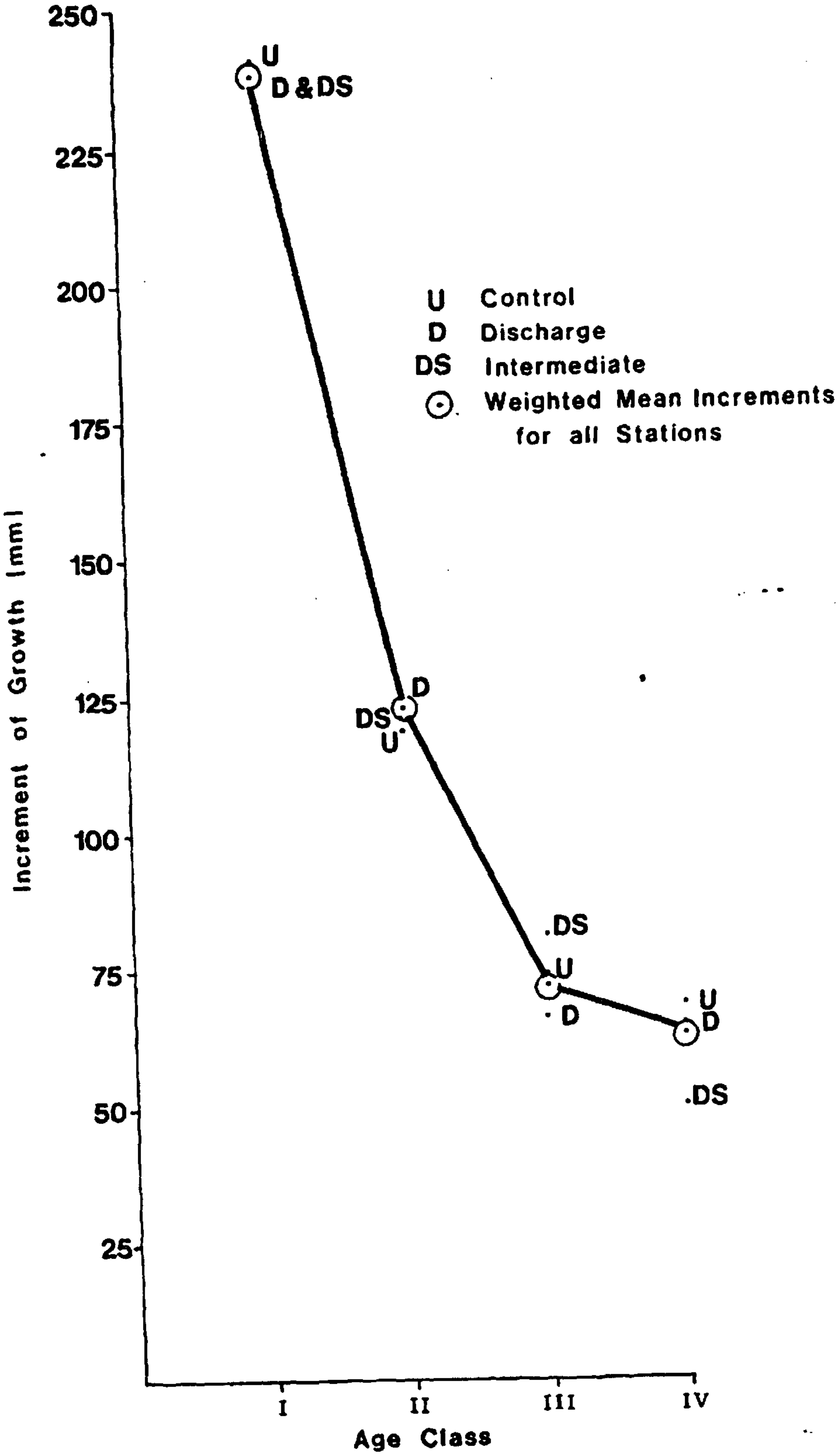


Figure 5.5. Increments of growth during the last full year of life for four age groups of sauger (Stizostedion canadense) from three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

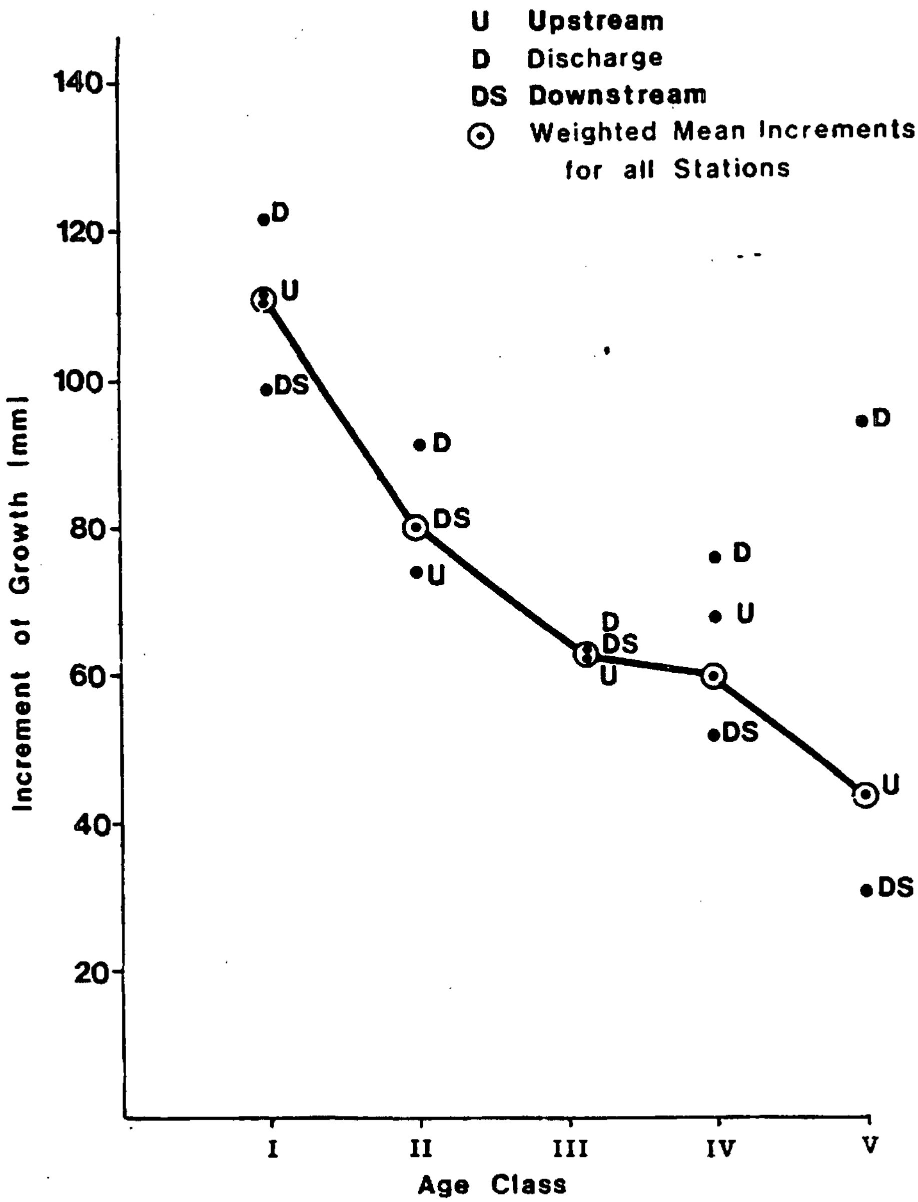


Figure 5.6. Increments of growth during the last full year of life for five age groups of freshwater drum (Aplodinotus grunniens) from three stations in Watts Bar Reservoir near Kingston Steam Plant (April 1974 through September 1975).

5.3.3 Summary

Scale samples were collected from six species of fish at three stations in Watts Bar Reservoir near Kingston Steam Plant to determine if thermal effluent from this plant affected age and growth of these species. For gizzard shad, bluegill, largemouth bass, and freshwater drum, increments of growth were generally larger from one of the thermally affected stations (discharge or downstream). However, it is doubtful whether these increases are attributable to thermal effects alone. Sauger and channel catfish showed no growth trend indicative of thermal influences.

Growth rates of the six species from Watts Bar Reservoir were comparable to growth rates for these species from other waters (Appendix, Tables 4-9). Thus, it appears the effect of thermal effluent from Kingston Steam Plant on age and growth of those species investigated from Watts Bar Reservoir in the vicinity of the steam plant is negligible.

CHAPTER 6

ENTRAINMENT OF FISH EGGS AND LARVAE

In 1975 an ichthyoplankton survey was conducted on Watts Bar Reservoir in the vicinity of Kingston Steam Plant to assess the impact of entrainment losses on reservoir fish populations. Details and results were reported to the Environmental Protection Agency the following year (TVA 1976). TVA concluded in that report that operation of the steam plant did not constitute a significant adverse impact on the balanced, indigenous fish populations of Watts Bar Reservoir.

Current regulations require that steam-electric power plants be repermitted at five-year intervals. This report has been developed to aid the permit renewal request for the Kingston Plant.

6.1 Scope and Objectives

Although no ichthyoplankton surveys have been conducted near the plant since 1975, a wide variety of questions has arisen regarding entrainment measurement at the Kingston Plant and assessment of potential impact. Concerns addressed here are many and diverse but most fall within the three broad categories of hydraulic considerations, accuracy and precision of entrainment estimates, and quantification of entrainment impacts. In the following sections of this report it will become clear that, while many problems are introduced and discussed, all are not fully resolved. Indeed, several points considered serve only to emphasize complexities involved in entrainment estimation and impact assessment.

Ichthyoplankton data from 1975 and other data were reviewed to meet the following specific objectives:

1. To describe the nature of flows in the vicinity of the plant, especially as related to transport of larval fish populations.
2. To determine effects of different annual flow regimes on hydraulic and biological entrainment.
3. To determine why the biological entrainment estimate for 1975 (0.84 percent) was so much lower than hydraulic entrainment (22 percent).
4. To evaluate biological entrainment in terms of both transported and reservoir populations.
5. To determine whether or not operation of the plant has potential for a significant adverse impact on fish populations of Watts Bar Reservoir.

6.2 Flow Characteristics and Hydraulic Entrainment

River flows in the vicinity of the plant are complex. As shown in Figure 6.1, the plant is located on a peninsula at the confluence of the Clinch and Emory Rivers. The plant intake is on the Emory River with discharge to the Clinch River downstream from confluence with the Emory. Discharge from the Clinch River is cooler than Emory River waters and an underwater dam located immediately below the confluence of these two rivers deflects these cooler waters up the Emory beyond the plant intake.

A skimmer wall 7.5 m deep aids in selecting cooler deep water for condenser cooling (TVA 1974). However, water temperatures in the intake basin (Figure 6.2) are intermediate between those of the Clinch and Emory revealing some Emory River water is also entrained.

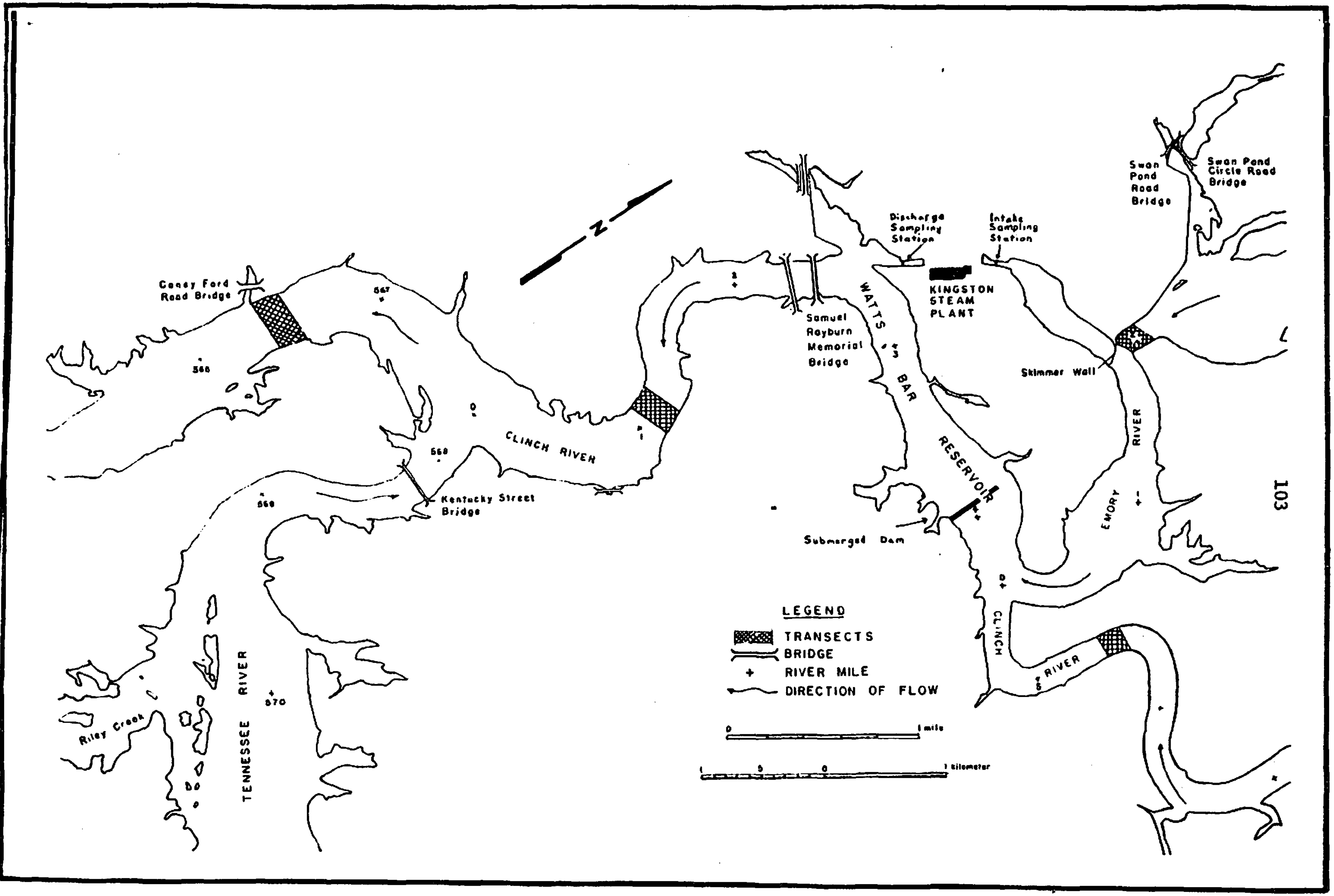


Figure 6.1. Kingston Steam Plant on Watts Bar Reservoir, and location of transect sampling stations from TVA (1976).

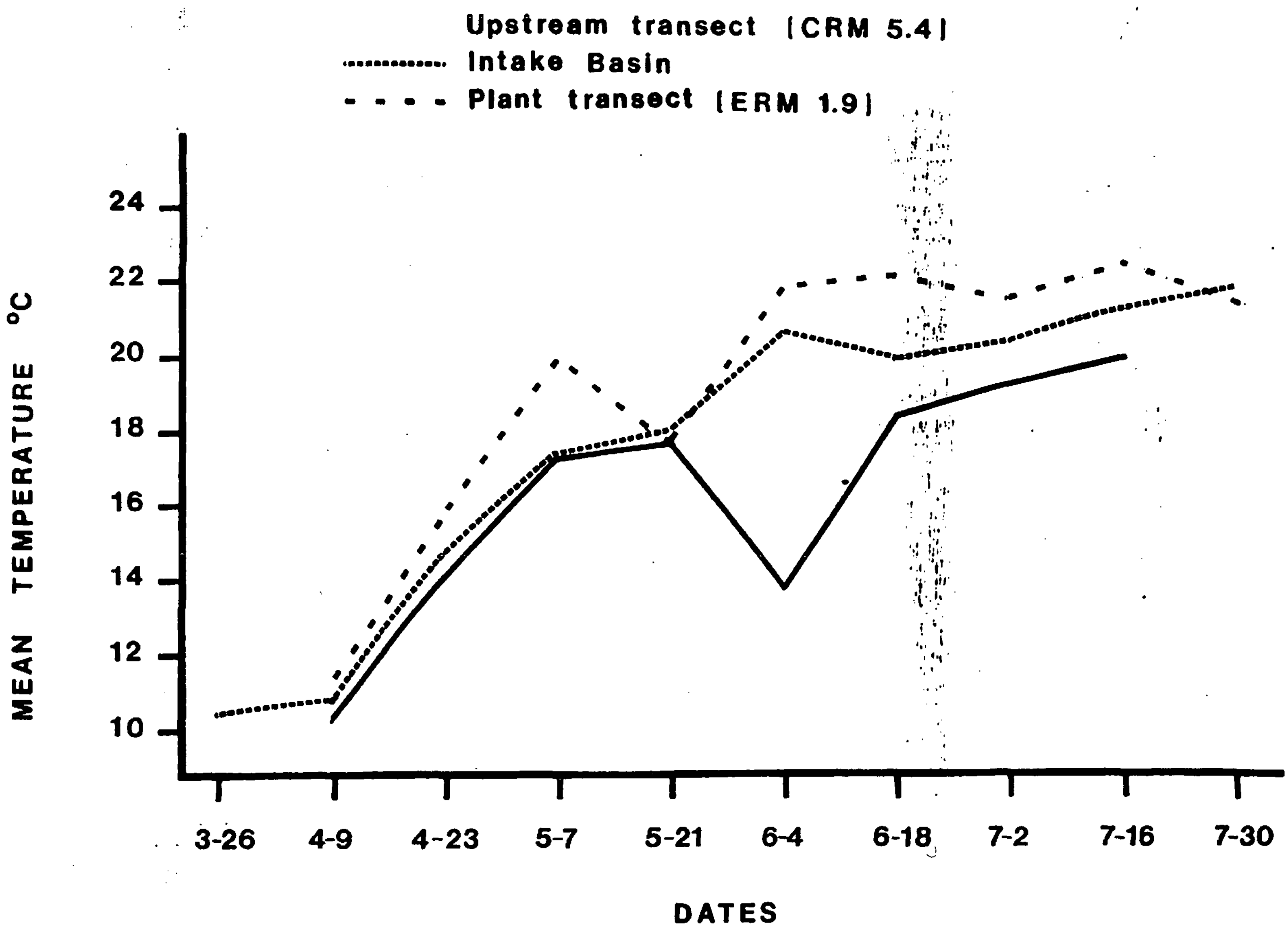


Figure 6.2. Mean middepth temperatures taken at two reservoir transects and within the intake channel on sampling dates, Watts Bar Reservoir, 1975.

The 7-day, 10-year low flow in the Clinch River is 85 m^3/s (7.34×10^6 m^3/day) and 0.006 m^3/s (4.89×10^2 m^3/day) in the Emory (TVA Data Services Branch). Maximum cooling water demand for the plant is 61 m^3/s (TVA 1955). Discharge in the Clinch River averaged 255 m^3/s on sample dates during the study period in 1975.

Hydraulic entrainment by Kingston Steam Plant in 1975 was approximately 22 percent. During wet years such as 1975, large streamflows depress hydraulic entrainment. During average or dry years hydraulic entrainment is proportionately greater. The effect of dry years on biological entrainment is not known.

Kingston Steam Plant is a base load power facility and for purposes of impact assessment is considered to have a constant intake demand. Plant intake demand in 1975 (TVA 1976) was near maximum on most sample dates.

Hydraulic conditions in Watts Bar Reservoir in the vicinity of the plant are highly variable. In 1975, flows in the Clinch River varied between 2.6 and 10.0 times intake demand (TVA 1976). There were also large fluctuations within 24-hour periods caused by hydroelectric operations at Melton Hill Dam. Since the primary source for cooling water is the Clinch River, low flows in the Clinch increase withdrawal of Emory waters for cooling, such that the two rivers provide varying contributions to intake cooling waters. Flows in the Emory River are not regulated and depend on rainfall in the watershed. Typically, variations in Emory River 24-hour flows are small while weekly variations can be greater. Flows on sample dates in 1975 varied between 2.5 and 0.02 times the intake demand.

Average Clinch and Emory River discharges constitute 78 percent and 22 percent of the flow past the plant, respectively (Table 6.1). If the 7-day, 10-year low flows for the Clinch and Emory Rivers (7.34×10^6 m^3/day and 4.89×10^2 m^3/day, respectively) were to occur simultaneously during maximum intake demand, hydraulic entrainment would be 71.8 percent of the flow past the plant. Combined flows in the Clinch and Emory Rivers during 1969 to 1978 averaged 16.84×10^6 m^3/day. This was 24.8 percent of the total flow through Watts Bar Dam.

Spring flows in 1975 were greater than other years during the 1969 to 1978 period and hydraulic entrainment proportionally lower (Figure 6.3). Mean flow during 1975 was more than 26.20×10^6 m^3/day. Historical data show hydraulic entrainment (assuming maximum plant operation) generally averaged 20 to 40 percent and could have exceeded 40 percent in 2 of 10 years during 1969 to 1978. This is a very significant portion of the flow passing the plant. However, from Table 6.1 it is clear that only 25 percent of the total reservoir flow actually passes the plant with the potential for reservoir-wide (far field) impacts reduced accordingly.

Hydraulic entrainment can also be expressed in terms of total reservoir volume (at constant full pool). Table 6.2 shows the volume of various reservoir segments corresponding to areas represented by transect samples in 1975. During maximum intake demand, daily withdrawals by the plant total 5.4 percent of the water volume upstream from the plant but only 0.4 percent of the total volume of the reservoir.

6.3 Estimation of Biological Entrainment

The accuracy of biological entrainment estimates is determined by the experimental design and sampling efficiency of the gear types used.

Table 6.1. Average discharges March to August for three locations on Watts Bar Reservoir 1969 through 1978.*

	Discharge x 10^6 x m^3/day			
	Emory River	Clinch River	Clinch and Emory River	Watts Bar Dam
1969	2.24	6.99	9.23	43.36
1970	3.41	10.97	14.37	51.99
1971	3.32	10.58	13.90	58.39
1972	3.76	14.14	17.90	68.57
1973	7.02	18.16	25.18	97.69
1974	2.84	15.88	18.73	83.30
1975	5.08	21.12	26.20	97.92
1976	2.88	9.13	12.01	53.10
1977	3.88	13.08	16.97	70.05
1978	3.19	10.70	13.89	54.83
Average	3.76	13.08	16.84	67.92

*Source - TVA Data Services Branch

Average contribution of Clinch and Emory Rivers = 24.8%

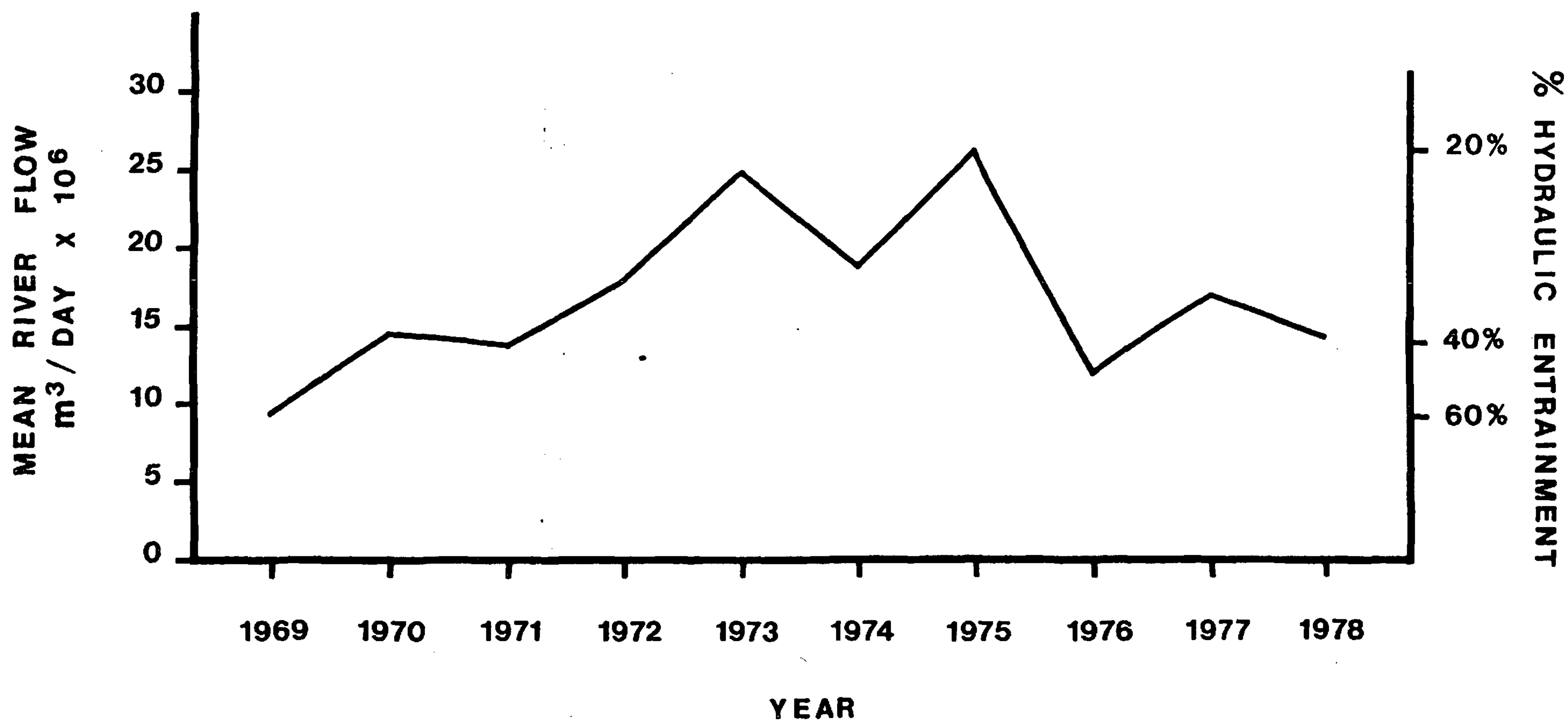


Figure 6.3. Annual mean river flow (Clinch and Emory combined) and maximum hydraulic entrainment for the years 1969-78.

Table 6.2. Relative areas and volumes of four segments of Watts Bar Reservoir at full pool.*

Reservoir Segment	Area (ha)	Volume (ha-meters)	Percent of Total Volume
Emory River arm	1,129	4,925	3.9
Clinch River above Emory	1,184	4,616	3.6
From Clinch/Emory confluence to Clinch/Tennessee River confluence	487	2,958	2.3
Watts Bar Reservoir exclusive of Clinch and Emory Rivers	12,582	115,121	90.2

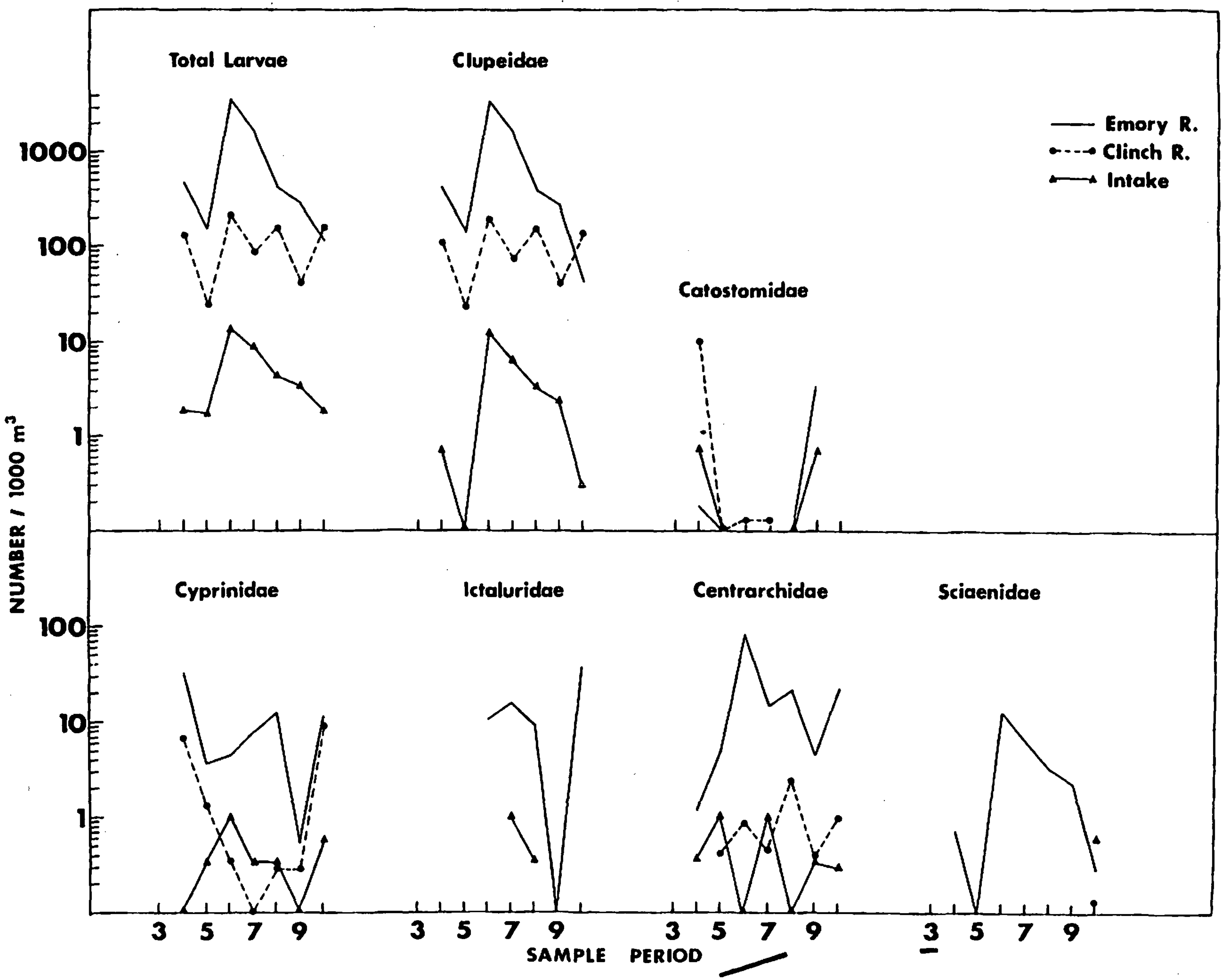
*Source - TVA Data Services Branch

The 1975 data (Figure 6.4) showed densities of fish larvae measured in intake waters were generally lower than those observed in either the Clinch or Emory Rivers. This difference could result from either avoidance of stationary intake nets by larvae or their vertical distribution in relation to openings under the skimmer wall, or both.

Aron and Collard (1969), Noble (1970), and Graser (1977) have shown that sampling efficiency of towed (or pushed) nets varies with sampling speed and size of the net mouth. One meter conical push nets (0.78 m^2 mouth area) used at Kingston Steam Plant were pushed at 1.27 m/s while vertical nets (1.88 m^2 mouth area) sampled at approximately 0.5 m/s. Water velocity through stationary intake nets (0.19 m^2 mouth area) varied but was generally about 0.25 m/s. Discharge samples were taken concurrently with intake samples using identical gear types. Velocity through discharge station nets was roughly twice (0.5 m/s) that of intake nets. A more complete description of samplers is found in TVA (1976).

In order to address sampling efficiency of intake stationary nets, data collected with discharge stationary nets were examined. Nets located approximately 100 m from the point of discharge sampled a population that had recently traversed the cooling system of the power plant. Many of these larvae were probably dead or dying with living individuals undoubtedly disoriented by the time they reached the discharge channel. This combination of factors should virtually eliminate net avoidance in the discharge. The high velocities and turbulence of discharge waters make it improbable that dead larvae would settle out of the water column before reaching the discharge nets. Thus, discharge samples should be a more accurate measure of numbers entrained.

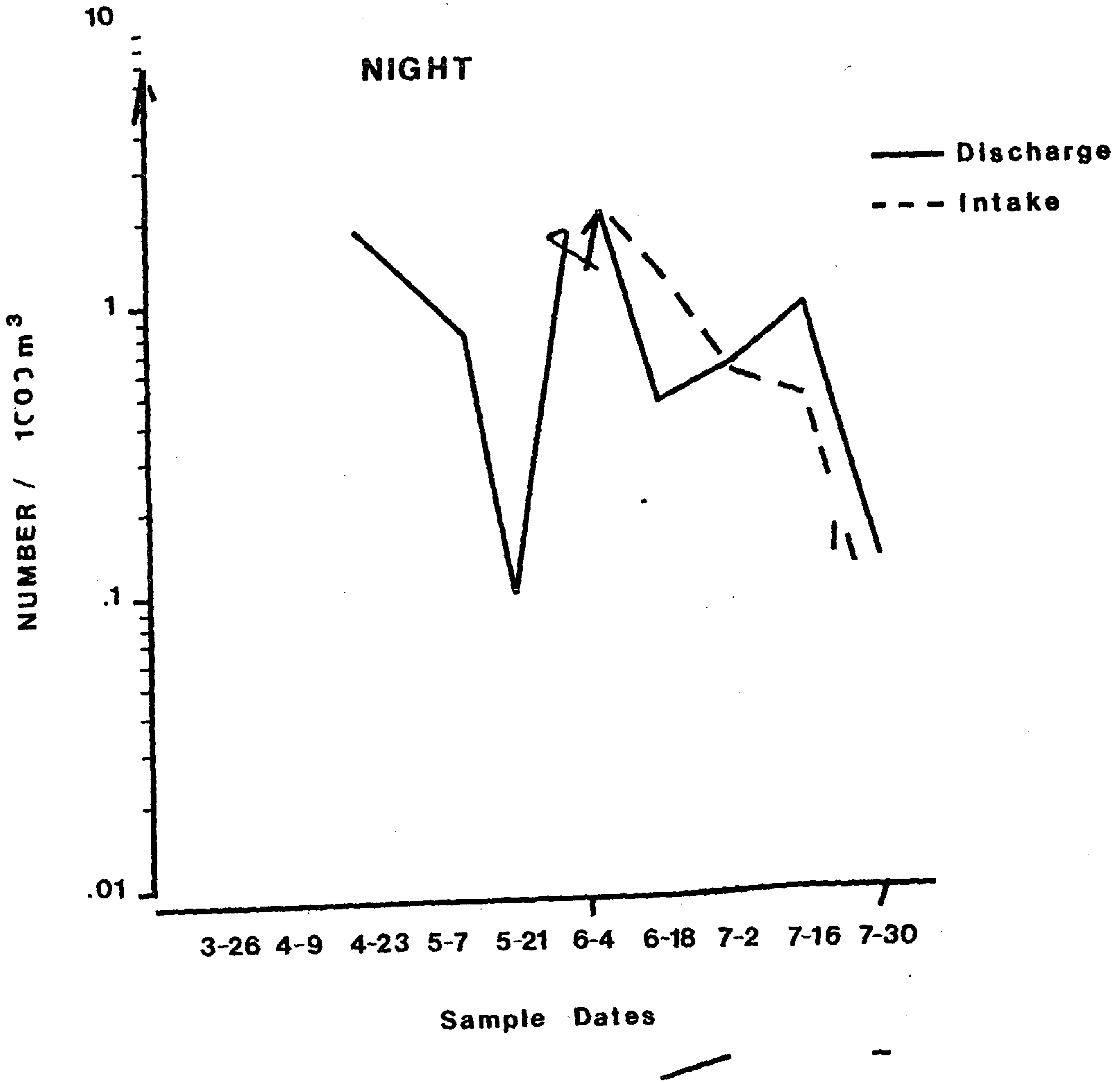
Figure 6.4. Mean densities of fish larvae in Watts Bar Reservoir and in intake samples at Kingston Steam Plant, 1975. See Section 2.4 for details on biweekly sampling periods (from TVA 1976).



Clupeids were the only larvae collected in sufficient numbers in intake and discharge waters to allow detailed analysis and are the only taxon considered here. Clupeid larvae first appeared in entrainment samples on May 7 and were present through the end of the study. Nocturnal densities (Figure 6.5) for intake and discharge samples during June and July were similar, suggesting little or no net avoidance at night. This is further borne out by seasonal length class densities (Figure 6.6) of night entrainment samples. In larger size classes (9-19 mm), where density differences due to avoidance should be most pronounced, none was apparent. The only difference in length class distributions between night intake and discharge samples was in the smallest length classes (3-8 mm) which were abundant in discharge samples but absent in intake samples.

The presence of small larvae in the discharge was apparently the result of spawning in this area. Large numbers of unidentified eggs (probably clupeid) were collected in the discharge channel April 23-June 4 (Table 6.3). Night egg densities were usually an order of magnitude greater than day densities, suggesting very heavy night spawning in the discharge. During this period few eggs and virtually no clupeid larvae were collected in the intake channel, day or night, indicating these small larvae originated in the discharge channel. The banks of the discharge channel are riprapped and it is believed that clupeids deposit eggs among the riprap where the young find limited refuge until being swept clear of the area. It is not apparent why small larvae were common in the discharge on May 7 and not April 23, May 21, or June 4 when eggs were also abundant. Almost all larvae 3-7 mm total length found in the discharge channel were collected on May 7 and 21 and these

Figure 6.5. Density of clupeid larvae collected at night in intake and discharge samples during biweekly sampling at Kingston Steam Plant, 1975.



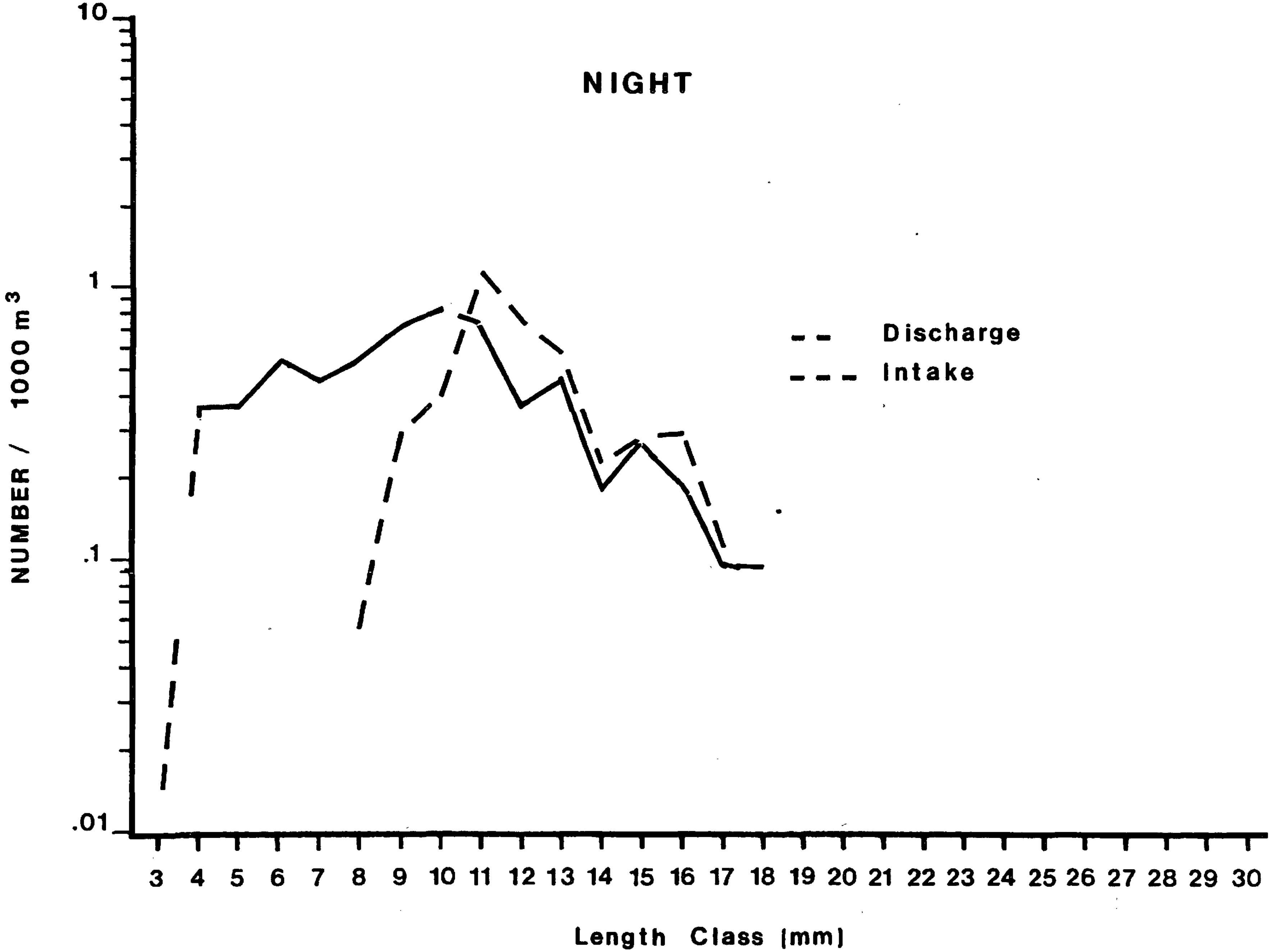


Figure 6.6. Seasonal size class densities of clupeid larvae collected at night in intake and discharge samples at Kingston Steam Plant, 1975.

Table 6.3. Biweekly estimates (No./1,000m^3) of unidentified* eggs collected in day and night samples in intake and discharge waters at Kingston Steam Plant, 1975.

Date	Day		Night	
	Intake	Discharge	Intake	Discharge
3/26	0	0	0	0
4/9	0	0	0	0
4/23	0	5,059.00	0	68,251.00
5/7	13.30	5,479.00	0	42,368.00
5/21	6.28	78,693.00	0	230,647.00
6/4	57.93	958.00	0	39,832.00
6/18	0	38.70	0	0
7/2	0.70	0	0	0
7/16	0	0	0	0
7/30	0	0	0	0

*Probably clupeid eggs.

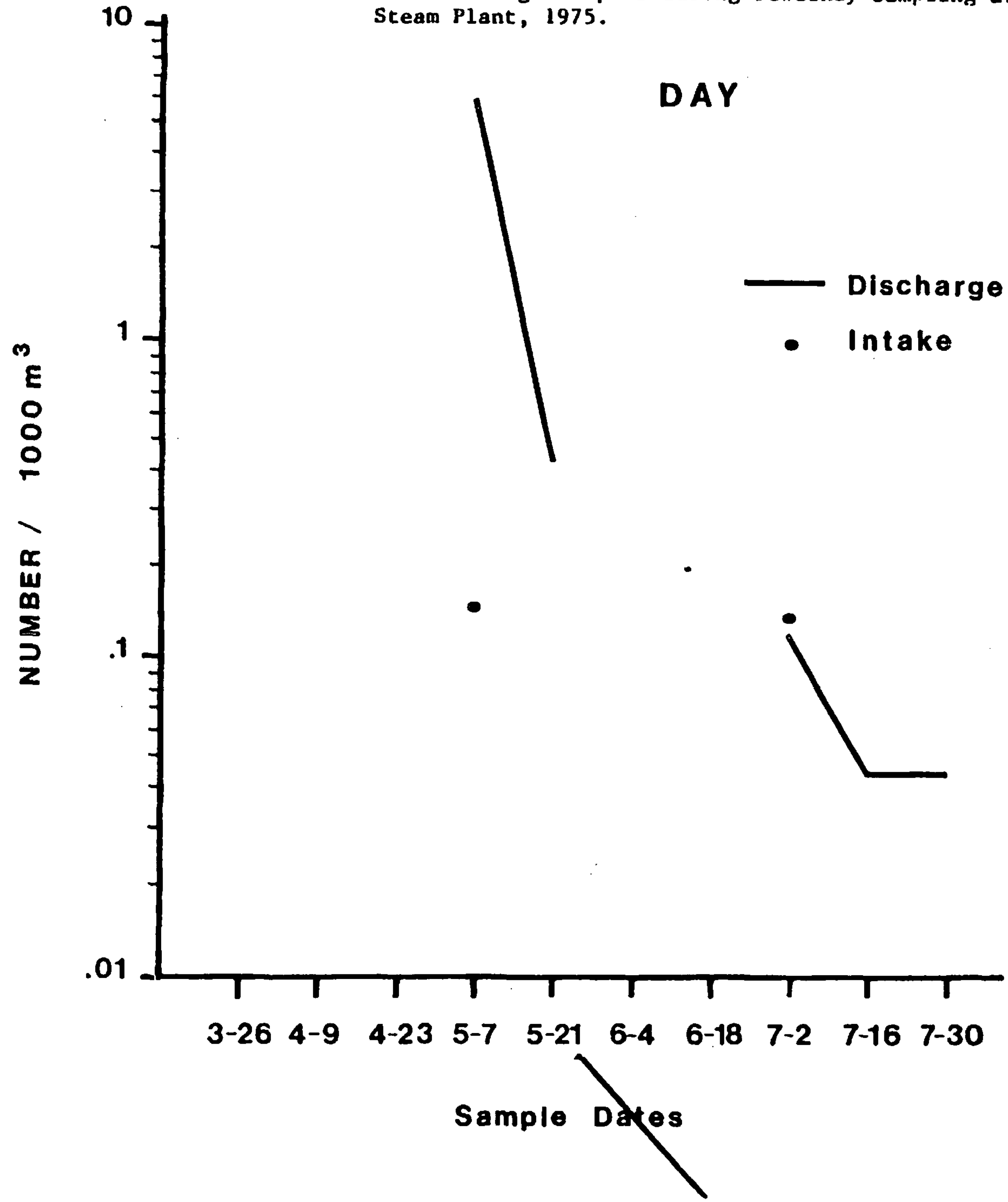
account for differences in length distributions shown in Figure 6.5. Discharge samples after May were not contaminated by spawning in this area and are probably a reasonable baseline from which to judge intake samples.

Significant avoidance of intake nets during day sampling was evidenced by greater densities in discharge samples (Figures 6.7 and 6.8). However, since day discharge densities after June 4 (little or no spawning in the discharge) were much lower than night discharge densities (Figure 6.9), apparently fewer larvae were entrained by the plant (i.e., transported through the intake channel) during day.

Clupeid larvae have been found to concentrate in surface waters during both day and night, but particularly during day (Taber 1967, Walker 1975, Graser 1979, and Tuberville 1979). Reservoir samples were taken only at night but comparison of shallow and deep densities at both the plant and upstream transects (Table 6.4) indicates the usual nocturnal pattern. It is likely then that day vertical distribution of clupeids is also surface oriented. Therefore, lower densities observed in daytime stationary netting may reflect, in addition to avoidance, low density in the intake channel caused by concentration of larvae above deep openings in the skimmer wall, therefore reducing their vulnerability to entrainment.

In summary, it appears that night intake samples may provide estimates of entrainment. Day intake densities were low, apparently due to a combination of net avoidance and vertical distribution patterns. As a result, entrainment during day may be less than at night as evidenced by generally lower densities in the intake and discharge channel during day.

Figure 6.7. Density of clupeid larvae collected during daytime in intake and discharge samples during biweekly sampling at Kingston Steam Plant, 1975.



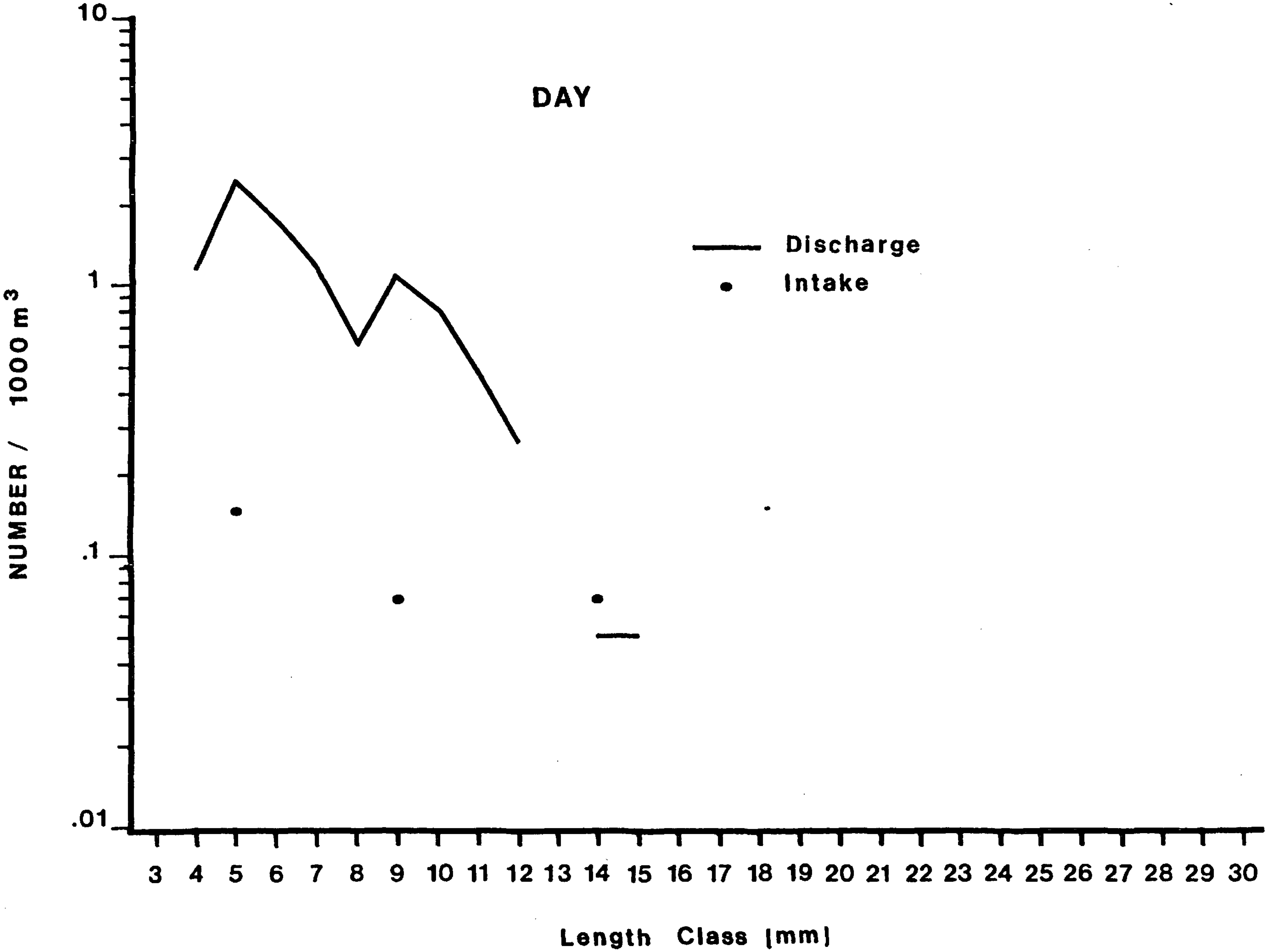


Figure 6.8. Seasonal size class densities of clupeid larvae collected during daytime in intake and discharge samples at Kingston Steam Plant, 1975.

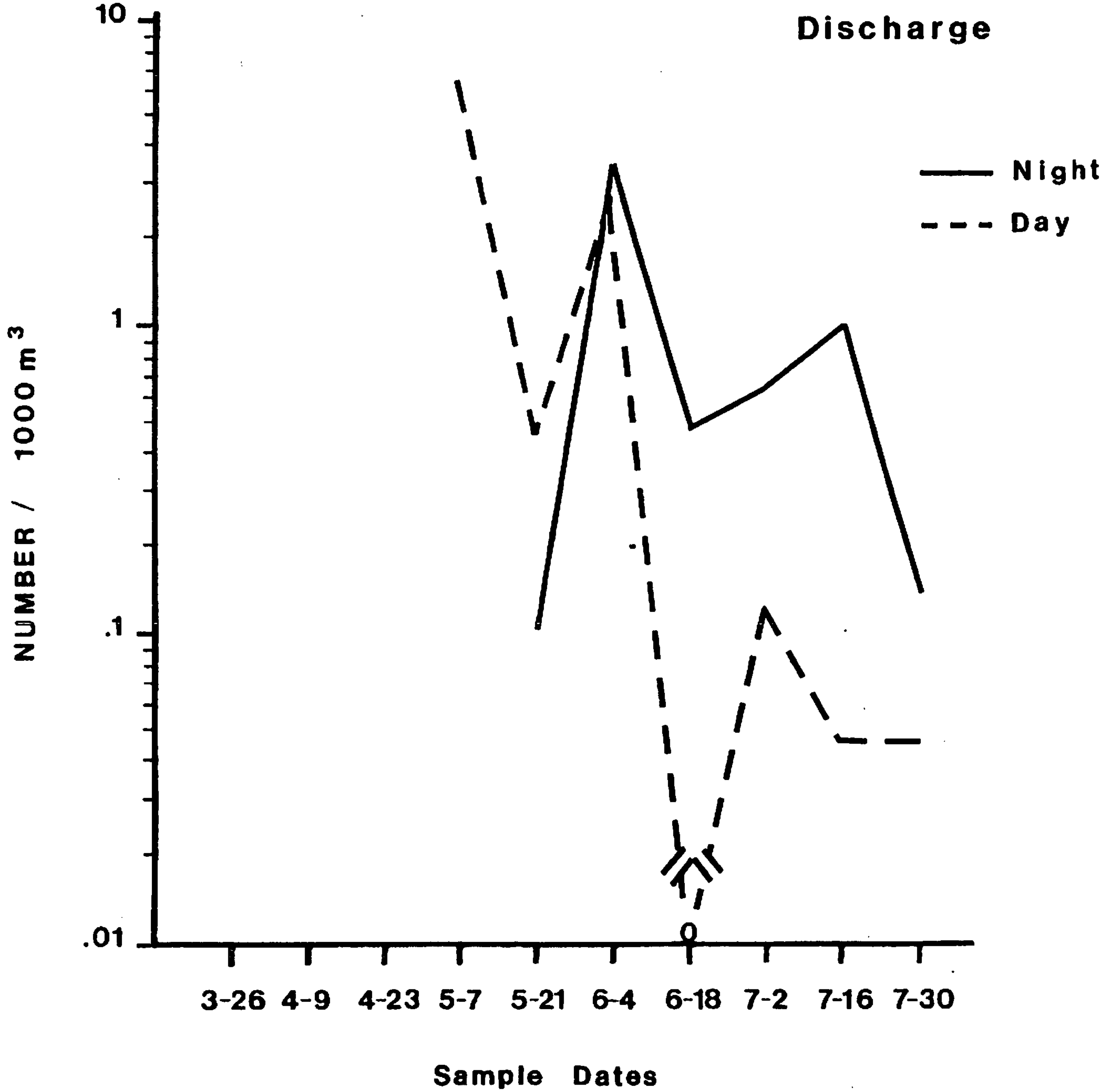


Figure 6.9. Density of clupeid larvae collected in the discharge channel of Kingston Steam Plant during day and night sampling, 1975.

Table 6.4. Night densities (numbers per 1,000 m^3) of fish larvae in shallow and deep waters at two transects on Watts Bar Reservoir, 1975.

Family		Plant Transect (Emory River)	Upstream Transect (Clinch River)
Clupeidae	shallow	1,692.37	353.04
	deep	905.61	53.06
Cyprinidae	shallow	24.12	5.83
	deep	6.17	1.19
Catostomidae	shallow	2.55	1.60
	deep	0	1.79
Ictaluridae	shallow	0.46	0
	deep	11.45	0
Percichthyidae	shallow	0.81	0.11
	deep	0	0
Centrarchidae	shallow	64.58	2.86
	deep	14.98	0.60
Percidae	shallow	0	0
	deep	0	0.60
Sciaenidae	shallow	0	0.11
	deep	0	0
Sciaenid eggs	shallow	0	10.41
	deep	0.46	39.35

6.4 Expected versus Observed Biological Entrainment

When biological entrainment does not approximate hydraulic entrainment, it must be assumed that the experimental design was inadequate or that some selective mechanism(s) is operating. It is evident that biological and hydraulic entrainment at Kingston are not similar.

Hydraulic entrainment at Kingston Steam Plant in 1975 averaged 22.70 percent while biological entrainment was only 0.84 percent (Table 6.5), yielding a biological to hydraulic entrainment ratio of 0.04. This was the second lowest of all of TVA's steam plants and lowest for those with skimmer walls. Generally, plants with skimmer walls had the lowest biological/hydraulic entrainment ratios. It appears skimmer walls may partially protect surface-dwelling larvae.

From section 6.3 it is evident that discharge, rather than intake, samples provide the most reliable estimates of biological entrainment. Further, it is suggested from section 6.3 and Table 6.5 that vertical distribution of clupeid larvae in relation to the skimmer wall openings selectively protects larvae from entrainment.

If, because of the skimmer wall, surface dwelling larvae are protected, then "expected" entrainment estimate may be calculated from density data from deep strata in the source waters (Clinch and Emory Rivers). If it is further assumed that the relative contribution of each river to the entrained water mass is proportionate to the flow in each river, then the expected entrainment estimate can be calculated for each sample period as:

Steam Plant	Percent Biological Entrainment	Percent Hydraulic Entrainment[5]	Entrainment Ratio (biological/ hydraulic)	Skimmer Wall
Bull Run	6.57	10.31	0.64	Present
Cumberland	3.60	8.73	0.41	Present
Gallatin	1.57	18.3	0.09	Present
Kingston	0.84	22.70	0.04	Present
Paradise	1.98	9.72	0.20	Present
		Mean	0.28	
Allen[1,2]	≈2.50	2.05	1.22	None Present
Colbert	3.00	2.32	1.29	None Present
John Sevier	16.00	26.50	0.60	None Present
New Johnsonville	0.26	2.19	0.01	None Present
Shawnee[3]	1.95	1.10	1.77	None Present
Watts Bar (fossil)[1]	0.24	0.95	0.25	None Present
Widows Creek[4]	1.50	5.74	0.26	None Present
		Mean	0.77	

1. No intake channel.
2. Not based on transport model.
3. Not based on intake samples.
4. Two intake configurations, one with and one without intake channel.
5. Based on sample period averages.

$$\frac{\left[\left(D_e \cdot \frac{Q_e}{Q_c + Q_e}\right) + \left(D_c \cdot \frac{Q_c}{Q_c + Q_e}\right)\right] Q_i}{(N_e + N_c)} = \text{theoretical entrainment}$$

where D_e = Density (no./1,000 m^3) in deep strata in the Emory River

D_c = Density (no./1,000 m^3) in deep strata in the Clinch River

Q_e = Flow (m^3/day) in the Emory River on a given date

Q_c = Flow (m^3/day) in the Clinch River on a given date

Q_i = Flow (m^3/day) through the plant on a given date

N_e = Number larvae transported in the Emory

N_c = Number larvae transported in the Clinch

An "observed" entrainment estimate was also calculated as in TVA (1976), but using discharge densities instead of intake densities.

Both "expected" and "observed" estimates were computed from night samples only in June and July. Entrainment estimates were calculated for each sample period and overall for the period of concern using the integration method described in TVA (1976).

Observed entrainment (Table 6.6) ranged from 0.23 to 9.09 percent and was always less than the expected (5.45 to 19.62 percent). Both were consistently lower than hydraulic entrainment (17.56 to 39.75 percent).

Although the expected entrainment is closer to the actual than is the hydraulic entrainment, a considerable difference still exists. Most of this difference may be attributable to patterns of vertical distribution of clupeid larvae which were masked by the gear types used.

Shallow strata were sampled with 1 m conical push nets such that "deep" strata refers here to waters deeper than 1 m. The skimmer wall openings, however, are 7.5 m deep. Hence, the deep waters sampled

Table 6.6. Estimated entrainment (percent) of larval fish by Kingston Steam Plant for transported (T) and reservoir (R) populations. Transport percentages from TVA (1976).

Family	Estimated Population	Sample Periods 3	4	5	6	7	8	9	10
Clupeidae	T	NP	0.146	0	1.05	0.92	0.40	2.25	0.05
	R	NP	0.000003	0	0.000018	0.000019	0.000008	0.000001	0.000002
Cyprinidae	T	NP	0	4.38	53.92	14.41	13.52	0	1.65
	R	NP	0	0.000046	0.000748	0.000309	0.000211	0	0.000171
Catostomidae	T	0	2.73	0	0	0	0	0	0
	R	0	0.000070	0	0	0	0	0.000025	0
Ictaluridae	T	NP	NP	NP	0	26.25	52.76	NP	0
	R	NP	NP	NP	0	0.000415	0.000299	NP	0
Centrarchidae	T	NP	66.53	18.87	0	18.56	0	31.42	6.71
	R	NP	0.000084	0.000433	0	0.000435	0	0.000065	0.000104

(NP = family not present during sample period) by vertical net hauls included that portion of the water column 1.0-7.5 m deep. If densities decline with depth, as suggested by Table 6.4, it is possible that most larvae in the "deep" stratum are actually in the upper portion of the deep stratum, that is in the 1.0-7.5 m zone. Therefore, the deeper waters most vulnerable to entrainment may contain very few individuals.

Table 6.6. Percent hydraulic, expected and observed, entrainment during June and July at Kingston Steam Plant, 1975.

Date	Percent Hydraulic Entrainment	Percent Expected Entrainment	Percent Observed Entrainment
6-4	25.23	14.99	2.71
6-18	23.47	19.62	0.62
7-2	17.56	5.45	0.66
7-16	39.75	16.87	9.09
7-30	25.45	8.94	0.23

Furthermore, the thermal stratification present near the skimmer wall as a result of layering of Emory and Clinch waters may induce transported larvae to move up into the warmer, shallower waters. Edwards, et al. (1977), and Netsch, et al. (1971), suggest that highest densities of clupeid larvae are associated with waters above the thermocline.

In summary, it appears that observed entrainment estimates are reasonably accurate and that they differ from the expected entrainment primarily because of distributional patterns not detected by the gear types used in reservoir sampling in 1975.

In addition to skimmer walls and vertical distribution, other factors may contribute to an entrainment ratio of less than one. Day and night intake samples were taken while only night reservoir samples were taken. Because of increased net avoidance during day, averaged intake densities are depressed. Also, sampling efficiency of active samplers used in the reservoir were probably greater than passive samplers (stationary nets) used in the intake and discharge channels. However, these problems are common to entrainment studies (Table 6.5) at all TVA steam plants.

Figure 6.4 indicates most families of fish, eggs, and larvae were more abundant in the Emory River than in the Clinch. Because a large portion of plant cooling water comes from the Clinch River (Figure 6.2) which has lower larval densities than the Emory River (Table 6.4), actual biological entrainment is lower than would be estimated from Emory River transect samples.

6.5 Entrainment Impact

In order to facilitate the 1975 entrainment investigation and provide a means of interpreting the resulting data, assumptions were made concerning the behavior of ichthyoplankton in Watts Bar Reservoir. A transport model developed by Marcy (1971, 1973, 1975) represented the only feasible model then available. This model assumed complete planktonicity of fish eggs and larvae of all sizes with ichthyoplankters transported at the same rate as the associated water mass. This transport theory was intuitively known to be invalid in 1975 but provided a means of addressing entrainment. Studies by Wallace (1978) have since documented weaknesses of the transport model.

Entrainment estimates (0.84 percent) of the fish larvae transported past the plant in 1975 were so low little consideration was given to the reservoir population as a whole or downstream replacement of entrained larvae. However, another alternative is to consider the total reservoir population in relation to that entrained.

Estimates of the number of larvae present each sample period in Watts Bar Reservoir were made using transect density data weighted by reservoir segment volumes (Table 6.7). Intake densities were weighted by volume of water withdrawn by the plant to estimate the number of larvae entrained. Entrainment percentages were then calculated for each family for each sample period using reservoir estimates and estimates of numbers entrained each sample period. In no case did any family incur as much as 0.01 percent entrainment. It is clear, then, that when the entire reservoir is considered, entrainment losses are negligible, given that current estimates of numbers entrained are reasonable.

When the total reservoir populations rather than transported populations are considered, changes in river flow conditions and effects of dry years on entrainment are sufficiently unimportant and need not merit consideration. However, location of the plant below tailwaters of Melton Hill Dam is an important consideration relative to reproduction of migratory spawning fish. Furthermore, the plant draws mostly from the Clinch River and as described in section 6.3, can withdraw a significant portion of the Clinch River for cooling water. These facts suggest that the plant could be a significant impact to migratory spawners such as *Morone* spp., catostomids, and *Stizostedion* spp. However, if significant spawning occurs by *Morone* spp. and *Stizostedion* spp. in the Clinch

River, it was not evident in the samples taken in 1975. Only 17 *Morone* spp. and two *Stizostedion* spp. larvae were collected that year (TVA 1976). There were 130 catostomid larvae collected, but 66 percent were taken below the plant and only four individuals were collected in intake nets indicating relatively limited spawning above the plant and low levels of entrainment. Furthermore, other tailwaters such as Fort Loudoun on the Tennessee River and Tellico on the Little Tennessee River are available to migratory spawners.

6.6 Impact Assessment

The assessment of entrainment impact on adult populations is a complex problem. There is currently no reliable method for quantitatively determining this impact. Methods developed by Hackney and Webb (1977), Hackney (1977), and Goodyear (1978) are more sophisticated but require extensive information on age, growth, and mortality rates for all species considered. Even these more sophisticated approaches require gross assumptions. Lacking other more reliable methods, the assessment of entrainment impact essentially becomes an intuitive judgment based on available data and reasonable conservative interpretation.

In this case, when the entire reservoir is considered, significant adverse impact is highly improbable. However, impact on the Clinch arm of the reservoir can only be considered insignificant if samples reliably estimate low numbers entrained. Indications are this was the case.

6.7 Conclusions

Most of the evidence presented here supports a conclusion of no significant impact; however, the quality of data collected and sampling scheme used in 1975 are not commensurate with current standards. Sample size was insufficient to allow detailed analysis of entrainment for most species; complete resolution of this question requires verification of the quality of entrainment samples and determination of the importance of Melton Hill tailwaters as a spawning ground.

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APPENDIX

Table 1. Characteristics of cove rotenone sites in Watts Bar Reservoir.

River mile	Date	Area (ha)	Mean Depth (m)	Maximum Depth (m)	Lake Stage (ft)	Surface Temperature (C°)
TRM						
530.6	7/06/78	0.29	1.3	3.7	740.8	30.5
531.0	7/06/78	0.40	1.6	5.2	740.8	29.5
532.9	8/06/64	0.61	1.8	6.7	741.2	28.9
533.0	8/06/64	0.65	1.3	3.1	741.2	28.9
	8/02/73	0.40	1.3	2.5	741.5	27.8
535.2	8/04/64	0.73	3.0	8.5	740.6	30.0
537.5	8/04/64	0.81	2.5	6.1	740.6	28.9
	7/31/73	0.53	1.7	4.0	740.1	29.0
541.1	8/14/73	0.37	1.6	4.5	740.4	27.0
	9/05/57	0.73	2.6	8.5	740.7	27.8
	8/04/60	0.73	1.7	-	740.9	30.0
	7/30/64	0.81	1.2	4.3	740.8	29.4
541.7	7/30/64	0.61	1.5	4.0	740.8	32.2
	8/16/73	0.28	1.1	1.5	740.8	26.0
546.7	7/28/64	0.61	2.2	5.8	740.4	29.4
	8/02/73	0.77	2.1	3.5	741.5	27.0
	7/08/75	0.53	1.6	3.7	740.1	25.6
547.7	7/28/64	0.65	2.2	6.1	740.4	29.4
551.4	7/27/76	0.49	1.2	2.8	740.5	30.5
	7/06/77	0.38	1.4	3.7	741.0	29.3
551.6	7/23/64	0.81	1.4	5.2	741.0	27.8
552.7	7/29/76	0.34	0.8	1.8	740.8	30.0
552.8	7/23/64	0.77	1.3	4.6	741.0	31.7
	7/31/73	0.65	1.8	2.5	740.1	31.0
	7/10/75	0.53	1.1	2.4	740.6	25.0
558.0	6/21/76	0.54	1.6	3.4	740.7	22.0
	7/06/77	0.35	1.4	3.4	741.0	30.0
560.4	9/03/57	1.21	2.4	7.3	740.2	25.0
	9/04/58	1.34	2.7	6.7	740.7	24.4
	8/27/59	1.34	2.7	6.7	741.0	-
	8/02/60	1.34	3.0	-	740.5	28.6
	7/21/64	0.65	1.5	4.1	740.2	27.2
	7/21/64	0.65	1.2	3.4	740.2	24.4
	8/07/73	0.51	3.1	3.5	740.3	25.0
	7/15/75	0.51	1.0	4.0	740.0	23.5
	6/23/76	0.42	1.4	3.7	740.6	25.0
	5/12/77	0.53	1.6	4.3	740.4	18.9
	7/21/77	0.53	1.9	5.5	740.8	29.9
	10/11/77	0.54	1.7	3.7	740.9	18.9
	6/14/79	0.39	1.3	3.7	740.9	24.5
	7/15/80	0.43	1.6	3.4	740.4	29.5
564.8	10/05/49	0.65	-	3.7	738.6	20.5
	8/09/73	0.45	1.9	2.5	740.9	25.5
	7/17/75	0.41	1.4	3.3	740.7	23.3

Table 1. (Continued)

River mile	Date	Area (ha)	Mean Depth (m)	Maximum Depth (m)	Lake Stage (ft)	Surface Temperature (C^o)
567.3	10/04/50	0.81	-	4.3	739.3	21.1
	9/27/51	0.81	-	3.1	738.2	21.7
	10/20/53	0.81	-	5.5	738.3	20.5
570.0	7/16/64	0.93	1.5	3.1	741.0	-
570.8	7/16/64	0.89	0.8	1.8	741.0	22.8
575.5	7/14/64	0.73	1.7	4.9	740.6	-
575.6	7/26/73	0.69	1.0	1.5	741.5	24.0
577.1	7/14/64	0.85	0.8	2.5	740.6	23.9
	7/22/75	0.39	1.1	-	740.5	27.3
	6/23/76	0.46	0.6	2.3	740.6	23.0
	7/19/76	0.51	0.8	1.8	740.1	23.0
	8/17/76	0.44	1.1	2.7	740.6	25.1
<u>CRM</u>						
4.9	8/09/60	0.69	1.8	-	741.0	23.9
	7/09/64	0.69	1.4	3.7	740.9	-
	7/24/73	0.74	2.1	2.5	740.2	28.0
	7/24/75	0.41	1.0	3.0	740.9	23.0
	6/21/76	0.27	0.4	5.0	740.7	25.5
	5/10/77	0.24	0.9	2.7	740.8	17.7
	7/19/77	0.24	1.0	2.5	740.4	27.6
	10/13/77	0.31	1.0	1.8	740.5	16.7
	6/12/79	0.56	1.2	3.4	741.1	21.7
	7/17/80	0.38	0.8	2.2	741.0	21.0
16.9	7/09/64	0.77	0.6	1.5	740.9	20.5
<u>LERM</u>						
3.5	7/07/64	0.57	1.8	4.3	740.4	-
<u>ERM</u>						
0.5	7/07/64	0.73	1.5	3.7	740.4	26.7

Table 2. Harvest categories and size classes* used in rotenone surveys on Watts Bar Reservoir, 1947 through 1980.

Species	Young Millimeters (inches)	Intermediate Millimeters (inches)	Adult Millimeters (inches)
Sport			
White bass	Less than 150 (5.9)	151-200 (5.9-7.9)	201 (7.9) and over
Yellow bass	" " 150 (5.9)	151-200 (5.9-7.9)	201 (7.9) " "
Striped bass	" " 175 (6.9)	176-375 (6.9-14.8)	376 (14.8) " "
Rock bass	" " 75 (3.0)	76-125 (3.0-4.9)	126 (5.0) " "
Bluegill	" " 75 (3.0)	76-125 (3.0-4.9)	126 (5.0) " "
Other sunfish	" " 75 (3.0)	76-125 (3.0-4.9)	126 (5.0) " "
Smallmouth bass	" " 100 (3.9)	101-200 (4.0-7.9)	201 (7.9) " "
Spotted bass	" " 100 (3.9)	101-200 (4.0-7.9)	201 (7.9) " "
Largemouth bass	" " 100 (3.9)	101-225 (4.0-8.9)	226 (8.9) " "
Crappie	" " 75 (3.0)	76-175 (3.0-6.9)	176 (6.9) " "
Sauger	" " 200 (7.9)	201-275 (7.9-10.8)	276 (10.9) " "
Walleye	" " 200 (7.9)	201-275 (7.9-10.8)	276 (10.9) " "
Yellow perch	" " 75 (3)	76-125 (4-5)	126 (6) " "
Commercial			
Lamprey	Less than 50 (2.0)	51-125 (2.0-4.9)	126 (5.0) and over
Gar	" " 300 (11.8)	301-475 (11.9-18.7)	476 (18.7) " "
Skipjack herring	" " 150 (5.9)	151-275 (5.9-10.8)	276 (10.9) " "
Mooneye	" " 150 (5.9)	151-300 (5.9-11.8)	301 (11.9) " "
Carp	" " 200 (7.9)	201-300 (7.9-11.8)	301 (11.9) " "
Buffalo	" " 200 (7.9)	201-300 (7.9-11.8)	301 (11.9) " "
Carpsucker	" " 175 (6.9)	176-250 (6.9-9.8)	251 (9.9) " "
Redhorses	" " 175 (6.9)	176-250 (6.9-9.8)	251 (9.9) " "
Other suckers	" " 175 (6.9)	176-250 (6.9-9.8)	251 (9.9) " "

Table 2. (Continued)

Species	Young Millimeters (inches)	Intermediate Millimeters (inches)	Adult Millimeters (inches)
Commercial (Continued)			
Blue catfish	Less than 125 (4.9)	126-225 (5.0-8.9)	226 (8.9) and over
Channel catfish	" " 125 (4.9)	126-225 (5.0-8.9)	226 (8.9) " "
Bullheads	" " 100 (3.9)	101-175 (4.0-6.9)	176 (6.9) " "
Flathead catfish	" " 125 (4.9)	126-275 (5.0-10.8)	276 (10.9) " "
Freshwater drum	" " 125 (4.9)	126-200 (5.0-7.9)	201 (7.9) " "
Prey**			
Gizzard shad	Less than 125 (4.9)	-	126 (5.0) and over
Threadfin shad	" " 125 (4.9)	-	126 (5.0) " "
Orangespotted sunfish	" " 50 (2.0)	51-75 (2.0-3.0)	76 (3.0) " "
Miscellaneous forage fish	All sizes	-	-

*The size class divisions are arbitrary but are based on knowledge of growth rates and information from creel census and commercial harvest records.

**Shad were recorded as young-of-year or harvestable; sizes of other forage fish, except orange-spotted sunfish, were not differentiated.

Table 3. Classification of maturity stages as suggested by Kestoven (1960).

I. Virgin	Very samll sexual organs close under the vertebral column. Testes and ovaries transparent, colorless to grey. Eggs invisible to naked eye.
II. Maturing virgin	Testes and ovaries translucent, grey-red. Length half, or slightly more than half, the length of ventral cavity. Single eggs can be seen with magnifying glass.
III. Developing	Testes and ovaries opaque, reddish with blood capillaries. Occupy about half of ventral cavity. Eggs visible to the eye as whitish granular.
IV. Developing	Testes reddish-white. No milt-drops appear under pressure. Ovaries orange reddish. Eggs clearly discernible; opaque. Testes and ovaries occupy about two-thirds of ventral cavity.
V. Gravid	Sexual organs filling ventral cavity. Testes white, drops of milt fall with pressure. Eggs completely round, some already translucent and ripe.
VI. Spawning	Roe and milt run with slight pressure. Most eggs translucent with few opaque eggs left in ovary.
VII. Spawning/spent	Not yet fully empty. No opaque eggs left in ovary.
VIII. Spent	Testes and ovaries empty, red. A few eggs in the state of reabsorption.
IX. Recovering spent	Testes and ovaries translucent, grey-red. Length half, or slightly more than half, the length of ventral cavity. Single eggs can be seen with magnifying glass.

Table 4. Estimated total length (mm) at each annulus for gizzard shad (*Dorosoma cepedianum*) from Watts Bar Reservoir and other waters.

Location	(n)*	Annuli 1	2	3	4	5	6
Watts Bar Reservoir (Present study)	(328)	84	183	234	252	275	-
Guntersville Reservoir (TVA 316a investigations)	(362)	97	185	228	254	295	315
Kentucky Lake (TVA 316a investigations)	(507)	106	184	220	262	-	-
Barkley Reservoir (TVA 316a investigations)	(301)	89	157	185	211	264	-
Old Hickory Reservoir (TVA 316a investigations)	(151)	81	157	193	224	245	279

*Sample size

Table 5. Estimated total length (mm) at each annulus for channel catfish (<u>Ictalurus punctatus</u>) from Watts Bar Reservoir and other waters.

Location	(n)*	Annuli 1	2	3	4	5	6	7	8
Watts Bar Reservoir (Present study)	(247)	124	212	274	323	362	404	369	-
Chickamauga Reservoir (TVA Pre-op investigations)	(95)	114	204	263	313	361	394	441	395
Pickwick Reservoir (TVA 316a investigations)	(410)	113	221	311	370	413	459	-	-
Guntersville Reservoir (TVA 361a investigations)	(149)	107	211	299	365	430	445	-	-
Kentucky Lake (TVA 316a investigations)	(517)	95	176	247	299	345	370	418	492
Barkley Reservoir (TVA 316a investigations)	(389)	131	228	296	346	384	439	489	-

*Sample size

Table 6. Estimated total length (mm) at each annulus for bluegill (*Lepomis macrochirus*) from Watts Bar Reservoir and other waters.

Location	(n)*	Annulus 1	2	3	4	5	6	7
Watts Bar Reservoir (Present study)	(189)	45	97	141	172	184	-	-
Guntersville Reservoir (TVA 316a investigations)	(1,361)	41	100	142	164	172	182	-
Kentucky Lake (TVA 316a investigations)	(380)	40	102	149	169	178	-	-
Barkley Reservoir (TVA 316a investigations)	(216)	47	102	146	165	181	-	-
Old Hickory Reservoir (TVA 316a investigations)	(130)	47	96	129	138	145	168	171
Area of John Sevier Steam Plant (TVA 316a investigations)	(691)	47	101	133	149	169	176	-

*Sample size

Table 7. Estimated total lemgth (mm) at each annulus for largemouth bass (Micropterus salmoides) from Watts Bar Reservoir and other waters.

Location	(n)*	Annulus									
		1	2	3	4	5	6	7	8	9	10
Watts Bar Reservoir (Present study)	(155)	118	225	303	373	364	405	-	-	-	-
Chickamauga Reservoir (TVA Pre-op investigations)	(60)	105	217	272	330	402	460	462	531	567	583
Old Hickory Reservoir (TVA 316a investigations)	(225)	93	164	230	307	323	-	-	-	-	-
Melton Hill Reservoir (TVA 316a investigations)	(48)	175	282	302	-	-	-	-	-	-	-
Norris Lake, Tennessee (Chance, et al., 1975)	(-)	167	307	370	403	441	495	-	-	-	-
East Tennessee average (Chance, et al., 1975)	(-)	119	254	342	411	452	497	-	-	-	-

*Sample size

Table 8. Estimated total length (mm) at each annulus for sauger (<u>Stizostedion canadense</u>) from Watts Bar Reservoir and other waters.

Location	(n)*	Annulus 1	2	3	4	5
Watts Bar Reservoir (Present study)	(528)	223	343	420	459	465
Guntersville Reservoir (TVA 316a investigations)	(127)	245	356	416	-	-
Kentucky Reservoir (TVA 316a investigations)	(458)	208	322	402	-	-
Barkley Reservoir (TVA 316a investigations)	(356)	197	301	350	375	-
Old Hickory Reservoir (TVA 316a investigations)	(257)	191	312	408	517	-

*Sample size

Table 9. Estimated total length (mm) at each annulus for freshwater drum (*Aplodinotus grunniens*) from Watts Bar Reservoir and other waters.

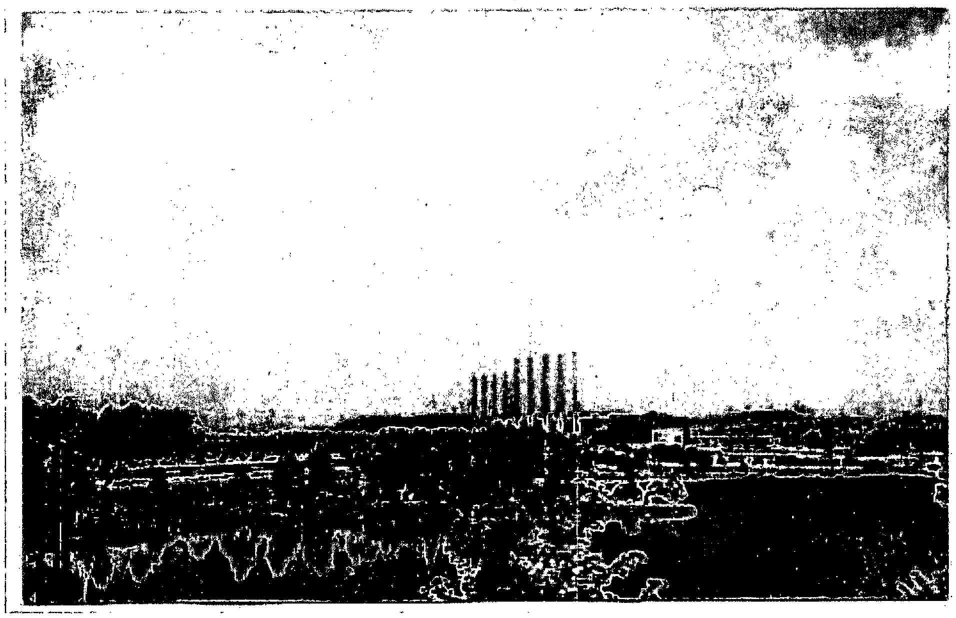
Location	(n)*	Annulus 1	2	3	4	5	6	7
Watts Bar Reservoir (present study)	(289)	93	173	236	268	278	351	-
Chickamauga Reservoir (TVA Pre-op investigations)	(175)	87	154	212	245	295	383	-
Barkley Reservoir (TVA 316a investigations)	(194)	96	167	220	254	298	370	380
Melton Hill Reservoir (TVA 316a investigations)	(355)	89	171	223	252	259	308	-
Watts Bar Reservoir (Hargis, 1966)	(130)	84	142	185	216	236	249	262

*Sample size

TENNESSEE VALLEY AUTHORITY

KINGSTON FOSSIL PLANT
NPDES PERMIT NO. TN0005452
316(b) MONITORING PROGRAM

FISH IMPINGEMENT AT KINGSTON FOSSIL PLANT DURING 2004 THROUGH 2006



ENVIRONMENTAL STEWARDSHIP AND POLICY

2007

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LIST OF ACRONYMS

BIP	Balanced Indigenous Population
CCW	Condenser Cooling Water
CWA	Clean Water Act
EA	Equivalent Adult
EPA	Environmental Protection Agency
EPRI	Formerly known as the Electric Power Research Institute
KIF	Kingston Fossil Plant
PF	Production Foregone
RFAI	Reservoir Fish Assemblage Index
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority

Introduction

Kingston Fossil Plant (KIF), placed into operation in 1955, withdraws condenser cooling water (CCW) from Watts Bar Reservoir and is subject to compliance with the Tennessee Water Quality Act and the federal Clean Water Act (CWA). Section 316(b) of the CWA requires the location, design, construction, and capacity of cooling water intake structures to reflect the best technology available for minimizing adverse environmental impact. Impingement mortality is a component of 316(b) and is defined as an impact in which fish and/or shelfish are trapped or impinged against an intake screen and often killed in the process. In response to the Environmental Protection Agency (EPA) issuance of a 2004 rule for implementing Section 316(b) (a rule subsequently suspended in 2007) and in accordance with the Proposal for Information Collection submitted to the Tennessee Department of Environment and Conservation (TDEC) in 2005, Tennessee Valley Authority (TVA) conducted impingement monitoring at KIF from November 2004 through November 2006 to assess the effects of impingement on the aquatic community of Watts Bar Reservoir. This report presents impingement data collected from the CCW intake screens during 2004-2006 with comparisons to historical data collected during 1974-1978.

Per an agreement reached in September 2001 with TDEC, Division of Water Pollution Control, TVA performs Reservoir Fish Assemblage Index (RFAI) (Hickman and Brown 2002) sampling once every two years to demonstrate that KIF operation is not impacting the balanced indigenous population (BIP). TVA conducted these RFAI studies to evaluate fish communities in areas immediately upstream and downstream of KIF during the 2001, 2003, and 2005 (Scott 2006). The primary reason for gathering these data is to support the continuation of Section 316(a) thermal variance for KIF. However, the RFAI monitoring also gives an indication of the overall impact of plant operations on the reservoir fish assemblage and benthic community, including potential impacts from the plant's cooling water intake.

Plant Description

KIF is located on a peninsula formed by the Clinch and Emory River embayments of Watts Bar Reservoir approximately 4.4 km (2.7 miles) above the confluence of the Clinch and Tennessee Rivers (Figure 1). The final unit of the nine-unit plant was placed in commercial operation December 2, 1955, bringing the total capacity to 1,700 megawatts. With an average summer water temperature of 23.9°C (75.02°F), Units 1-4 each require 6.6 m^3/s (241 cfs) CCW and Units 5-9 each require 9.2 m^3/sec (324.8 cfs) for an approximate plant total flow of 73.3 m^3/s (2,587 cfs) for condenser cooling purposes.

The 18 condenser circulating water pumps each withdraw from separate suction pits. Water enters the intake structure through trashracks constructed of vertical 1.59 cm (5/8 in) steel bars with 9.21 cm (3-5/8 in) openings. The racks are periodically cleaned by a rake operated by the intake gantry crane. Following the trashracks, the CCW passes through the vertical traveling screens. These are constructed of 0.6 X 3 m (2 X 10 ft) screen panels of 12-gauge galvanized wire with 9.5 mm (3/8 in) square openings. The panels are fastened top to bottom to form an endless belt and attached to chains operating between sprockets at the bottom and drive sprockets supported on the intake deck. Debris and fish collected on the traveling screens are washed off into a sluice trench that extends the length of the pumping station deck and empties into a 68.6 cm (27 in) concrete pipe which conveys the screen backwash discharge underground in a southerly direction for 440 m (1,442 ft) to empty into the CCW discharge basin.

Intake Channel and Skimmer Wall

An intake channel extends 1,372 m (4,500 ft) from the pumping station to the original streambed of the Emory River in the Swan Pond Embayment of Watts Bar Reservoir (Figure 1). A 126 m (413 ft) long skimmer wall is positioned across the intake channel and extends 7.5 m (24 ft) below the water surface. The maximum depth of the intake channel is 12.5 m (40 ft).

The skimmer wall provides water at a substantially lower temperature to the plant's condensers during the summer months. A still further significant temperature reduction was obtained by the construction of a submerged dam or barrier on the Clinch River near kilometer 6.3 (mile 3.9), downstream from the mouth of the Emory River. The computed reduction in intake temperatures has been as much as 2.5°C (4.5°F), resulting in a substantial saving in fuel consumption at KIF. The dam is built of quarry-run limestone dumped into position from barges. The 1.8 m (6 ft) wide submerged dam crest is at an approximate elevation of 220 m (722 ft), which ensures an adequate navigation depth at all times.

Methods

Weekly impingement monitoring began on November 16, 2004, and continued through November 6, 2006. To simplify comparisons in this report, data from November 16, 2004, through November 8, 2005, will be referred to as Year-One, and from November 16, 2005, through November 6, 2006, as Year-Two.

To collect each sample, the plant intake screens were rotated and washed on a prearranged schedule by the plant Assistant Unit Operator to remove all fish and debris. After 24 hours, screens were again rotated and washed with an Aquatic Monitoring and Management crew on site. Fish and debris were collected in a catch basket constructed of 9.5 mm (3/8 in) mesh at the end of the sluice pipe where the monitoring crew removed and processed the sample. Fish were sorted from debris, identified, separated into 25 mm (1 in) length classes, enumerated, and weighed. Data were recorded by one member of the crew and checked and verified (signed) by the other for quality control. Quality Assurance/Quality Control procedures for impingement sampling (TVA 2004) were followed to ensure samples were comparable with historical impingement mortality data.

Historical impingement sampling was conducted by TVA from August 1974 through April 1975 (TVA 1976). Additional sampling was conducted three days per week by Oak Ridge National Laboratory personnel during the periods November 1976 through April 1977 and September 1977 through April 1978 (TVA 1981).

Moribund/Dead Fish

The majority of fish collected from a 24-hr screen wash were dead when processed. Incidental numbers of fish which appeared to have been dead for more than 24 hours (i.e., exhibiting pale gills, cloudy eyes, fungus, or partial decomposition) were not included in the sample. Also, during winter, threadfin shad occasionally suffer die-offs and are often impinged after death or in a moribund state (Griffith and Tomljanovich 1975, Griffith 1978). If these die-off incidents were observed, they were documented to specify that either all, or a portion of impinged threadfin shad during the sample period were due to cold-shock and would not have been impinged otherwise. Any fish collected alive were returned to the reservoir after processing.

Data Analysis

Impingement data from weekly 24-hour samples were extrapolated for each week to provide estimates of total fish impinged by week and an estimate for each year of the study. In rare situations when less than a 24-hr sample occurred, data were normalized to 24 hrs.

Historical data collected during 1976-1978 (TVA 1981) were collected during three days per week and weekly estimates were extrapolated accordingly. For annual estimates, data collected from September or November through April were extrapolated to annual totals impinged. These annual estimates, even though based on less than full-year samples, should be relatively comparable to current data presented here (2004-2006) since sampling covered the period of peak impingement.

To facilitate the implementation of and compliance with the EPA regulations for Section 316(b) of the CWA prior to its suspension by EPA, impingement losses of fish were evaluated by extrapolating the losses to equivalent reductions of adult fish, or of biomass production available to predators. In conformance with methods utilized by EPA in its Technical Development Documents in support of the Phase II Rule (EPA 2004), EPRI (formerly known as the Electric Power Research Institute) has identified two models (Barnthouse 2004) for extrapolating losses of fish eggs, larvae, and juveniles at intake structures to numbers or production of older fish. The Equivalent Adult (EA) model quantifies entrainment and impingement losses in terms of the number of fish that would have survived to a given future age. The Production Foregone (PF) model applies to forage fish species to quantify the loss from entrainment and impingement in terms of potential available forage for consumption by predators. Required inputs to the models are site-specific data on the distribution and abundance of fish populations vulnerable to entrainment and impingement. TVA in turn also used these models to determine the "biological liability" of the CCW intake structure.

Results and Discussion

Numbers of fish collected by year and species are presented in Table 1. During Year-One and Year-Two of recent impingement monitoring, 26,511 and 32,171 fish were collected, respectively (Table 1). The total number of species collected each year was similar with 30 species in Year-One and 33 in Year-Two (Table 1).

Total numbers estimated impinged by extrapolation by species and year for Year-One and Year-Two are presented in Table 2. Threadfin shad comprised 95% of the two-year total followed by gizzard shad, freshwater drum, and channel catfish at 1% each (Table 2).

In Table 3, the estimated total fish impinged and percent of the annual total by month for both years are presented. The estimated annual impingement extrapolated from weekly samples was 185,577 during Year-One and 225,197 during Year-Two (Table 4). Peak impingement occurred during October through December at KIF (Table 3 and Figure 2). The proportion of total fish impinged during October through December each year was 86% in Year-One and 69% in Year-Two.

A plot of daily (24-hour average) ambient intake water temperatures for KIF during each of the two years sampled is presented in Figure 3. Lower temperatures appear to be generally correlated with peak impingement as previously reported in numerous studies

(EPRI 2005, Griffith and Tomljanovich 1975, Griffith 1978, McLean et al., 1980). A recent study by Fost (2006) also indicated that cold-stressed threadfin and gizzard shad can be classified as either impaired or moribund. Impaired shad could recover if environmental conditions improved and would therefore not die if not impinged. Moribund fish, on the other hand, are assumed to not be able to recover and die regardless of impingement. Fost's data indicated that threadfin shad began to exhibit reduced or impaired swimming performance at 7.5°C (45.5°F). Figure 3 also presents average KIF intake temperatures from 1986-2006 for comparison. While winter temperatures during both Year-One and Year-Two dropped below the Fost threshold, these temperatures did not appear to coincide with specific impingement peaks in this study period (Figure 2).

Threadfin and/or gizzard shad typically comprise over 90% of fish impinged on cooling-water intake screens of thermal power stations in the Southeastern U. S. (EPRI 2005). They also comprise an average of 35%-56% of total fish biomass where they occur (Jenkins 1967). No state or federal protected fish species were collected or are known to occur in the vicinity of KIF.

Application of the EA and PF models to the estimated total numbers of impinged fish indicated that 7,893 and 8,216 in Year-One and Year-Two, respectively (Table 4), would have been expected to survive to either harvestable (EA) size/age or to provide forage (PF). This reduced number is considered the "biological liability" resulting from plant CCW impingement mortality based on the guidance developed for the now suspended 316(b) regulations.

As part of TVA's Vital Signs Monitoring Program (Scott 2006), resident fish communities were sampled in Watts Bar Reservoir upstream and downstream of KIF in 2001, 2003, and 2005. Results indicated "Good" fish communities at both sites and TVA concluded that operations at KIF are not impacting the fish community of Watts Bar Reservoir.

Comparison with Historical Data

Estimated impingement from historical sampling conducted during 1974-1978 (including the extrapolated annual totals for number of fish impinged) and the numbers estimated after EA and PF reduction are presented in Table 4. The extrapolated total for 1974-1975 was 335,076; for 1976 was 1,163,232; and for 1977-1978 was 2,881,039. Table 5 presents the percent composition by number of major species impinged during 1974-1978 and 2004-2006. Threadfin shad dominance was consistent at between 95% and 98% except during 1977-1978 when threadfin shad comprised only 48% of the total. Peak impingement during October through January for the historical data (Figure 4) agrees with that observed during 2004-2006 (Figure 3). For the historical study it was concluded that based on data collected during 1974-1975, impingement of fish at KIF resulted in no adverse environmental impact (TVA 1976).

The Watts Bar Reservoir area experienced an unusually cold winter during 1976-1977 which caused a significant die-off of threadfin shad from cold shock. McLean, et al. (1979, 1980) conducted studies at KIF to determine (1) the physical and biological causes of impingement of threadfin shad and (2) the effects of impingement on the threadfin shad population and on the threadfin shad-predator population of Watts Bar Reservoir. Impingement samples taken three times per week from mid-November 1976 through April 1977 produced an estimate of 240,000 threadfin shad impinged during this 5-1/2 month period. The impingement rate for threadfin shad was strongly associated with temperature. Approximately 3,000 threadfin shad were impinged per day during November. On December 7, water temperature decreased from 7°C (44.6°F) to 4°C (39.2°F) and the following day 42,000 threadfin were impinged. Water temperature later decreased to 2.7°C (36.86°F) which is below the lower lethal limit for threadfin shad (Griffith and Tomljanovich 1975) and stressed shad were observed in large numbers in the KIF intake channel. Dead and moribund threadfin shad were observed in shallow embayments and along the reservoir shoreline during this period. The heated CCW discharge channel at KIF was the only place that healthy threadfin shad were observed throughout the winter (Schneider and Tuberville 1981).

Despite the obvious significant mortality in the threadfin shad population that was estimated at 95% in Watts Bar Reservoir, more than twice as many threadfin shad were impinged the following winter (1977-1978). From late September 1977 through the end of April 1978, an estimated 560,000 threadfin shad were impinged at KIF (McLean et al., 1980). As observed during the previous year, almost all threadfin shad were impinged before January 25.

Total numbers of all fish estimated impinged during the winter of 1977-1978 (2,881,039) were also higher (Table 4). While the percent composition of threadfin shad was lower (48%) during this period, skipjack herring composition (28%) as well as gizzard shad at 22% was significantly higher during 1977-1978 (Table 5). The fact that threadfin shad demonstrated the ability to rebound from a reservoir-wide, non-plant induced mortality (cold stress) indicates that impingement mortality at KIF does not represent an adverse impact to the threadfin shad population of Watts Bar Reservoir.

Summary and Conclusions

Impingement of fish by the KIF CCW was monitored during 2004-2006 and compared with historical data collected during 1974-1978. Total numbers of fish estimated to be impinged annually were lower during 2004-2006 than during 1974-1978. The average number estimated to be impinged during 2004-2006 (two years) was 205,387, compared to 1,459,782 per year during 1974-1978. Annual fish impingement totals were noticeably lower during 2005-2006 than during historical monitoring periods (1974-1978). RFAI scores in 2003 and 2005 of 43 and 44 for downstream and upstream samples, respectively, indicated good fish communities at both sites. Resident fish communities at these locations reached 71.1% and 73.3% of their potential scores for downstream and upstream sites, respectively. All the score averages for the Tennessee River stations in the vicinity of KIF indicate "Good" fish communities, and the nearest downstream Watts Bar Reservoir average met the adjusted 70% screening criteria for designation as BIP.

These factors as described above provide evidence of a balanced and healthy fish community and indicate that the KIF CCW intake has not adversely impacted the Watts Bar Reservoir biota.

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Tennessee Valley Authority. 2004. Impingement Counts. Quality Assurance Procedure No. RSO&E-BR-23.11, Rev 1. TVA River Systems Operation and Environment, Aquatic Monitoring and Management, Knoxville, TN. 11 pgs.

Table 1. List of Fish Species by Family, Scientific, and Common Name Including Numbers Collected in Impingement Samples During 2004-2006 at TVA's Kingston Fossil Plant.

Family	Scientific Name	Common Name	Total Number Impinged	
			Year-One	Year-Two
Petromyzontidae	*Ichthyomyzon castaneus*	Chestnut lamprey	2	0
Clupeidae	*Alosa pseudoharengus*	Alewife	65	36
	Dorosoma cepedianum	Gizzard shad	514	308
	Alosa chrysochloris	Skipjack herring	2	68
	Dorosoma petenense	Threadfin shad	25,320	30,491
	D. petenense x *D. cepedianum*	Hybrid shad	1	0
Cyprinidae	*Pimephales notatus*	Bluntnose minnow	1	6
	Pimephales vigilax	Bullhead minnow	0	3
	Pimephales promelas	Fathead minnow	1	0
	Cyprinella spiloptera	Spotfin shiner	0	1
	Campostoma oligolepis	Largescale stoneroller	1	0
	Notropis atherinoides	Emerald shiner	0	3
	Notropis photogenis	Silver shiner	1	0
Catostomidae	*Hypentelium nigricans*	Northern hogsucker	5	3
	Minytrema melanops	Spotted sucker	1	0
Ictaluridae	*Ictalurus furcatus*	Blue catfish	13	38
	Ictalurus punctatus	Channel catfish	210	137
	Pylodictis olivaris	Flathead catfish	26	5
	Ameiurus natalis	Yellow bullhead	3	0
Atherinidae	*Labidesthes sicculus*	Brook silverside	0	1
Moronidae	*Morone saxatilis*	Striped bass	18	29
	Morone chrysops	White bass	0	3
	Morone mississippiensis	Yellow bass	58	129
Centrarchidae	*Lepomis cyanellus*	Green sunfish	4	0
	Lepomis macrochirus	Bluegill	61	211
	Lepomis gulosus	Warmouth	0	3
	Lepomis megalotis	Longear sunfish	0	5
	Lepomis auritus	Redbreast sunfish	2	7
	Lepomis microlophus	Redear sunfish	0	1

Table 1. (continued)

Family	Scientific Name	Common Name	Total Number Impinged	
			Year-One	Year-Two
Centrarchidae	*Ambloplites rupestris*	Rock bass	9	2
	Micropterus dolomieu	Smallmouth bass	1	2
	Micropterus punctulatus	Spotted bass	14	13
	Micropterus salmoides	Largemouth bass	1	4
	Pomoxis annularis	White crappie	2	8
	Pomoxis nigromaculatus	Black crappie	0	6
Percidae	*Percina sciera*	Dusky darter	0	2
	Etheostoma blennioides	Greenside darter	0	1
	Percina caprodes	Logperch	22	20
	Perca flavescens	Yellow perch	0	1
	Sander canadense	Sauger	2	4
	Sander vitreus	Walleye	1	0
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	150	620
		Total number of fish	**26,511**	**32,171**
		Total number of species	**30**	**33**

Table 2. Estimated Annual Numbers, Biomass, and Percent Composition of Fish Impinged by Species at Kingston Fossil Plant During 2004-2006.

Species	Estimated Number			Estimated Biomass (g)			Percent Composition by Number
	Year-One	Year-Two	Average	Year-One	Year-Two	Total	
Threadfin shad	177,240	213,451	195,346	525,959	511,644	1,037,603	95
Freshwater drum	1,050	4,361	2,706	39,326	204,736	244,062	1
Gizzard shad	3,598	2,149	2,874	40,656	26,922	67,578	1
Channel catfish	1,470	959	1,215	7,112	9,751	16,863	1
Bluegill	427	1,477	952	5,061	9,345	14,406	T
Yellow bass	406	854	630	8,610	14,924	23,534	T
Alewife	455	231	343	9,261	1,652	10,913	T
Skipjack herring	14	476	245	8,260	5,110	13,370	T
Striped bass	126	217	343	1,050	1,400	2,450	T
Blue catfish	91	217	308	1,001	6,818	7,819	T
Logperch	154	140	294	2,030	1,652	3,682	T
Spotted bass	238	0	238	1,162	0	1,162	T
Flathead catfish	182	35	217	2,674	224	2,898	T
Rock bass	63	14	77	1,435	322	1,757	T
White crappie	14	56	70	56	4,165	4,221	T
Redbreast sunfish	14	49	63	42	105	147	T
Northern hogsucker	35	21	56	245	147	392	T
Bluntnose minnow	7	42	49	7	168	175	T
Sauger	14	28	42	11,375	21,119	32,494	T
Black crappie	0	42	42	0	854	854	T
Largemouth bass	7	28	35	35	483	518	T
Longear sunfish	0	35	35	0	1,939	1,939	T
White bass	0	35	35	0	3,773	3,773	T
Green sunfish	28	0	28	91	0	91	T
Smallmouth bass	7	21	28	35	147	182	T
Yellow bullhead	21	0	21	315	0	315	T
Emerald shiner	0	21	21	0	63	63	T
Warmouth	0	21	21	0	1,218	1,218	T
Chestnut lamprey	14	0	14	875	0	875	T
Bullhead minnow	0	14	14	0	70	70	T
Dusky darter	0	14	14	0	420	420	T
Fathead minnow	7	0	7	35	0	35	T
Hybrid shad	7	0	7	35	0	35	T

Table 2. (continued)

Species	Estimated Number			Estimated Biomass (g)			Percent Composition by Number
	Year-One	Year-Two	Average	Year-One	Year-Two	Total	
Largescale stoneroller	7	0	**7**	35	0	**35**	**T**
Silver shiner	7	0	**7**	70	0	**70**	**T**
Spotted sucker	7	0	**7**	4,410	0	**4,410**	**T**
Walleye	7	0	**7**	4,305	0	**4,305**	**T**
Brook silverside	0	7	**7**	0	56	**56**	**T**
Greenside darter	0	7	**7**	0	56	**56**	**T**
Redear sunfish	0	7	**7**	0	70	**70**	**T**
Spotfin shiner	0	7	**7**	0	7	**7**	**T**
Yellow perch	0	7	**7**	0	315	**315**	**T**
Total	**185,577**	**225,197**		**675,563**	**829,675**		

T = Trace < one percent

Table 3. Numbers of Fish Impinged at Kingston Fossil Plant by Month and Percent of Annual Total During Year-One and Year-Two and for Both Years Combined.

Month	Total Number of Fish Impinged Year-One	Percent of Annual Total	Total Number of Fish Impinged Year-Two	Percent of Annual Total	Years One and Two Combined	Percent of Two-Year Total
Nov	9,009	34	4,291	14	13,300	23
Dec	10,623	40	12,980	42	23,603	41
Jan	322	1	1,023	3	1,345	2
Feb	128	0	1,729	6	1,857	3
Mar	148	1	6,132	20	6,280	11
Apr	88	0	252	1	340	1
May	51	0	62	0	113	0
Jun	25	0	94	0	119	0
Jul	630	2	242	1	872	2
Aug	1,989	8	1,702	5	3,691	6
Sep	563	2	534	2	1,097	2
Oct	2,935	11	3,130	10	6,065	11
Total	**26,511**		**32,171**		**58,682**	

Table 4. Total Numbers of Fish Estimated Impinged by Year at Kingston Fossil Plant and Numbers Following Application of Equivalent Adult and Production Foregone Models.

	1974-1975	1976*	1977-1978	2004-2005	2005-2006
Extrapolated Annual Number Impinged	335,076	1,163,232	2,881,039	185,577	225,197
Number after EA and PF Reduction	5,862	7,077	20,622	7,893	8,216

*1976 data extrapolated from seven samples between 11/19/76–12/01/76

Table 5. Percent Composition (By Number and After EA and PF Models Applied) of Major Species of Fish Impinged at TVA's Kingston Fossil Plant During 1974-1978 and 2004-2006.

	1974-1975		1976*		1977-1978		2004-2005		2005-2006	
Species Composition	**% by Number**	**% after PA and EF**	**% by Number**	**% after PA and EF**	**% by Number**	**% after PA and EF**	**% by Number**	**% after PA and EF**	**% by Number**	**% after PA and EF**
Threadfin shad	95	89	98	94	48	45	96	89	95	86
Skipjack herring	2	2	-	-	28	26	-	-	-	-
Gizzard shad	-	-	-	-	22	20	-	-	1	1
Freshwater drum	1	2	2	3	1	3	1	1	2	5
Channel catfish	-	-	-	-	-	-	1	1	-	1
Bluegill	1	2	-	-	-	-	-	1	1	2
Logperch	-	2	-	-	-	-	-	1	-	-
White bass	-	1	-	-	-	2	-	-	-	-
Yellow bass	-	-	-	-	-	1	-	2	-	2
White crappie	-	-	-	-	-	1	-	-	-	-
Striped bass	-	-	-	-	-	-	-	1	-	1
Alewife	-	-	-	-	-	-	-	1	-	-
Sauger	-	-	-	1	-	-	-	1	-	1
Total	**99**	**99**	**100**	**98**	**99**	**98**	**100**	**100**	**99**	**99**

***1976 data from seven samples between 11/19/76–12/01/76**

Dash denotes not a major species during that year.

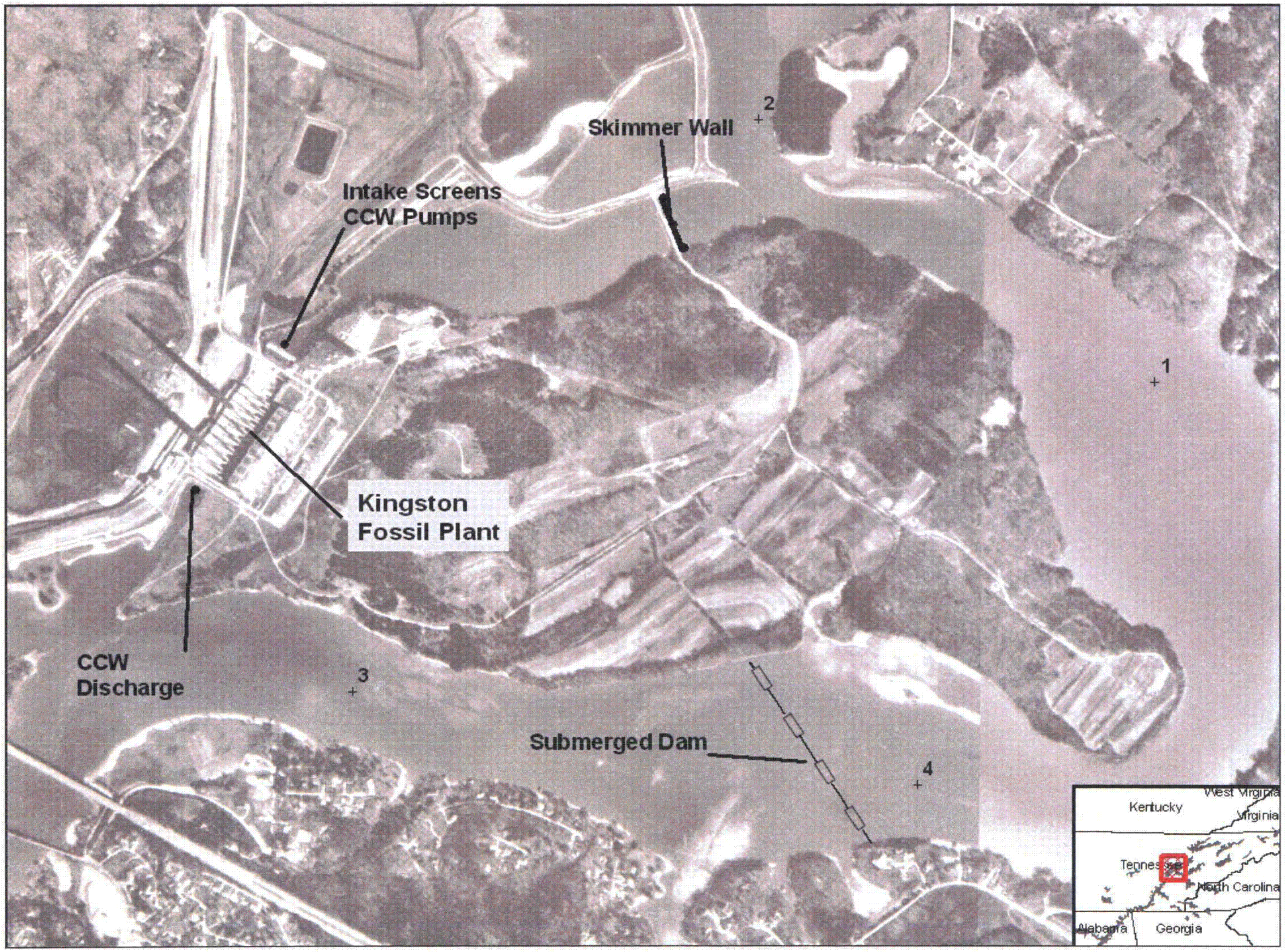

Figure 1. Aerial photograph of Kingston Fossil Plant including CCW intake structure, skimmer wall, intake basin, and discharge channel.

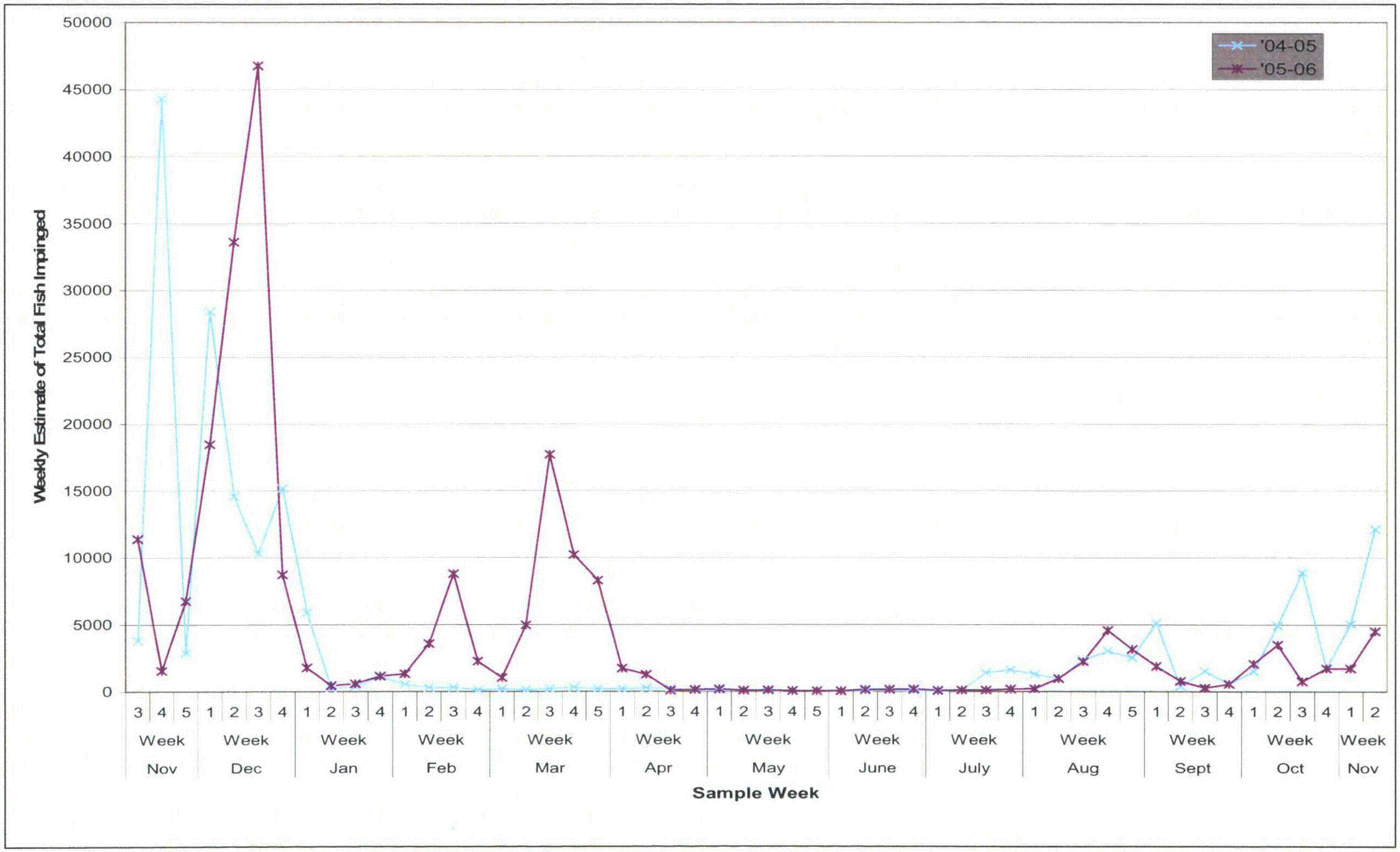

Figure 2. Estimated weekly fish impingement at TVA's Kingston Fossil Plant during 2004-2006.

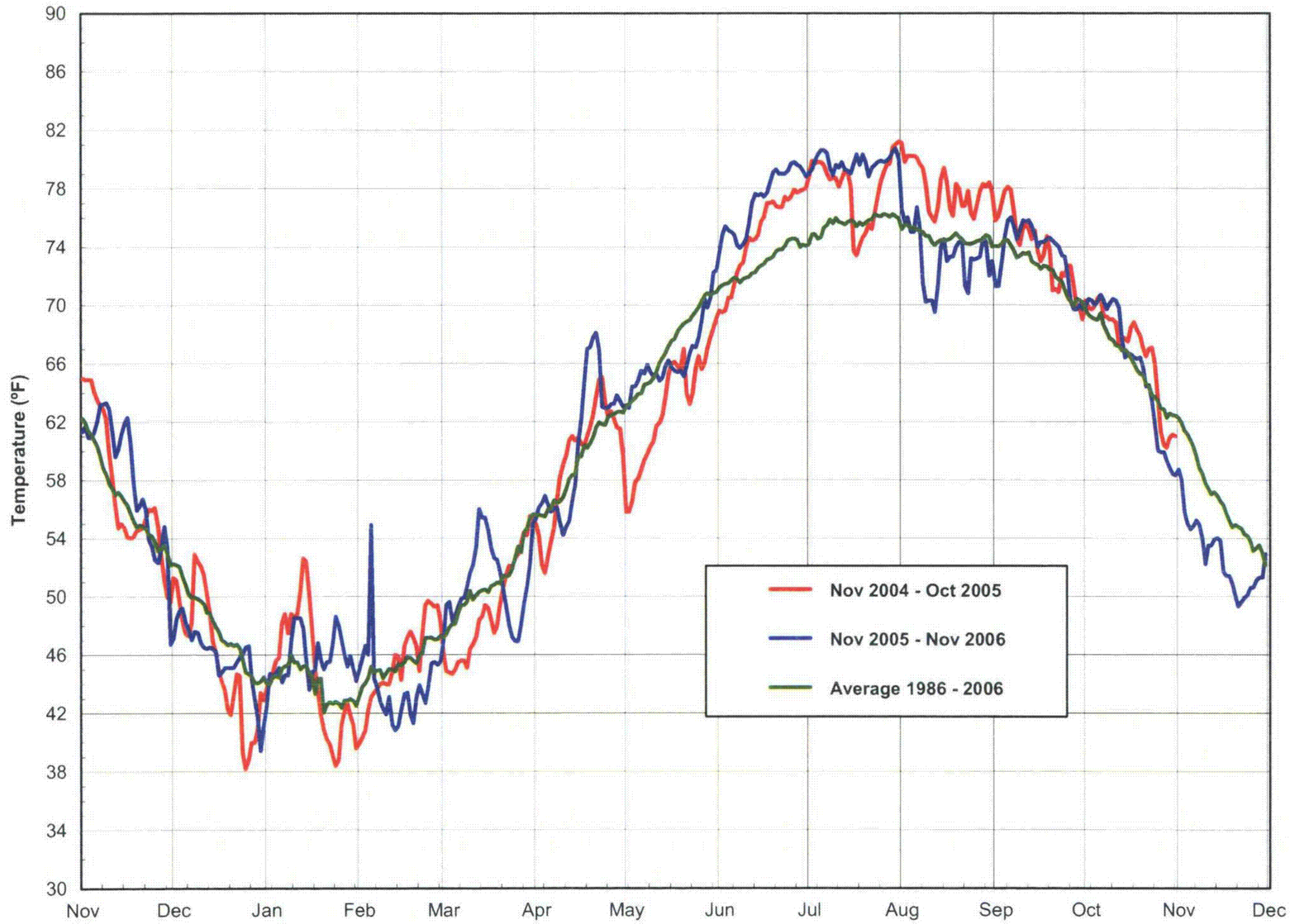

Figure 3. Ambient daily (24-hr avg) water temperature at Kingston Fossil Plant intake during historical (1986-2006) and recent (2004-2006) impingement monitoring.

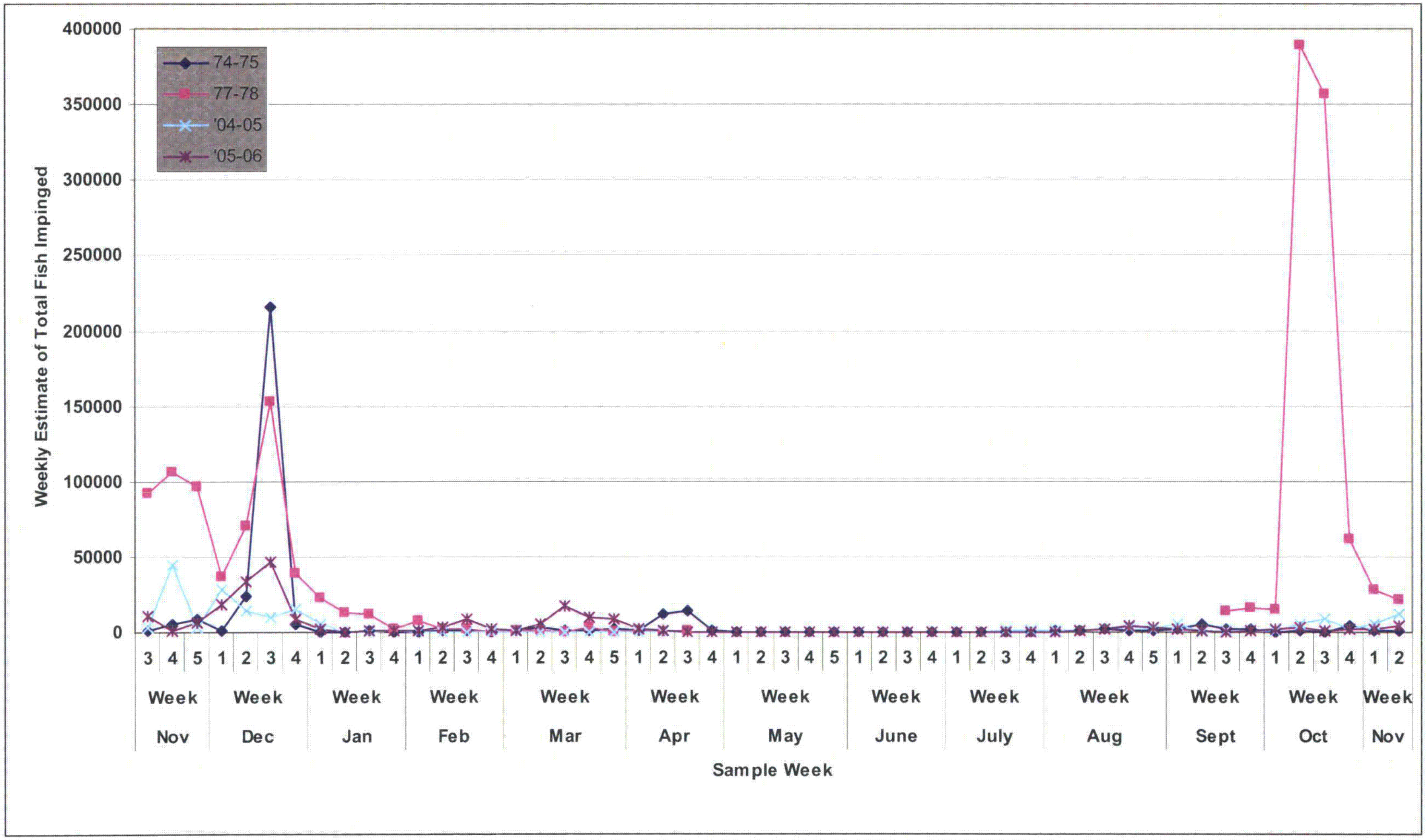

Figure 4. Comparison of estimated weekly fish impingement at TVA's Kingston Fossil Plant during historical and recent monitoring periods.

Document: EIS Administrative Record
Index Field: Supporting Documentation
Project Name: Watts Bar Nuclear Plant Unit 2 Completion
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February 16, 2007

Mr. Jim Chardos
Tennessee Valley Authority
1101 Market Street
BR3A
Chattanooga, Tennessee 37402

Subject: Delivery of Final Watts Bar Nuclear Plant Severe Accident Analysis

Reference: TVA Contract No: 59204

Dear Mr. Chardos

In accordance with the reference contract, Science Applications International Corporation (SAIC) is transmitting the enclosed paper and electronic, in Word format, a copy of the final Watts Bar Nuclear Plant severe accident analysis report. This final report reflects all comments received during the telephone call and the follow up e-mail you transmitted to me on February 12, 2007.

Please do not hesitate to contact me if there are any questions on the final report. SAIC will prepare and transmit all references identified as not received from TVA and the supporting calculation file. My telephone and fax numbers are: 301-353-8326 and 301-353-8300, respectively and my email address is 'karimir@saic.com'.

Sincerely,

Roy Karimi, Sc. D.
Science Applications International Corporation
20201 Century Boulevard
Germantown, Maryland 20874

Attachments

Watts Bar Nuclear Plant Severe Reactor Accident Analysis

Prepared for:

Tennessee Valley Authority

Prepared by:

Roy Karimi
Science Applications International Corporation
20201 Century Boulevard
Germantown, Maryland 20874

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We cannot guarantee or assure you that risks, vulnerabilities and threats other than those addressed in this report will not occur nor can we guarantee or assure you that, even if you implement the recommendations we have proposed, your business, facilities, computer networks and systems, software, computer hardware and other tangible equipment and assets will not be compromised, damaged or destroyed or your employees and others on your premises will not be injured or harmed.

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Watts Bar Nuclear Plant Severe Reactor Accident Analysis

Executive Summary

Tennessee Valley Authority (TVA) is preparing a Supplemental Environmental Impact Statement for the Watts Bar Nuclear (WBN) Plant site that includes future operation of Watts Bar Unit 2. This analysis was performed to estimate the human health impacts from potential accidents at the site. The term "accident" refers to any unintentional event (i.e., outside the normal or expected plant operation envelope) that results in a release or a potential for a release of radioactive material to the environment. The Nuclear Regulatory Commission (NRC) categorizes accidents as either design basis or severe. Design basis accidents are those for which the risk is great enough that NRC requires plant design and construction to prevent unacceptable accident consequences. Severe accidents are those that NRC considers too unlikely to warrant design controls.

TVA maintains a probabilistic safety assessment model to use in evaluating the most significant risks of radiological release from WBN fuel into the reactor and from the reactor into the containment structure. In 1995, both TVA and NRC concluded that, except for a few procedural changes implemented as part of the WBN operation, none of the Severe Accident Mitigation design alternatives were beneficial to further mitigating the risk of severe accidents. Since then, TVA has implemented the industry-required design and corresponding mitigating action changes as required by NRC for continued operation of WBN Unit 1, and is expected to implement them for operation of Unit 2. The design changes have already been implemented in the WBN Unit 1 probabilistic safety assessment model. The analysis is based on the WBN Unit 1 probabilistic safety assessment model, which considered applicable for Unit 2 operations because of its similarity to Unit 1. Only severe reactor accident scenarios leading to core damage and containment bypass or failure are considered, here. Accident scenarios that do not lead to containment bypass or failure are not presented because the public and environmental consequences would be significantly less.

The MACCS2 computer code (Version 1.13.1) was used to perform probabilistic analyses of radiological impacts. The generic input parameters given with the MACCS2 computer code that were used in the NRC's severe accident analysis (NUREG-1150) formed the basis for the analysis. These generic data values were supplemented with parameters specific to Watts Bar nuclear plant and the surrounding area. Site-specific data included population distribution, economic parameters, and agricultural product. Plant-specific release data included nuclide release, release duration, release energy (thermal content), release frequency, and release category (i.e., early release, late release). The behavior of the population during a release (evacuation parameters) was based on declaration of a general emergency and the emergency planning zone (EPZ) evacuation time. These data in combination with site specific meteorology were used to simulate the probability distribution of impact risks (exposure and fatalities) to the surrounding 80-kilometer (within 50 miles) population.

Table ES-1 summarizes the consequences of the beyond design-basis accident, with mean meteorological conditions, to the maximally exposed offsite individual, an average individual, and the population residing within an 80-kilometer (50-mile) radius of the reactor site. The analysis assumed that a site emergency would have been declared early in the accident sequence and that all nonessential site personnel would have evacuated the site in accordance with site emergency procedures before any radiological releases to the environment occurred. In addition, emergency action guidelines would have been implemented to initiate evacuation of 99.5 percent of the public within 16 kilometers (10 miles) of the plant. The location of the maximally exposed offsite individual may or may not be at the site boundary for these accident sequences because emergency action guidelines would have been implemented and the population would be evacuating from the path of the radiological plume released by the accident.

Table ES–1 Severe Accident Annual Risks

Release Category (frequency per reactor year)	*Maximally Exposed Offsite Individual*		*Population within 80 Kilometers (50 miles)*		
			Average Individual		*General Public*
	Dose Risk [a] *(rem/year)*	*Cancer Fatality* [b]	*Dose Risk* [a] *(rem/year)*	*Cancer Fatality* [b]	*Dose Risk* [a] *(person- rem/year)*
Maximum dose and risk					
I - Early Containment failure (3.4×10^{-7})	1.2×10^{-5}	1.4×10^{-8}	5.8×10^{-6}	3.5×10^{-9}	12.3
II - Containment Bypass (1.4×10^{-6})	1.7×10^{-5}	9.9×10^{-8}	2.7×10^{-5}	1.6×10^{-8}	57.3
III - Late Containment Failure (3.0×10^{-6})	2.2×10^{-6}	1.3×10^{-9}	2.8×10^{-6}	1.7×10^{-9}	5.9

[a] Includes the likelihood of occurrence of each release category.
[b] Increased likelihood of cancer fatality per year.

Overall, the risk results presented above are small. Completion and operation of WBN Unit 2 would not change the risks evaluated here because the likelihood of an accident that could affect both units and lead to radioactive releases beyond those analyzed here would be extremely low. This is consistent with the conclusions of NRC's Generic Environmental Impact Statement for License Renewal of Nuclear Plants, (GEIS). Accidents that could affect multiunit sites are initiated by external events. Severe accidents initiated by external events as tornadoes, floods, earthquakes, and fires traditionally have not been discussed in quantitative terms in final environmental statements and were not considered in the GEIS. In the GEIS, however, NRC staff did evaluate existing impact assessments performed by NRC and the industry at 44 nuclear plants in the United States and concluded that the risk from beyond-design-basis earthquakes at existing nuclear power plants is small. Additionally, the staff concluded that the risks from other external events are adequately addressed by a generic consideration of internally initiated severe accidents.

WATTS BAR NUCLEAR PLANT SEVERE REACTOR ACCIDENT ANALYSIS

1. Introduction

Tennessee Valley Authority (TVA) is preparing a supplemental environmental impact statement for the Watts Bar Nuclear (WBN) Plant site that includes future operation of Watts Bar Unit 2. This analysis is being performed to estimate the human health impacts from potential accidents at the site. The term "accident" refers to any unintentional event (i.e., outside the normal or expected plant operation envelope) that results in a release or a potential for a release of radioactive material to the environment. The Nuclear Regulatory Commission (NRC) categorizes accidents as either design-basis or severe. Design-basis accidents are those for which the risk is great enough that NRC requires plant design and construction to prevent unacceptable accident consequences. Severe accidents are those that NRC considers too unlikely to warrant design controls.

TVA maintains a probabilistic safety assessment (PSA) model to use in evaluating the most significant risks of radiological release from WBN fuel into the reactor and from the reactor into the containment structure. For the WBN Unit 1 Severe Accident Mitigation Design Alternative (SAMDA) analysis conducted in 1995, TVA used the PSA model output as input to an NRC-approved model that calculated economic costs and dose to the public from hypothesized releases from the containment structure into the environment. Using regulatory analysis techniques, TVA calculated the monetary value of the unmitigated WBN severe accident risks. TVA and NRC concluded that, except for a few procedural changes implemented as part of the WBN operation, none of the SAMDAs were beneficial to further mitigating the risk of severe accidents (NRC 1995). Since then, TVA has implemented the industry-required equipment design and corresponding mitigating action changes required by NRC for continued operation of WBN Unit 1 and is expected to implement them for operation of Unit 2. Therefore, prior to operation of Unit 2, the plant will meet all required designs and conditions for mitigating the risk of severe accidents.

Based on the statement of the work (TVA 2007), the analysis herein will follow a method similar to that used in the *Final Environmental Impact statement for the Production of Tritium in a Commercial Light Water Reactor* (CLWR EIS) (DOE 1999). TVA's analyses of design-basis accidents are described in the WBN Updated Final Safety Analysis Report and are not within the scope of this analysis. This analysis is limited to severe reactor accidents. The analyses presented here are based on the WBN Unit 1 PSA model, which is considered applicable for Unit 2 operations, because of the similarity to Unit 1 operations. Only severe reactor accident scenarios leading to core damage and containment bypass or failure are considered here. Accident scenarios that do not lead to containment bypass or failure are not presented because the public and environmental consequences would be significantly less. Three modes of containment failures are defined: containment bypass, early containment failure, and late containment failure (see **Table 1**).

The magnitude of the radioactive release to the atmosphere resulting from an accident depends on the timing of the reactor vessel failure and the containment failure. Source terms associated with various release categories describe the fractional releases for representative radionuclide groups, as well as the timing, duration, and energy of potential releases.

Table 1 Definition and Causes of Containment Failure Mode Classes

Failure mode	*Definition and Causes*
Containment Bypass	Involves failure of the pressure boundary between the high-pressure reactor coolant and low-pressure auxiliary system. For pressurized water reactors, steam generator tube rupture, either as an initiating event or as a result of severe accident conditions, will lead to containment bypass. In this scenario, if core damage occurs, a direct path to the environment can exist.
Early Containment Failure	Involves structure failure of the containment before, during, or slightly after (within a few hours of) reactor vessel failure. A variety of mechanisms can cause structure failure, including direct contact of core debris with containment, rapid pressure and temperature loads, hydrogen combustion, and fuel coolant interaction (ex-vessel steam explosion). Failure to isolate containment or to provide early venting of containment after core damage also is classified as early containment failures.
Late Containment Failure	Involves structural failure of the containment several hours after reactor vessel failure. A variety of mechanisms can cause late structure failure, including gradual pressure and temperature increase, hydrogen combustion, and basemat melt-through by core debris. Venting containment late in the accident also is classified as a late containment failure.

2. Representative Severe Reactor Accident Scenarios

Plant damage states that lead to containment failure (failure mode defined as bypass, early, and late) and release of radioactive materials to the environment are considered in this section. The representative accident scenarios are limited to the dominant sequence or sequences within a plant damage state that are major contributors to the release level categories associated with each of the containment failure modes defined above. The information is based on TVA's most recent analysis of severe accidents performed under the individual plant examination program, which covers both the level 1 and level 2 probabilistic risk assessments in detail. TVA's analyses of the Watts Bar and Sequoyah individual plant examinations were submitted to NRC in September 1992 (TVA 1992a, TVA 1992b). Both of these analyses have been revised since (TVA 1995, TVA 1994).

The selected release categories and examples of various accident scenarios leading to containment failure and/or bypass are presented below. Release Category I results from a reactor vessel breach with early containment failure. Release Category II results from a reactor vessel breach with containment bypass. Release Category III results from a reactor vessel breach with late containment failure. **Table 2** shows the equilibrium reactor core nuclide inventory at the time of a reactor trip (TVA 2007). **Table 3** provides important information on time to core damage, containment failure, release duration, and the isotope release fractions associated with each of the release categories (TVA 2007). **Table 4** provides a representation of the dominant accident scenarios that lead to each release category and the likelihood of their occurrence (TVA 2007).

Table 2 Watts Bar Unit 1 Core Inventory

Nuclide	*Isotope*	*Group* [a]	*Curies* [b]
Cobalt	Co-58	6	1.11E+06
	Co-60	6	8.67E+05
Krypton	Kr-83m	1	1.15E+07
	Kr-85m	1	2.39E+07
	Kr-85	1	1.03E+06
	Kr-87	1	4.81E+07
	Kr-88	1	6.66E+07
Xenon	Xe-131m	1	1.05E+06
	Xe-133m	1	6.16E+06
	Xe-133	1	1.91E+08
	Xe-135m	1	4.05E+07
	Xe-135	1	6.43E+07
	Xe-138	1	1.67E+08
Iodine	I-130	2	1.93E+06
	I-131	2	9.46E+07
	I-132	2	1.39E+08
	I-133	2	1.95E+08
	I-134	2	2.16E+08
	I-135	2	1.86E+08
Bromine	Br-83	2	1.15E+07
	Br-84	2	2.14E+07
Cesium	Cs-134	3	1.66E+07
	Cs-135	3	0.00E+00
	Cs-136	3	5.89E+06
	Cs-137	3	1.17E+07
	Cs-138	3	1.81E+08
Rubidium	Rb-86	3	1.87E+05
	Rb-88	3	6.83E+07
	Rb-89	3	8.92E+07
Strontium	Sr-89	4	9.34E+07
	Sr-90	5	8.94E+06
	Sr-91	5	1.16E+08
	Sr-92	5	1.24E+08
Yttrium	Y-90	7	9.48E+06
	Y-91m	7	6.76E+07
	Y-91	7	1.21E+08
	Y-92	7	1.25E+08
	Y-93	7	9.48E+07
	Y-94	7	1.51E+08
	Y-95	7	1.57E+08
Zirconium	Zr-95	7	1.67E+08
	Zr-97	7	1.61E+08
Niobium	Nb-95	7	1.69E+08
	Nb-97m	7	1.53E+08
	Nb-97	7	1.62E+08
Molybdenum	Mo-99	6	1.78E+08
Technetium	Tc-99m	6	1.57E+08
	Tc-99	6	0.00E+00
	Tc-101	6	1.61E+08

Nuclide	***Isotope***	***Group*** [a]	***Curies*** [b]
Ruthenium	Ru-103	6	1.48E+08
	Ru-105	6	1.00E+08
	Ru-106	6	5.00E+07
Rhodium	Rh-103m	6	1.48E+08
	Rh-105	6	9.55E+07
	Rh-106	6	5.33E+07
	Rh-107	6	5.77E+07
Antimony	Sb-127	4	8.05E+06
	Sb-129	4	3.03E+07
	Sb-130	4	1.00E+07
Tellurium	Te-125m	4	1.93E+04
	Te-127m	4	1.33E+06
	Te-127	4	7.93E+06
	Te-129m	4	5.81E+06
	Te-129	4	2.88E+07
	Te-131m	4	1.86E+07
	Te-131	4	7.99E+07
	Te-132	4	1.36E+08
	Te-133	4	1.06E+08
	Te-134	4	1.73E+08
Barium	Ba-137m	5	1.11E+07
	Ba-139	5	1.73E+08
	Ba-140	5	1.73E+08
	Ba-141	5	1.56E+08
	Ba-142	5	1.49E+08
Lanthanum	La-140	7	1.79E+08
	La-141	7	1.58E+08
	La-142	7	1.54E+08
	La-143	7	1.46E+08
Cerium	Ce-141	8	1.59E+08
	Ce-143	8	1.48E+08
	Ce-144	8	1.29E+08
Praseodymium	Pr-143	7	1.44E+08
	Pr-144	7	1.30E+08
	Pr-145	7	1.01E+08
Neodymium	Nd-147	7	6.39E+07
Neptunium	Np-239	8	1.87E+09
Plutonium	Pu-238	8	3.15E+05
	Pu-239	8	3.48E+04
	Pu-240	8	4.38E+04
	Pu-241	8	1.49E+07
	Pu-243	8	2.86E+07
Americium	Am-241	7	9.80E+03
	Am-242	7	7.93E+06
Curium	Cm-242	7	3.98E+06
	Cm-244	7	1.61E+05

[a] The grouping is based on NUREG-1465.
[b] Source: TVA 2007.

Table 3 Release Category Timing and Source Terms

Release Times, Heights, Energies, and Source Terms for Selected Release Categories					
Release Category	***Release Height (meters)***	***Warning Time (hours)***	***Release Time (hours)***	***Release Duration (hours)***	***Release Energy*** [a] ***(megawatts)***
I	10.00	8	10	2	28
II	10.00	20	24	4	1
III	10.00	20	30	10	3.5

Fission Product Source Terms (fraction of total inventory)										
Release Category	***NG***	***I***	***Cs***	***Te***	***Sr***	***Ru***	***La***	***Ce***	***Ba***	***Mo***
I	0.90	0.042	0.043	0.044	0.0027	0.0065	0.00048	0.004	0.0046	0.0065
II	0.91	0.21	0.19	0.0004	0.0023	0.07	0.00028	0.00055	0.025	0.07
III	0.94	0.0071	0.011	0.0052	0.00036	0.00051	4.2×10^{-6}	4.0×10^{-6}	0.0013	0.00051

NG = Noble gases.
[a] These values were taken from similar accident scenarios given in NUREG/CR-4551.
Sources: TVA 1992a, TVA 1992b, TVA 2007.

Table 4 Release Category Frequencies and Related Accident Sequences for the Watts Bar Nuclear Plant

Release Category	***Frequency***	***Remarks***
I	3.4×10^{-7}	The major accident contributors to this release event are initiated by loss of offsite power and the essential raw cooling water system; failure of the emergency diesels to start and/or failures in the 125-volt direct current distribution system, together with loss of secondary cooling; and no recovery before core melt.
II	1.4×10^{-6}	The main contributor to this release event is initiated by a steam generator tube rupture in conjunction with either an operator error or a random failure of electrical distribution systems, leading to failure of the coolant system and failure to control the affected steam generator before core melt occurs.
III	3.0×10^{-6}	The major accident contributors to this release event are initiated by loss of offsite power and various failures in the alternating current distribution systems; no recovery of power before core melts; a reactor coolant system loss-of-coolant accident (large- and medium-sized loss-of-coolant accident); and failure to establish long-term core cooling.

Source: TVA 2007.

3. Methodology for Estimating Radiological Impacts

3.1 Introduction

The MACCS2 computer code (Version 1.13.1) was used to perform probabilistic analyses of radiological impacts. A detailed description of the MACCS model is provided in NUREG/CR-4691 (NRC 1990). The enhancements incorporated in MACCS2 are described in the MACCS2 User's Guide (NRC 1998).

The input parameters given with the MACCS2 Sample Problem A, which include the data used in NUREG 1150 (NRC 1998), formed the basis for the analysis. These generic data values were supplemented with parameters specific to the WBN Plant and the surrounding area. Site-specific data included population distribution, economic parameters, and agricultural product. Plant-specific release data included nuclide release, release duration, release energy (thermal content), release frequency, and release category (i.e., early release, late release). The behavior of the population during a release (evacuation parameters) was based on declaration of a general emergency and the emergency planning zone (EPZ) evacuation time. These data, in combination with site-specific meteorology, were used to simulate the probability distribution of impact risks (exposure and fatalities) to the surrounding 80-kilometer (within 50 miles) population.

3.2 Site-Specific Parameters

This section describes the method and assumptions used to develop site-specific parameters.

Population

The population surrounding the WBN Plant site was estimated for the year 2030. The distribution is given in terms of the population at 29 distances, ranging from 0.25 miles to 50 miles from the plant, the direction of each of the 16 compass points (north, north-northeast, northeast, etc.). The population projections were determined using SECPOP 2000: *Sector Population, Land Fraction, and Economic Estimation Program* (NRC 2003). SECPOP 200 provides United States population data files based on the 1990 and 2000 censuses, as well as economic files based on 1992 and 1997 U.S. Census Bureau data. Using the WBN Plant geographic location (longitude and latitude), population sectors were created from the 1990 and 2000 census data. These data were used to calculate a decennial population growth factor (ratio of population estimates; that is, the 2000 population divided by 1990 population) for each segment. Using the segment-specific decennial population growth factor, projections for the year 2030 were made by multiplying the 2000 segment population data by the cube of the decennial growth factor. For those segments with a zero 1990 population and a non-zero 2000 population, the 2030 population was estimated by multiplying the 2000 segment population data by 4 (i.e., 3 decades increase plus the 2000 data). For those segments where the 2000 census data showed a population increase of more than 300 percent over that of 1990 census, the projected future increase in population was limited to the estimated population growth of the county where the segment resides. The total projected population within 50 miles of the site was estimated to be 2,104,700, (see **Table 5**).

Agriculture and Economy

Agriculture production information was generated using SECPOP 2000. SECPOP provides the MACCS2 model with required information on the crops season and shares (fraction of land devoted to the crop). The SECPOP-generated data were compared with those used in the CLWR EIS, which was based on data for neighboring counties. The SECPOP data were considered more representative (more recent) and, except for the pasture, use larger land fractions for specific crops.

MACCS2 also requires spatial distribution of certain economic data (fraction of land devoted to farming, annual farm sales, fraction of farm sales resulting from diary production, property values of farm and nonfarm land). SECPOP also produces this data for each site. Although these data were generated and added to the site data, they were not used in the analysis.

Table 5 Projected 2030 Population Distribution within 80 Kilometers (50 miles) of Watts Bar Nuclear Plant

Direction	*Miles*										
	0-1	*1-2*	*2-3*	*3-4*	*4-5*	*5-10*	*10-20*	*20-30*	*30-40*	*40-50*	*0-50*
N	0	0	0	0	705	1,955	4,852	47,765	67,755	6,893	129,925
NNE	0	0	0	481	1	356	9,575	14,464	13,843	2,521	41,241
NE	0	0	839	2,959	98	7,971	9,192	30,082	25,374	70,042	146,557
ENE	0	16	915	169	88	3,023	4,079	19,752	111,960	294,902	434,904
E	0	80	0	408	40	3,533	12,819	53,190	46,972	65,400	182,442
ESE	0	0	1,080	9	212	709	10,395	22,008	11,364	27,534	73,311
SE	0	232	9	301	1961	2,329	27,122	12,978	5,620	7,771	58,323
SSE	0	0	48	340	870	3,227	12,991	13,689	4,806	10,050	46,021
S	0	248	27	210	578	2,911	4,886	56,939	71,573	22,039	159,411
SSW	0	6	0	2	332	1,696	9,027	23,855	76,659	188,224	299,801
SW	0	0	271	0	0	1,984	16,342	16,416	64,934	112,113	212,060
WSW	0	0	57	24	975	1,958	16,297	4,867	20,804	8,636	53,618
W	0	12	675	602	0	1,215	2,472	9,012	4,457	9,870	28,315
WNW	0	103	0	0	508	460	4,737	36,531	7,587	20,668	70,594
NW	0	12	2,577	1,376	78	2,983	3,677	56,672	14,498	14,029	95,902
NNW	0	44	0	133	383	1,301	4,611	36,554	14,084	15,164	72,274
Total	0	753	6,498	7,014	6,829	37,611	153,074	454,774	562,290	875,856	2,104,699

Note: To convert from mile to kilometer multiply the value by 1.609.

Evacuation

Evacuation data, including delay time before evacuation, area evacuated, average evacuation speed, and travel distance, was obtained from the *Tennessee Multi-Jurisdictional Radiological Emergency Response Plan for the Watts Bar Nuclear Plant,* Annex H (TVA 2006). For this analysis, the evacuation and sheltering region was defined as a 10-mile radial distance (the EPZ) centered on the plant. A sheltering period was defined as the phase occurring before initiation of evacuation procedures. During the sheltering period, shielding factors appropriate for sheltered activity were used to calculate doses to individuals in contaminated areas.

At the end of the sheltering period, residents would begin traveling out of the region. Travel speeds and delay times were based on the evacuation data also found in the *Tennessee Multi-Jurisdictional Radiological Emergency Response Plan for the Watts Bar Nuclear Plant,* Annex H (TVA 2006). General population evacuation times for the various areas within the 10-mile radius were averaged to determine an overall evacuation delay time and evacuation speed. Average evacuation speeds based on the most conservative general population evacuation times in an adverse weather condition were considered (see **Table 6**).

Table 6 Evacuation Times 0-to-16-kilometer (0-to-10-mile) Area

Sectors	*Permanent Population, Adverse Condition (hrs-min)*	*Special Population, Adverse Condition (hrs-min)*	*General Population, Adverse Condition (hrs-min)*
1	6 - 40	3 - 40	5 - 12
2	4 - 23	2 - 41	3 - 47
3	4 - 21	2 - 43	5 - 0
4	4 - 10	2 - 36	3 - 41
5	4 - 37	2 - 53	4 - 05
6	4 - 25	2 - 45	3 - 54
7	4 - 21	2 - 43	3 - 51
8	4 - 25	2 - 45	3 - 54
9	3 - 26	2 - 15	3 - 30
10	3 - 26	2 - 15	3 - 30
11	3 - 26	2 - 30	3 - 50
12	3 - 26	2 - 30	3 - 54
13	3 - 26	2 - 0	3 - 30
14	3 - 26	1 - 35	3 - 30
15	3 - 20	1 - 30	3 - 25
Total	61 - 20	37 - 21	58 - 33
Average hours	4 - 5	2 - 29	3 - 54
Average speed over 10 miles (miles per hour)	2.45	4.02	2.56
(meters per second)	1.1	1.8	1.15

Source: WBN 2006.

Based on the data cited above, an average evacuation speed of 1 meter per second following a sheltering and evacuation delay time of 45 minutes and 2.50 hours were used. These delay values are provided in both the *Tennessee Multi-Jurisdictional Radiological Emergency Response Plan for the Watts Bar Nuclear Plant,* Annex H, (TVA 2006) and NUREG/CR-4551, Vol. 2 (NRC 1990). In addition, consistent with the analysis in the CLWR EIS and the NUREG-1150 evaluation of the Sequoyah Nuclear Plant, it was assumed that 99.5 percent of the population in the 10-mile EPZ would be evacuated.

For this analysis, it was conservatively assumed that persons residing farther than 10 miles away from the plant would continue their normal activities unless the following predicted radiation dose levels were exceeded. At locations where a 50-rem whole body effective dose equivalent in 1 week was predicted, it was assumed that relocation would take place after half a day. If a 25-rem whole body dose equivalent in 1 week were predicted, relocation of individuals in those sectors was assumed to take place after 1 day.

Meteorology

Annual onsite meteorology data sets from 2001 through 2005 were used to prepare the sequential hourly data (8760 hours) required for use in MACCS2 (TVA 2007). The 2001 sequential hourly meteorology data was found to result in the largest risk and was used for all of the analyses presented below. The conditional dose from each of the other years was found to be within 20 percent of the chosen year. The 2003 weather data set was found to result in the lowest population doses. Two sampling methods, bin sampling and stratified random sampling, were used. In bin sampling, the representative subset is selected by sampling the weather sequences after sorting them into weather bins defined by windspeed, atmospheric stability, and intensity and distance of the occurrence of rain. In stratified sampling, the representative subset is selected by randomly sampling hourly weather data from each day. The analysis is based four samples per day. This selection was based on a test by the developer of the MACCS code that indicated that random samples from each 6-hour interval of the year would yield results closer to those obtained from sampling all 8760 hours of the year. The stratified random sampling resulted in less than 10 percent higher doses.

4. Analysis Results

Table 7 summarizes the consequences of the beyond-design-basis accident, with mean meteorological conditions, to the maximally exposed offsite individual and an average individual in the public within an 80-kilometer (50-mile) radius of the reactor site. The analysis assumes that a site emergency would have been declared early in the beyond-design-basis accident sequence and that all nonessential site personnel would have evacuated the site in accordance with site emergency procedures before any radiological releases to the environment occurred. In addition, emergency action guidelines would be implemented to initiate evacuation of the public within 16.1 kilometers (10 miles) of the plant. The location of the maximally exposed offsite individual may or may not be at the site boundary for these accident sequences because emergency action guidelines would have been implemented and the population would be evacuating from the path of the radiological plume released by the accident. The MACCS2 computer code models the evacuation sequence to estimate the dose to the maximally exposed individual and the general population within 80 kilometers (50 miles) of the accident. **Table 8** summarizes the risks associated with the beyond-design-basis accident to the same receptors in terms of latent cancer fatalities (considering the likelihood of occurrence for each release category). The frequency of each release category is given in Table 4. **Table 9** shows the population dose risks (accident consequence multiplied by the release frequency) for each accident release category.

Table 7 Severe Accident Consequences

Release Category	*Maximally Exposed Offsite Individual*		*Average Individual Population within 80 Kilometers (50 miles)*	
	Dose (rem)	*Cancer Fatality* [a]	*Dose (rem)*	*Cancer Fatality* [a]
Weather Bin Sampling				
I - Early Containment Failure	34.9	0.042	16	0.0096
II - Containment Bypass	11.8	0.0071	18.6	0.0111
III - Late Containment Failure	0.72	0.00043	0.89	0.00053
Weather Stratified Sampling				
I - Early Containment Failure	22	0.0264	17.2	0.0103
II - Containment Bypass	5.04	0.0030	19.4	0.0120
III - Late Containment Failure	0.34	0.00020	0.93	0.00056

[a] Increased likelihood of cancer fatality based on the health risk factor of 0.0006 cancers per rem for exposures below 20 rem. For exposures greater than or equal to 20 rem, the health risk factor is doubled.

Table 8 Severe Accident Annual Risks

Release Category	*Maximally Exposed Offsite Individual*		*Average Individual Population within 80 Kilometers (50 miles)*	
	Dose [a] (rem/year)	*Cancer Fatality [b]*	*Dose [a] (rem/year)*	*Cancer Fatality [b]*
Weather Bin Sampling				
I - Early Containment Failure	1.2×10^{-5}	1.4×10^{-8}	5.5×10^{-6}	3.3×10^{-9}
II - Containment Bypass	1.7×10^{-5}	9.9×10^{-9}	2.6×10^{-5}	1.6×10^{-8}
III - Late Containment Failure	2.2×10^{-6}	1.3×10^{-9}	2.7×10^{-6}	1.6×10^{-9}
Weather Stratified Sampling				
I - Early Containment Failure	7.5×10^{-6}	9.0×10^{-9}	5.8×10^{-6}	3.5×10^{-9}
II - Containment Bypass	7.0×10^{-6}	4.2×10^{-9}	2.7×10^{-5}	1.6×10^{-8}
III - Late Containment Failure	1.0×10^{-6}	6.2×10^{-10}	2.8×10^{-6}	1.7×10^{-9}

[a] Includes the likelihood of occurrence of each release category.
[b] Increased likelihood of cancer fatality per year.

Table 9 Annual 80-Kilometer (50-mile) Population Dose Risk

Release Category	*Weather Bin Sampling*	*Weather Stratified Sampling*
	Dose [a] (person-rem/year)	*Dose [a] (person-rem/year)*
I - Early Containment Failure	11.5	12.3
II - Containment Bypass	54.7	57.3
III - Late Containment Failure	5.6	5.9

[a] Includes the likelihood of occurrence of each release category. The population within 80 kilometers (50 miles) is projected to be 2,104,700.

The risk results presented here are generally higher than those given in the CLWR EIS for the same accidents due to the use of different data inputs such as higher core inventory, slower evacuation speed, and a larger population. The ratio of isotopic core inventory is higher by a factor 1 to 3. The evacuation speed is slower by a factor of 2/3, and the population is almost twice the size of that projected in the CLWR EIS. The release frequencies used in this analysis are lower by a factor 2 to 5 than those used in the CLWR EIS. These frequencies are based on Revision 3 of the WBN Plant probabilistic safety assessment model (TVA 2007).

Overall, the risk results presented above are small. Completion and operation of WBN Unit 2 would not change the risks evaluated here because the likelihood of an accident that could affect both units and lead to radioactive releases beyond those analyzed here is extremely low. This is consistent with the conclusions of NRC's *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (GEIS) (NRC 1996). Accidents that could affect multiunit sites are initiated by external events. Severe accidents initiated by external events as tornadoes, floods, earthquakes, and fires traditionally have not been discussed in quantitative terms in final environmental statements and were not considered in the GEIS (NRC 1996). In the GEIS, however, NRC staff did evaluate existing impact assessments performed by NRC and the industry at 44 nuclear plants in the United States and concluded that the risk from beyond-design-basis earthquakes at existing nuclear power plants is small. Additionally, the staff concluded that the risks from other external events are adequately addressed by a generic consideration of internally initiated severe accidents.

4.1 Sensitivity Analysis

This section discusses how changes in the analysis assumptions would affect the calculated consequences. The parameters evaluated in this section include release energy, evacuation speed, evacuation fraction with a 16-kilometer EPZ, and release frequency. The effect of the weather sampling method is provided in the baseline analysis above. For the sensitivity evaluations, the input parameters corresponding to Release Category I were used. For each evaluation, only the selected input parameter would be changed.

Release Energy

The release energy (heat content) would lift the plume to a higher elevation where it would spread over a large area downwind from the accident. This effect would reduce the plume contaminant concentration in the vicinity of the plant. Since the analysis used complete washout of the plume at the last ring, the effect of the release energy on the population beyond 50 miles would be negligible. For this analysis, the release energy was reduced from 28 MW to 1 MW. The results indicate that the new population dose risk would decrease by about 4 percent. The dose to nearby residents in the vicinity of the plant would increase, but because these individuals would be evacuated or sheltered, the health effects would be small.

Evacuation Speed

The evacuation speed used in the baseline analysis was 1.0 meter per second, or 2.34 miles per hour. The evacuation time analysis for the 0-to-10-kilometer (0-to-10-mile) area given in the *Tennessee Multi-Jurisdictional Radiological Emergency Response Plan for the Watts Bar Nuclear Plant,* Annex H, (TVA 2006) shows a range of evacuation times from 2 to more than 6 hours, with an average duration value of 4 hours. For the sensitivity analyses, average evacuation speeds of 1.5 and 0.7 meters per second (or 3.36 and 1.57 miles per hour) were used. The new population dose risks for these evacuation speeds were determined to be within 0.87 and 1.25 of the baseline consequences for the cases with the 1.5 and 0.7 meters per second evacuation speeds, respectively.

Evacuation Fraction

The baseline public evacuation fraction within the 16-kilometer (10-mile) EPZ was 99.5 percent. For this analysis, it was assumed that 95 percent of the public would be evacuating. The new population dose risk would increase by about 1.2 percent above the baseline dose risk. Therefore, the impact of lower evacuation fraction would be very small.

4.1.1 Release Frequency

The risks of accidents are proportional to their projected frequency of occurrence. The release frequency values provided in Table 4 are best estimate values. The 95^{th} percentile uncertainty on these estimates could range between 2 to 5 (TVA 2007). Therefore, the population dose risk could vary proportionally as well. The final risk results would be small (see Table 9).

5. MACCS2 Computer Code

The MACCS2 computer code, Version 1.13.1, was used to estimate the radiological doses and health effects that could result from postulated accidental releases of radioactive materials to the atmosphere. The specification of the release characteristics, designated a "source term," can consist of up to four Gaussian plumes that are often referred to simply as "plumes."

The radioactive materials released are modeled as being dispersed in the atmosphere where they are transported by the prevailing wind. During transport, whether or not there is precipitation, particulate material can be modeled as being deposited on the ground. If contamination levels exceed a user-specified criterion, mitigative actions can be triggered to limit radiation exposures.

Two aspects of the code's structure are basic to understanding its calculations: (1) the calculations are divided into modules and phases, and (2) the region surrounding the facility is divided into a polar-coordinate grid. These concepts are described in the following sections.

MACCS2 is divided into three primary modules: ATMOS, EARLY, and CHRONC. Three phases are defined as the emergency, intermediate, and long-term phases. The relationship among the code's three modules and three phases of exposure are summarized below.

The ATMOS module performs calculations pertaining to atmospheric transport, dispersion, and deposition, as well as the radioactive decay that occurs before release and while the material is in the atmosphere. It utilizes a Gaussian plume model with Pasquill-Gifford dispersion parameters. The phenomena treated include building wake effects, buoyant plume rise, plume dispersion during transport, wet and dry deposition, and radioactive decay and in-growth. The results of the calculations are stored for use by EARLY and CHRONC. In addition to the air and ground concentrations, ATMOS stores information on wind direction, arrival and departure times, and plume dimensions.

The EARLY module models the time period immediately following a radioactive release. This period is commonly referred to as the emergency phase. The emergency phase begins at each successive downwind distance point where the first plume of the release arrives. The duration of the emergency phase is specified by the user and can range between 1 and 7 days. The exposure pathways considered during this period are direct external exposure to radioactive material in the plume (cloudshine), exposure from inhalation of radionuclides in the cloud (cloud inhalation), exposure to radioactive material deposited on the ground (groundshine), inhalation of resuspended material (resuspension inhalation), and skin dose from material deposited on the skin. Mitigative actions that can be specified for the emergency phase include evacuation, sheltering, and dose-dependent relocation.

The CHRONC module performs all of the calculations pertaining to the intermediate and long-term phases. CHRONC calculates the individual health effects that result from both direct exposure to contaminated ground and inhalation of resuspended materials, as well as indirect health effects caused by the consumption of contaminated food and water by individuals who could reside both on and off the computational grid.

The intermediate phase begins at each successive downwind distance point upon conclusion of the emergency phase. The user can configure the calculations with an intermediate phase that has a duration as short as zero or as long as 1 year. Essentially, there is no intermediate phase, and a long-term phase begins immediately upon conclusion of the emergency phase.

These models are implemented on the assumption that the radioactive plume has passed and the only exposure sources (groundshine and resuspension inhalation) are from ground-deposited material. For this reason, MACCS2 requires the total duration of a radioactive release to be limited to no more than 4 days. Potential doses from food and water ingestion during this period are not considered.

The mitigative action model for the intermediate phase is very simple. If the intermediate phase dose criterion is satisfied, the resident population is assumed to be present and subject to radiation exposure from groundshine and resuspension for the entire intermediate phase. If the intermediate phase exposure exceeds the dose criterion, then the population is assumed to be relocated to uncontaminated areas for the entire intermediate phase.

The long-term phase begins at each successive downwind distance point after conclusion of the intermediate phase. The exposure pathways considered during this period are groundshine, resuspension inhalation, and food and water ingestion.

The exposure pathways considered are those resulting from ground-deposited material. A number of protective measures can be modeled in the long-term phase to reduce doses to user-specified levels, including decontamination, temporary interdiction, and condemnation. The decisions on mitigative action in the long-term phase are based on two sets of independent actions: (1) decisions relating to whether land at a specific location and time is suitable for human habitation (habitability), and (2) decisions relating to whether land at a specific location and time is suitable for agricultural production (farmability).

All of the MACCS2 calculations are stored on the basis of a polar-coordinate spatial grid that treats calculations of the emergency phase and calculations of the intermediate and long-term phases somewhat differently. The region potentially affected by a release is represented with an (r,2) grid system centered on the location of the release. The radius, r, represents downwind distance. The angle, 2, is the angular offset from north, going clockwise.

The user specifies the number of radial divisions and their endpoint distances. The angular divisions used to define the spatial grid are fixed in the code and correspond to the 16 points of the compass (each is 22.5 degrees wide). The 16 points of the compass are used in the U.S. to express wind direction. The compass sectors are referred to as the coarse grid.

Since emergency phase calculations use dose-response models for early fatalities and early injuries that can be highly nonlinear, these calculations are performed on a finer grid basis than the calculations of the intermediate and long-term phases. For this reason, emergency phase calculations are performed with the 16 compass sectors divided into three, five, or seven equal, angular subdivisions. The subdivided compass sectors are referred to as the fine grid.

The compass sectors are not subdivided into fine subdivisions for the intermediate and long-term phases because these calculations are limited to cancer and genetic effects and do not include estimates of the often highly nonlinear early fatality and early injury health effects. In contrast to the emergency phase, the calculations for these phases are performed using doses averaged over the full 22.5-degree compass sectors of the coarse grid.

Two types of doses, "acute" and "lifetime," may be calculated using the MACCS2 code. Acute doses are calculated to estimate deterministic health effects that can result from high doses delivered at high dose rates. Such conditions may occur in the immediate vicinity of a nuclear power plant following a hypothetical severe accident where containment failure has been assumed to occur. Examples of health effects based on acute doses are early fatality, prodromal vomiting, and hypothyroidism. Lifetime doses are the conventional measure of detriment used for radiological protection. These are 50-year dose commitments to either specific tissues (e.g., red marrow, lungs) or a weighted sum of tissue doses defined by the International Commission on Radiological Protection and referred to as an "effective dose." Lifetime doses may be used to calculate the stochastic health effect risk resulting from exposure to radiation. MACCS2 uses the calculated lifetime dose in cancer risk calculations.

5.1 Data and General Assumptions

To assess the consequences of beyond-design-basis accidents, the following data and assumptions were incorporated into the MACCS2 analysis.

- The **nuclide inventory** at accident initiation (e.g., reactor trip) of those radioactive nuclides that are important for the calculation of offsite consequences is given in Table 2.

- The **atmospheric source term** produced by the accident was described by the number of plume segments released; sensible heat content; timing; duration; height of release for each plume segment; time when offsite officials are warned that an emergency response should be initiated; and for each important radionuclide, the fraction of that radionuclide's inventory released with each plume segment. The release fractions for each accident scenario are provided in Table 3. MACCS2 calculates the atmospheric source terms based on the core nuclide inventory at the time of reactor trip, release time after the reactor trip, and the associated release fractions.

- **Meteorological data** characteristics of the site region were described by 1 year of hourly windspeed, atmospheric stability, and rainfall recorded at each site. Although 1 year of hourly readings contains 8,760 weather sequences, MACCS2 calculations examine only a representative subset of these sequences. As stated earlier in Section 3.1.2, two types of weather sampling were used: bin sampling and stratified sampling. These two methods are the most used methods selected by MACCS users. Bin sampling requires the user to provide rain intensity at downwind distances; stratified sampling is a purely random selection of hourly data from those occurring at the site. The analysis was based on 139 weather data in bin sampling and 1460 weather data in stratified sampling. Stratified random sampling resulted in less than 10 percent higher doses.

- **Population distribution information** regarding the Watts Bar site was based on data from the 2000 census as used in the SECPOP 2000 computer code (NRC 2003). The generated population data for the site was extrapolated to the year 2030 using the incremental increase in population during the decade recorded from census 1990 to 2000). This data is provided in Table 5 for a polar coordinate grid with 16 angular sectors aligned with the 16 compass directions and 10 radial intervals that extend outward to 80 kilometers (50 miles).

- **Habitable land fractions** for the region around each reactor site were determined in a manner similar to the population distribution. The census block group boundary files include polygons that are classified as water features. The percentage of each sector that is covered by water was determined by fitting this data to the polar coordinate grid.

- **Farmland fractions** are the percentage of land devoted to farming (DOE 1999).

- **Emergency response assumptions** for evacuation, including delay time before evacuation, area evacuated, average evacuation speed, and travel distance, are provided in the Tennessee Multi-Jurisdictional Plans, see Section 3.1.2. Average evacuation speeds are based on the most conservative general population evacuation times.

- **Shielding and exposure data** must be input into the MACCS2 code. The code requires shielding factors to be specified for people evacuating in vehicles (cars, buses); taking shelter in structures (houses, offices, schools); and continuing normal activities either outdoors, in vehicles, or indoors. Because inhalation doses depend on breathing rate, breathing rates must be specified for people who are continuing normal activities, taking shelter, and evacuating. Since indoor concentrations of gasborne radioactive materials are usually substantially less than outdoor concentrations, MACCS2 also requires that inhalation and skin protection shielding factors (indoor/outdoor concentration ratios) be provided.

The protection factors presented in **Table 10** were used in this analysis. The values in this table are for the Sequoyah Nuclear Plant, as stated in NUREG/CR-4551, and were used in the analysis for the WBN Plant.

Table 10 NUREG/CR-4551 Protection Factors

Protection Factor [a]	*Evacuees*	*Sheltering*	*Normal Activities*
Cloudshine Shielding Factor	1.0	0.65	0.75
Skin Protection Factor	1.0	0.33 [b]	0.41 [b]
Inhalation Protection Factor	1.0	0.33 [b]	0.41 [b]
Groundshine Shielding Factor	0.5	0.2	0.33 [c]

[a] A protection factor of 1.0 indicates no protection, while a protection factor of 0.0 indicates 100 percent protection.
[b] These values were based on the recommendation from S. Acharya of NRC as it appears in Appendix A-2 of NUREG/CR-4551, Vol. 2. The recommended values in the report are 0.2 and 0.5 for sheltering and normal activities, respectively (NUREG/CR-4551, Vol. 2, Table 3.12).
[c] This value was based on the recommendation from S. Acharya of NRC as it appears in Appendix A-2 of NUREG/CR-4551, Vol. 2. The recommended value in the report is 0.5 (NUREG/CR-4551, Vol. 2, Table 3.12).

For this analysis, the evacuation and sheltering region was defined as a 10-mile radial distance centered on the plant. A sheltering period was defined as the phase occurring before initiation of the evacuation. During the sheltering period, shielding factors appropriate for sheltered activity were used to calculate doses for individuals in contaminated areas.

At the end of the sheltering period, residents begin traveling out of the region. Travel speeds and delay times are based on the Tennessee Multi-Jurisdictional Plans. The general population evacuation times for the various areas within the 10-mile radius were averaged to determine an overall evacuation delay time and evacuation speed for the WBN Plant.

- Maximally Exposed Offsite Individual (MEI) dose is the total dose estimated to be incurred by a hypothetical individual assumed to reside at a particular location on the spatial grid. Population data, therefore, have no bearing on the generation of this consequence measure. Only direct exposure is considered in these results. Exposures from ingestion of contaminated food and water are not included. In addition, generation of these results takes full account of any mitigative action models activated by exceeding the dose thresholds. During evacuation, individuals have no protection from direct exposure. Therefore, in certain scenarios, it is possible that an evacuee may incur a larger direct exposure dose than an individual who does not evacuate.

- Long-term protective measures such as decontamination, temporary relocation, contaminated crops, milk condemnation, and farmland production prohibition are based on U.S. Environmental Protection Agency (EPA) Protective Action Guides.

- Mitigative actions (relocation, evacuation, interdiction, condemnation) are implemented for beyond-design-basis accidents (vessel breach with containment bypass, vessel breach with early containment failure, and vessel breach with late containment failure).

- Dose conversion factors required by MACCS2 for the calculation of committed effective dose equivalents are cloudshine dose-rate factor; groundshine dose-rate factor; "lifetime" 50-year committed inhalation dose (used for calculation of individual and societal doses and stochastic health effects); and 50-year committed ingestion dose (used for calculation of individual and societal doses and stochastic health effects from food and water ingestion).

5.2 Health Effects Calculations

The health consequences from exposure to radionuclides due to accidental releases were calculated. Total effective dose equivalents were calculated and converted to estimates of cancer fatalities using dose conversion factors recommended by the International Commission on Radiological Protection. For individuals, the estimated probability of a latent cancer fatality occurring was reported for the maximally exposed individual, an average individual in the population within 80 kilometers (50 miles), and a noninvolved worker.

The nominal values of lifetime cancer risk for low dose or low dose rate exposure (less than 20 rad) used in this EIS are 0.0006 per person-rem for a population of all ages, including workers (ISCORS 2002). These dose-to-risk conversion factors are about 20 percent more than those established by the National Council on Radiation Protection and Measurement and used in the CLWR EIS.

The MACCS2 code was applied in a probabilistic manner using a weather bin and a stratified sampling method. Each of the sampled meteorological sequences was applied to each of the 16 sectors (accounting for the frequency of occurrence of the wind blowing in that direction). Individual doses as a function of distance and direction were calculated for each of the meteorological sequence samples. The mean dose values of the sequences were generated for each of the 16 sectors. The highest of these dose values was used for the maximally exposed individual and the noninvolved worker. Population doses are the sum of the individual doses in each sector.

6. Conclusions

Table 11 summarizes the consequences of the beyond design-basis accident, with mean meteorological conditions, to the maximally exposed offsite individual, an average individual, and the population residing within an 80-kilometer (50-mile) radius of the reactor site. The analysis assumed that a site emergency would have been declared early in the accident sequence and that all nonessential site personnel would have evacuated the site in accordance with site emergency procedures before any radiological releases to the environment occurred. In addition, emergency action guidelines would have been implemented to initiate evacuation of 99.5 percent of the public within 16 kilometers (10 miles) of the plant. The location of the maximally exposed offsite individual may or may not be at the site boundary for these accident sequences because emergency action guidelines would have been implemented and the population would be evacuating from the path of the radiological plume released by the accident.

Table 11 Severe Accident Annual Risks

Release Category (frequency per reactor year)	*Maximally Exposed Offsite Individual*		*Population within 80 Kilometers (50 miles)*		
			Average Individual		*General public*
	Dose Risk [a] (rem/year)	*Cancer Fatality [b]*	*Dose Risk [a] (rem/year)*	*Cancer Fatality [b]*	*Dose Risk [a] (person-rem/year)*
Maximum dose and risk					
I - Early Containment failure (3.4×10^{-7})	1.2×10^{-5}	1.4×10^{-8}	5.8×10^{-6}	3.5×10^{-9}	12.3
II - Containment Bypass (1.4×10^{-6})	1.7×10^{-5}	9.9×10^{-8}	2.7×10^{-5}	1.6×10^{-8}	57.3
III - Late Containment Failure (3.0×10^{-6})	2.2×10^{-6}	1.3×10^{-9}	2.8×10^{-6}	1.7×10^{-9}	5.9

[a] Includes the likelihood of occurrence of each release category.
[b] Increased likelihood of cancer fatality per year.

Overall, the risk results presented above are small. Completion and operation of WBN Unit 2 would not change the risks evaluated here because the likelihood of an accident that could affect both units and lead to radioactive releases beyond those analyzed here would be extremely low. This is consistent with the conclusions of NRC's GEIS (NRC 1996). Accidents that could affect multiple units are initiated by external events. Severe accidents initiated by external events as tornadoes, floods, earthquakes, and fires traditionally have not been discussed in quantitative terms in final environmental statements and were not considered in the GEIS (NRC 1996). In the GEIS, however, NRC staff evaluated existing impact assessments performed by NRC and the industry at 44 nuclear plants in the United States and concluded that the risk from beyond-design-basis earthquakes at existing nuclear power plants is small. Additionally, the staff concluded that the risks from other external events are adequately addressed by a generic consideration of internally initiated severe accidents.

7. References

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TVA (Tennessee Valley Authority), 1995, *Sequoyah Nuclear Plant Individual Plant Examination, Delta Report for Revision 1 Update*, September.

I assume that, if the above references are still applicable, TVA would have the copies needed.

TVA (Tennessee Valley Authority), 2006, *Tennessee Multi-Jurisdictional Radiological Emergency Response Plan for the Watts Bar Nuclear Plant*, Annex H. {This report is available, and TVA provided Annex H for analysis)

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TENNESSEE VALLEY AUTHORITY

WATTS BAR NUCLEAR PLANT

CONSTRUCTION AND OPERATIONAL EMPLOYEE SURVEY RESULTS

JULY 31, 1986

Knoxville, Tennessee

January 1987

WATTS BAR NUCLEAR PLANT
CONSTRUCTION AND OPERATIONAL EMPLOYEE SURVEY RESULTS
July 31, 1986

This is the seventh in a series of reports describing the results of surveys of the work force at the Watts Bar Nuclear Plant. The survey covered all employees as of July 31, 1986. Results are summarized for both construction and operational employees with each group subgrouped into trades and labor hourly (referred to as Hourly) and salary policy annual (referred to as Annual). The following information is presented in various tables: (1) the number and current residence of employees who did not move to work at the project; (2) the number of employees who moved into the area (referred to as Movers) and where they moved to; (3) a cross-tabulation of previous and current residence of all employees, aggregated at the county and State level; (4) the number of movers who brought their families and the number without a family in the area; (5) the total number of children accompanying movers with families and how many were of school age; and (6) the kind of accommodations selected by movers.

Tables A-1 and B-1 list the towns of current residence for both movers and nonmovers along with the number of each category living there. These tables are based on a "mailing address" location rather than jurisdictional location because employees were asked to provide a place mane even if they did not live within any municipal limits. However, for impact communities, information is tabulated for employees living within municipal limits in tables A-7 through A-9 and B-6 through B-8.

Most of the tables contain raw data from survey responses but table A-3 and the tables in Appendices C and D contain extrapolated data to enable comparisons among surveys and with projections. The extrapolation is done on a ratio basis of total employment to total respondents. This procedure assumes that the survey sample accurately reflects the situation of the total work force. It is possible that nonrespondents differ significantly from respondents but there is no obvious indication of that.

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APPENDIX A

WATTS BAR NUCLEAR PLANT
Results of the July 31, 1986
Construction Employee Survey

TABLE A-1
FOLLOW UP SURVEY
TOWN OF CURRENT RESIDENCE
WATTS BAR NUCLEAR PLANT EMPLOYEES
CONSTRUCTION EMPLOYEES 07-31-86

RUN DATE 03/13/87
RUN TIME 153557
REPORT 2

TOWN		MOVED TO TOWN	ALREADY IN TOWN	TOTAL	POPULATION
ATHENS	TN	35	38	73	12,080
CHATTANOOGA	TN	11	71	82	169,558
CLEVELAND	TN	9	41	50	26,415
CROSSVILLE	TN	18	20	38	6,394
DAYTON	TN	30	35	65	5,913
DECATUR	TN	26	30	56	1,069
EVENSVILLE	TN	7	12	19	250
HARRIMAN	TN	9	20	29	8,303
HIXSON	TN	9	33	42	
KINGSTON	TN	29	21	50	4,441
KNOXVILLE	TN	29	55	84	175,045
LENOIR CITY	TN	6	13	19	5,446
MADISONVILLE	TN	5	10	15	2,884
MARYVILLE	TN	6	3	9	17,480
NIOTA	TN	7	3	10	765
ROCKWOOD	TN	26	33	59	
SPRING CITY	TN	90	47	137	1,951
SWEETWATER	TN	12	22	34	4,725
TEN MILE	TN	26	11	37	200
SUBTOTAL		390	518	908	
BENTON	TN	0	7	7	1,115
CLINTON	TN	2	6	8	5,245
ENGLEWOOD	TN	1	6	7	1,840
ETOWAH	TN	3	9	12	3,758
GRANDVIEW	TN	2	7	9	300
GRAYSVILLE	TN	1	6	7	1,380
HARRISON	TN	0	11	11	6,206
OLIVER SPRINGS	TN	0	5	5	1,075
PIKEVILLE	TN	0	6	6	2,085
RICEVILLE	TN	4	6	10	500
SODDY DAISY	TN	2	33	35	8,388
TELLICO PLAINS	TN	1	8	9	698
WARTBURG	TN	0	5	5	630
SUBTOTAL		16	115	131	
OTHER		25	132	157	
TOTAL RESPONSES		431	765	1196	
WBNP WORKFORCE TOTAL 07-31-86				2103	

TABLE A-2
FOLLOW UP SURVEY
SOURCE AND LOCATION OF CONSTRUCTION EMPLOYEES RUN DATE 03/13/87

WATTS BAR NUCLEAR PLANT RUN TIME 153610

CONSTRUCTION EMPLOYEES 07-31-86 REPORT 4

FROM --- TO	--IMPACT COUNTIES MEIGS	RHEA	OTHER REC. COUNTIES	OTHER TENN. COUNTIES	OTHER (4)	TOTAL
MEIGS (1)	43		5			48
RHEA (1)	2	119	6			127
OTHER RECRUITING COUN (2)	8	20	643	3	1	675
OTHER TN. COUNTIES (3)	22	52	68	26		168
ALABAMA	9	13	23		1	46
ARKANSAS		1				1
GEORGIA	1	3	6	1	24	35
KENTUCKY	1	4	4			9
KENTUCKY		3	5			8
N. CAROLINA	4	1	6		1	12
S. CAROLINA			1			1
OTHER STATES	6	22	38			66
TOTAL	96	238	805	30	27	1196

NOTE: DATA ON DIAGONAL INDICATE NONMOVERS, WITH THE EXCEPTION OF MOVES WITHIN A COUNTY.
ALL OTHER DATA INDICATE MOVERS.
(1) RECRUITING COUNTY
(2) TENNESSEE COUNTIES: ANDERSON, BLEDSOE, BLOUNT, BRADLEY, CUMBERLAND, HAMILTON, KNOX, MCMINN, MONROE, MORGAN, POLK, ROANE, SEQUATCHIE, LOUDON
(3) ALL COUNTIES IN TENNESSEE OTHER THAN RECRUITING COUNTIES
(4) "OTHER" INCLUDES NON-RESPONSES OR ERRONEOUS RESPONSES FOR CURRENT ADDRESS.

TABLE A-3

WATTS BAR NUCLEAR PLANT
JULY 31, 1986, CONSTRUCTION EMPLOYEE SURVEY
DISTRIBUTION OF MOVERS AND ASSOCIATED POPULATION
BY COUNTY AND COMMUNITY

County	Percent of Movers	Number[1] of Movers	Population Influx[1] School Age	Population Influx[1] Total
Rhea	30	229	155	605
Meigs	12	93	39	197
Other	58	436	349	1,255
Total	100[2]	758	543	2,057
Community[3]				
Dayton	3	19	18	60
Spring City	7	53	37	132
Decatur	2	12	7	30
Total	12	84	62	22

1. Numbers extrapolated.
2. Percentages may not add up to 100 due to rounding.
3. Within municipal limits.

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TABLE A-4
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 008

RUN DATE 03/13/87
REPORT 1F
RUN TIME 153537

MOVER SUMMARY
CONSTRUCTION EMPLOYEES 07-31-86

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	60	44	89	57	22	1	61
HOUSE RENTED	26	21	49	32	10	6	32
APARTMENT RENTED	2	0	3	0	0	6	8
MOBILE HOME RENTED	4	2	4	3	0	10	14
MOBILE HOME OWNED	13	3	7	4	2	7	20
SLEEPING ROOM	0	0	0	0	0	4	4
MOTEL	0	0	0	0	0	3	3
OTHER	8	5	9	4	5	3	11
TOTAL	113	75	161	100	39	40	153
HOURLY EMPLOYEES							
HOUSE OWNED	126	65	159	79	31	5	131
HOUSE RENTED	40	20	46	21	11	14	54
APARTMENT RENTED	17	11	24	11	6	25	42
MOBILE HOME RENTED	1	0	2	0	0	6	7
MOBILE HOME OWNED	16	5	11	5	0	9	25
SLEEPING ROOM	0	0	0	0	0	1	1
MOTEL	0	0	0	0	0	1	1
OTHER	12	3	11	5	1	5	17
TOTAL	212	104	253	121	49	66	278
ALL EMPLOYEES							
HOUSE OWNED	186	109	248	136	53	6	192
HOUSE RENTED	66	41	95	53	21	20	86
APARTMENT RENTED	19	11	27	11	6	31	50
MOBILE HOME RENTED	5	2	6	3	0	16	21
MOBILE HOME OWNED	29	6	18	9	2	16	45
SLEEPING ROOM	0	0	0	0	0	5	5
MOTEL	0	0	0	0	0	4	4
OTHER	20	8	20	9	6	8	28
TOTAL	325	179	414	221	88	106	431

TABLE A-5
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 004

MEIGS
EMPLOYEES LIVING WITHIN THE COUNTY TOTAL
CONSTRUCTION EMPLOYEES 07-31-86

RUN DATE 03/13/87
REPORT 1B
RUN TIME 153537

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	2	2	5	4	0	0	2
HOUSE RENTED	2	2	6	4	0	2	4
APARTMENT RENTED	0	0	0	0	0	2	2
MOBILE HOME RENTED	3	1	2	1	0	7	10
MOBILE HOME OWNED	4	1	2	1	1	3	7
SLEEPING ROOM							
MOTEL	0	0	0	0	0	1	1
OTHER	2	2	4	1	3	2	4
TOTAL	13	8	19	11	4	17	30
HOURLY EMPLOYEES							
HOUSE OWNED	7	3	6	0	3	1	8
HOUSE RENTED	3	2	4	2	1	0	3
APARTMENT RENTED	0	0	0	0	0	2	2
MOBILE HOME RENTED	0	0	0	0	0	2	2
MOBILE HOME OWNED	3	1	1	1	0	4	7
SLEEPING ROOM							
MOTEL							
OTHER	1	0	2	0	0	0	1
TOTAL	14	6	13	3	4	9	23
ALL EMPLOYEES							
HOUSE OWNED	9	5	11	4	3	1	10
HOUSE RENTED	5	4	10	6	1	2	7
APARTMENT RENTED	0	0	0	0	0	4	4
MOBILE HOME RENTED	3	1	2	1	0	9	12
MOBILE HOME OWNED	7	2	3	2	1	7	14
SLEEPING ROOM							
MOTEL	0	0	0	0	0	1	1
OTHER	3	2	6	1	3	2	5
TOTAL	27	14	32	14	8	26	53

TABLE A-6
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 005

RHEA
EMPLOYEES LIVING WITHIN THE COUNTY TOTAL
CONSTRUCTION EMPLOYEES 07-31-86

RUN DATE 03/13/87
REPORT 18
RUN TIME 153537

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	21	16	33	25	6	0	21
HOUSE RENTED	12	8	18	12	6	1	13
APARTMENT RENTED	1	0	2	0	0	3	4
MOBILE HOME RENTED	0	0	0	0	0	2	2
MOBILE HOME OWNED	5	1	3	1	1	2	7
SLEEPING ROOM	0	0	0	0	0	3	3
MOTEL	0	0	0	0	0	1	1
OTHER	2	0	1	0	0	1	3
TOTAL	41	25	57	38	13	13	54
HOURLY EMPLOYEES							
HOUSE OWNED	29	12	33	14	8	1	30
HOUSE RENTED	12	5	14	6	3	7	19
APARTMENT RENTED	6	4	9	3	1	4	10
MOBILE HOME RENTED	0	0	0	0	0	3	3
MOBILE HOME OWNED	6	2	6	2	0	4	10
SLEEPING ROOM	0	0	0	0	0	1	1
MOTEL							
OTHER	1	0	0	0	0	2	3
TOTAL	54	23	62	25	12	22	76
ALL EMPLOYEES							
HOUSE OWNED	50	28	66	39	14	1	51
HOUSE RENTED	24	13	32	18	9	8	32
APARTMENT RENTED	7	4	11	3	1	7	14
MOBILE HOME RENTED	0	0	0	0	0	5	5
MOBILE HOME OWNED	11	3	9	3	1	6	17
SLEEPING ROOM	0	0	0	0	0	4	4
MOTEL	0	0	0	0	0	1	1
OTHER	3	0	1	0	0	3	6
TOTAL	95	48	119	63	25	35	130

TABLE A-7
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 001

DAYTON
EMPLOYEES LIVING WITHIN THE CITY LIMITS
CONSTRUCTION EMPLOYEES 07-31-86

RUN DATE 03/13/87
REPORT 1A
RUN TIME 153537

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED							
HOUSE RENTED	1	1	3	3	0	0	1
APARTMENT RENTED							
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	1	1	3	3	0	0	1
HOURLY EMPLOYEES							
HOUSE OWNED	5	1	6	3	1	0	5
HOUSE RENTED	2	1	3	2	0	0	2
APARTMENT RENTED	1	1	1	1	0	1	2
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER	1	0	0	0	0	0	1
TOTAL	9	3	10	6	1	1	10
ALL EMPLOYEES							
HOUSE OWNED	5	1	6	3	1	0	5
HOUSE RENTED	3	2	6	5	0	0	3
APARTMENT RENTED	1	1	1	1	0	1	2
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER	1	0	0	0	0	0	1
TOTAL	10	4	13	9	1	1	11

TABLE A-8
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 002

DECATUR
EMPLOYEES LIVING WITHIN THE CITY LIMITS
CONSTRUCTION EMPLOYEES 07-31-86

RUN DATE 03/13/87
REPORT 1A
RUN TIME 153537

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED							
HOUSE RENTED	1	1	2	1	0	1	2
APARTMENT RENTED	0	0	0	0	0	1	1
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL	0	0	0	0	0	1	1
OTHER	1	1	3	1	2	0	1
TOTAL	2	2	5	2	2	3	5
HOURLY EMPLOYEES							
HOUSE OWNED							
HOUSE RENTED							
APARTMENT RENTED							
MOBILE HOME RENTED							
MOBILE HOME OWNED	0	0	0	0	0	1	1
SLEEPING ROOM							
MOTEL							
OTHER	1	0	2	0	0	0	1
TOTAL	1	0	2	0	0	1	2
ALL EMPLOYEES							
HOUSE OWNED							
HOUSE RENTED	1	1	2	1	0	1	2
APARTMENT RENTED	0	0	0	0	0	1	1
MOBILE HOME RENTED							
MOBILE HOME OWNED	0	0	0	0	0	1	1
SLEEPING ROOM							
MOTEL	0	0	0	0	0	1	1
OTHER	2	1	5	1	2	0	2
TOTAL	3	2	7	2	2	4	7

TABLE A-9
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 003

SPRING CITY RUN DATE 03/13/87
EMPLOYEES LIVING WITHIN THE CITY LIMITS REPORT 1A
CONSTRUCTION EMPLOYEES 07-31-86 RUN TIME 153537

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	5	3	8	7	1	0	5
HOUSE RENTED	6	4	7	5	2	1	7
APARTMENT RENTED							
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM	0	0	0	0	0	1	1
MOTEL	0	0	0	0	0	1	1
OTHER	0	0	0	0	0	1	1
TOTAL	11	7	15	12	3	4	15
HOURLY EMPLOYEES							
HOUSE OWNED	6	3	7	1	3	0	6
HOUSE RENTED	1	0	0	0	0	3	4
APARTMENT RENTED	2	2	3	1	1	0	2
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED	0	0	0	0	0	1	1
SLEEPING ROOM	0	0	0	0	0	1	1
MOTEL							
OTHER							
TOTAL	9	5	10	2	4	6	15
ALL EMPLOYEES							
HOUSE OWNED	11	6	15	8	4	0	11
HOUSE RENTED	7	4	7	5	2	4	11
APARTMENT RENTED	2	2	3	1	1	0	2
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED	0	0	0	0	0	1	1
SLEEPING ROOM	0	0	0	0	0	2	2
MOTEL	0	0	0	0	0	1	1
OTHER	0	0	0	0	0	1	1
TOTAL	20	12	25	14	7	10	30

APPENDIX B

WATTS BAR NUCLEAR PLANT
Results of the July 31, 1986
Operational Employee Survey

TABLE B-1
FOLLOW UP SURVEY
TOWN OF CURRENT RESIDENCE
WATTS BAR NUCLEAR PLANT EMPLOYEES
OPERATIONAL EMPLOYEES 07-31-86

RUN DATE 10/06/86
RUN TIME 110948
REPORT 2

TOWN		MOVED TO TOWN	ALREADY IN TOWN	TOTAL	POPULATION
ATHENS	TN	35	19	54	12,080
CLEVELAND	TN	7	14	21	26,415
CROSSVILLE	TN	9	11	20	6,394
DAYTON	TN	23	32	55	5,913
DECATUR	TN	11	25	36	1,069
EVENSVILLE	TN	15	10	25	250
HARRIMAN	TN	5	14	19	8,303
HIXSON	TN	6	15	21	
KINGSTON	TN	19	21	40	4,441
KNOXVILLE	TN	21	25	46	175,045
LENOIR CITY	TN	5	6	11	5,446
ROCKWOOD	TN	10	15	25	
SPRING CITY	TN	68	60	128	1,951
SWEETWATER	TN	14	4	18	4,725
TEN MILE	TN	12	5	17	200
SUBTOTAL		260	276	536	
BENTON	TN	1	5	6	1,115
CHATTANOOGA	TN	3	22	25	169,558
PIKEVILLE	TN	0	6	6	2,035
SODDY DAISY	TN	1	11	12	8,388
SUBTOTAL		5	44	49	
OTHER		37	71	108	
TOTAL RESPONSES		302	391	693	
WBNP WORKFORCE TOTAL 07-31-86				1022	

TABLE B-2
FOLLOW UP SURVEY
SOURCE AND LOCATION OF OPERATIONAL EMPLOY EES   RUN DATE 10/06/86

WATTS BAR   NUCLEAR PLANT   RUN TIME 111004

OPERATIONAL   EMPLOYEES 07-31-86   REPORT 4

FROM --- TO	COMMUTING COUNTIES MEIGS	RHEA	OTHER COM. COUNTIES	OTHER TENN. COUNTIES	OTHER (4)	TOTAL
MEIGS (1)	35	1	3			39
RHEA (1)		114	2			116
OTHER COMMUTING COUN (2)	10	30	307			347
OTHER TN. COUNTIES (3)	1	29	39	4		73
ALABAMA	4	17	29		1	51
GEORGIA		3	3		4	10
KENTUCKY		4	2			6
KENTUCKY		1	2			3
N. CAROLINA		2	4		1	7
S. CAROLINA		1	2			3
OTHER STATES	5	14	19			38
TOTAL	55	216	412	4	6	693

NOTE: DATA ON DIAGONAL INDICATE NONMOVERS, WITH THE EXCEPTION OF MOVES WITHIN A COUNTY. ALL OTHER DATA INDICATE MOVERS.

(1) RECRUITING COUNTY
(2) TENNESSEE COUNTIES: ANDERSON, BLEDSOE, BLOUNT, BRADLEY, CUMBERLAND, HAMILTON, KNOX, MCMINN, MONROE, MORGAN, POLK, ROANE, SEQUATCHIE, LOUDON
(3) ALL COUNTIES IN TENNESSEE OTHER THAN COMMUTING COUNTIES
(4) "OTHER" INCLUDES NON-RESPONSES OR ERRONEOUS RESPONSES FOR CURRENT ADDRESS.

TABLE B-3
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 008

RUN DATE 10/06/86
REPORT 1F
RUN TIME 110939

MOVER SUMMARY
OPERATIONAL EMPLOYEES 07-31-86

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	52	30	79	35	11	3	55
HOUSE RENTED	8	8	16	10	5	4	12
APARTMENT RENTED	4	1	3	1	0	3	7
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED	9	4	10	5	1	3	12
SLEEPING ROOM							
MOTEL	0	0	0	0	0	2	2
OTHER	3	2	2	2	0	0	3
TOTAL	76	45	110	53	17	16	92
HOURLY EMPLOYEES							
HOUSE OWNED	116	72	167	84	37	9	125
HOUSE RENTED	21	8	26	13	1	10	31
APARTMENT RENTED	12	4	14	4	3	13	25
MOBILE HOME RENTED	1	1	2	1	1	3	4
MOBILE HOME OWNED	10	4	11	5	4	7	17
SLEEPING ROOM							
MOTEL	0	0	0	0	0	2	2
OTHER	5	1	4	1	1	1	6
TOTAL	165	90	224	108	47	45	210
ALL EMPLOYEES							
HOUSE OWNED	168	102	246	119	48	12	180
HOUSE RENTED	29	16	42	23	6	14	43
APARTMENT RENTED	16	5	17	5	3	16	32
MOBILE HOME RENTED	1	1	2	1	1	4	5
MOBILE HOME OWNED	19	8	21	10	5	10	29
SLEEPING ROOM							
MOTEL	0	0	0	0	0	4	4
OTHER	8	3	6	3	1	1	9
TOTAL	241	135	334	161	64	61	302

TABLE B-4
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 004

MEIGS
EMPLOYEES LIVING WITHIN THE COUNTY TOTAL
OPERATIONAL EMPLOYEES 07-31-86

RUN DATE 10/06/86
REPORT 18
RUN TIME 110939

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	1	1	2	1	1	0	1
HOUSE RENTED	0	0	0	0	0	1	1
APARTMENT RENTED							
MOBILE HOME RENTED							
MOBILE HOME OWNED	4	3	7	3	1	0	4
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	5	4	9	4	2	1	6
HOURLY EMPLOYEES							
HOUSE OWNED	10	7	19	9	9	0	10
HOUSE RENTED	1	1	3	3	0	1	2
APARTMENT RENTED							
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED	2	1	3	1	1	2	4
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	13	9	25	13	10	4	17
ALL EMPLOYEES							
HOUSE OWNED	11	8	21	10	10	0	11
HOUSE RENTED	1	1	3	3	0	2	3
APARTMENT RENTED							
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED	6	4	10	4	2	2	8
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	18	13	34	17	12	5	23

TABLE B-5
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 005

RHEA
EMPLOYEES LIVING WITHIN THE COUNTY TOTAL
OPERATIONAL EMPLOYEES 07-31-86

RUN DATE 10/06/86
REPORT 18
RUN TIME 110939

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	22	14	43	19	4	1	23
HOUSE RENTED	4	4	8	5	2	2	6
APARTMENT RENTED	0	0	0	0	0	2	2
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED	1	0	0	0	0	2	3
SLEEPING ROOM							
MOTEL	0	0	0	0	0	2	2
OTHER	2	2	2	2	0	0	2
TOTAL	29	20	53	26	6	10	39
HOURLY EMPLOYEES							
HOUSE OWNED	44	27	53	33	8	5	49
HOUSE RENTED	7	4	11	6	1	1	8
APARTMENT RENTED	0	0	0	0	0	4	4
MOBILE HOME RENTED	1	1	2	1	1	1	2
MOBILE HOME OWNED	4	2	2	3	1	4	8
SLEEPING ROOM							
MOTEL							
OTHER	0	0	0	0	0	1	1
TOTAL	56	34	68	43	11	16	72
ALL EMPLOYEES							
HOUSE OWNED	66	41	96	52	12	6	72
HOUSE RENTED	11	8	19	11	3	3	14
APARTMENT RENTED	0	0	0	0	0	6	6
MOBILE HOME RENTED	1	1	2	1	1	2	3
MOBILE HOME OWNED	5	2	2	3	1	6	11
SLEEPING ROOM							
MOTEL	0	0	0	0	0	2	2
OTHER	2	2	2	2	0	1	3
TOTAL	85	54	121	69	17	26	111

TABLE B-6
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 001

DAYTON
EMPLOYEES LIVING WITHIN THE CITY LIMITS
OPERATIONAL EMPLOYEES 07-31-86

RUN DATE 10/06/86
REPORT 1A
RUN TIME 110939

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	2	2	4	3	0	0	2
HOUSE RENTED							
APARTMENT RENTED							
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	2	2	4	3	0	0	2
HOURLY EMPLOYEES							
HOUSE OWNED	8	4	10	6	0	0	8
HOUSE RENTED	1	0	1	0	0	0	1
APARTMENT RENTED	0	0	0	0	0	2	2
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	9	4	11	6	0	2	11
ALL EMPLOYEES							
HOUSE OWNED	10	6	14	9	0	0	10
HOUSE RENTED	1	0	1	0	0	0	1
APARTMENT RENTED	0	0	0	0	0	2	2
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	11	6	15	9	0	2	13

TABLE B-7

FOLLOW UP SURVEY

WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 002

DECATUR RUN DATE 10/06/86

EMPLOYEES LIVING WITHIN THE CITY LIMITS REPORT 1A

OPERATIONAL EMPLOYEES 07-31-86 RUN TIME 110939

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED							
HOUSE RENTED	0	0	0	0	0	1	1
APARTMENT RENTED							
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	0	0	0	0	0	1	1
HOURLY EMPLOYEES							
HOUSE OWNED	2	2	6	3	3	0	2
HOUSE RENTED							
APARTMENT RENTED							
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	2	2	6	3	3	1	3
ALL EMPLOYEES							
HOUSE OWNED	2	2	6	3	3	0	2
HOUSE RENTED	0	0	0	0	0	1	1
APARTMENT RENTED							
MOBILE HOME RENTED	0	0	0	0	0	1	1
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	2	2	6	3	3	2	4

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	BELLEFONTE JUNE 1982	BELLEFONTE APRIL 1984	BELLEFONTE JULY 1986
TOTAL EMPLOYEES	4025	2290	979
EMPLOYEES SURVEYED	3061	2096	778
EXPECTED PEAK	4200	4200	4200
TOTAL MOVERS			
NUMBER	1557	970	362
% TOTAL EMPLOYMENT	39	42	37
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	SCOTTSBORO-700 HOLLYWOOD-131 HUNTSVILLE-75 STEVENSON-49 SECTION-39 GUNTERSVILLE-30 BRIDGEPORT-26	SCOTTSBORO-455 HOLLYWOOD-78 HUNTSVILLE-61 SECTION-27 STEVENSON-16 CHATTANOOGA-16 JASPER-16	SCOTTSBORO-170 HOLLYWOOD-35 SECTION-13
HOUSING TYPE SELECTED			
HOUSE-BOUGHT	488(31%)	327(34%)	181(50%)
RENTED	354(23%)	250(26%)	59(16%)
TOTAL	842 (54%)	577 (60%)	240 (66%)
M. HOME BOUGHT	242(16%)	141(15%)	55(15%)
RENTED	145 (9%)	47 (5%)	14 (4%)
TOTAL	387 (25%)	188 (19%)	69 (19%)
APARTMENT	197 (13%)	131 (14%)	35 (10%)
OTHER	131 (8%)	74 (8%)	18 (5%)
GRAND TOTAL	1557(100%)	970(100%)	362(100%)
MOVERS			
WITH FAMILIES	1069(69%)	689(71%)	287(79%)
WITHOUT FAMILIES	488(31%)	281(29%)	75(21%)
CHILDREN			
SCHOOL-AGE	888	586	351
NUMBER PER FAMILY	0.8	0.9	1.2
TOTAL	1362	866	253
NUMBER PER FAMILY	1.3	1.3	0.9

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	HARTSVILLE SEPT 1976	HARTSVILLE MAR 1977	HARTSVILLE SEPT 1977	HARTSVILLE MAR 1978	HARTSVILLE SEPT 1978
TOTAL EMPLOYEES	1275	1757	3450	4400	5600
EMPLOYEES SURVEYED	1222	1753	3200	4100	5500
EXPECTED PEAK	6800	6800	6800	6800	6800
TOTAL MOVERS					
NUMBER	188	360	910	1216	1588
% TOTAL EMPLOYMENT	15	20	26	28	28
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	GALLATIN-53 HARTSVILLE-34 LEBANON-41	CARTHAGE-15 CASTALIAN SPRNG-24 GALLATIN-83 HARTSVILLE-49 LAFAYETTE-16 LEBANON-55	CARTHAGE-34 CASTALIAN SPRNG-43 GALLATIN-176 HARTSVILLE-133 HENDERSONVILLE-66 LAFAYETTE-65 LEBANON-134 NASHVILLE-45	CARTHAGE-42 CASTALIAN SPRNG-61 GALLATIN-216 HARTSVILLE-186 HENDERSONVILLE-66 LAFAYETTE-84 LEBANON-165 NASHVILLE-54	CARTHAGE-66 CASTALIAN SPRNG-62 GALLATIN-261 HARTSVILLE-264 HENDERSONVILLE-91 LAFAYETTE-108 LEBANON-197 NASHVILLE-81
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	56(30%)	110(31%)	228(25%)	335(28%)	489(31%)
RENTED	24(13%)	53(15%)	159(17%)	229(19%)	289(18%)
TOTAL	80 (43%)	163 (45%)	387 (43%)	564 (46%)	778 (49%)
M. HOME BOUGHT	22(12%)	44(12%)	96(11%)	122(10%)	162(10%)
RENTED	20(11%)	36(10%)	95(10%)	132(11%)	182(11%)
TOTAL	42 (23%)	80 (22%)	191 (21%)	254 (21%)	344 (21%)
APARTMENT	35 (19%)	59 (16%)	173 (19%)	201 (17%)	251 (16%)
OTHER	29 (15%)	57 (16%)	153 (17%)	196 (16%)	215 (14%)
GRAND TOTAL	188(100%)	360(100%)	910(100%)	1251(100%)	1588(100%)
MOVERS					
WITH FAMILIES	108(57%)	218(61%)	554(61%)	786(65%)	1093(69%)
WITHOUT FAMILIES	79(42%)	141(39%)	356(39%)	430(35%)	495(31%)
CHILDREN					
SCHOOL-AGE	73	149	406	622	828
NUMBER PER FAMILY	0.7	0.7	0.7	0.8	0.8
TOTAL	124	260	665	973	1374
NUMBER PER FAMILY	1.1	1.2	1.2	1.2	1.3

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	HARTSVILLE MAR 1979	HARTSVILLE SEPT 1979	HARTSVILLE MAR 1980	HARTSVILLE SEPT 1980	HARTSVILLE MAR 1981
TOTAL EMPLOYEES	6600	6340	5440	5140	5255
EMPLOYEES SURVEYED	6300	6100	5290	4980	5110
EXPECTED PEAK	6800	6800	6800	6800	6800
TOTAL MOVERS					
NUMBER	2000	1950	1744	1709	1762
% TOTAL EMPLOYMENT	31	31	32	33	34
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CARTHAGE-93 CASTALIAN SPRNG-65 GALLATIN-326 HARTSVILLE-350 HENDERSONVILLE-102 LAFAYETTE-129 LEBANON-242 NASHVILLE-87	CARTHAGE-81 GALLATIN-337 HARTSVILLE-312 HENDERSONVILLE-81 LAFAYETTE-143 LEBANON-231 NASHVILLE-77 DIXON SPRINGS-73	CARTHAGE-76 CASTALIAN SPRNG-62 GALLATIN-310 HARTSVILLE-270 HENDERSONVILLE-77 LAFAYETTE-125 LEBANON-200 DIXON SPRINGS-73	CARTHAGE-63 CASTALIAN SPRNG-54 GALLATIN-309 HARTSVILLE-268 HENDERSONVILLE-79 LAFAYETTE-129 LEBANON-187 DIXON SPRINGS-53	CARTHAGE-64 CASTALIAN SPRNG-58 GALLATIN-305 HARTSVILLE-254 HENDERSONVILLE-80 LAFAYETTE-141 LEBANON-186 DIXON SPRINGS-57
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	588(29%)	635(32%)	633(36%)	651(38%)	675(38%)
RENTED	377(19%)	365(19%)	346(20%)	343(20%)	354(20%)
TOTAL	965 (48%)	1000 (51%)	979 (56%)	994 (58%)	1029 (58%)
M. HOME BOUGHT	222(11%)	246(13%)	238(14%)	227(13%)	234(13%)
RENTED	229(12%)	218(11%)	154 (9%)	131 (8%)	126 (7%)
TOTAL	451 (23%)	464 (24%)	392 (23%)	358 (21%)	360 (20%)
APARTMENT	319 (16%)	297 (15%)	235 (13%)	231 (14%)	227 (13%)
OTHER	268 (13%)	189 (10%)	138 (8%)	126 (7%)	145 (8%)
GRAND TOTAL	2003(100%)	1950(100%)	1744(100%)	1709(100%)	1761(100%)
MOVERS					
WITH FAMILIES	1390(69%)	1428(73%)	1344(76%)	1309(77%)	1350(77%)
WITHOUT FAMILIES	613(31%)	522(27%)	410(24%)	400(23%)	412(23%)
CHILDREN					
SCHOOL-AGE	1089	1217	1195	1231	1325
NUMBER PER FAMILY	0.8	0.9	0.9	0.9	1.0
TOTAL	1749	1847	1805	1838	1958
NUMBER PER FAMILY	1.3	1.3	1.4	1.4	1.5

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	HARTSVILLE SEPT 1981		HARTSVILLE NOV 1982	
TOTAL EMPLOYEES	4360		650	
EMPLOYEES SURVEYED	4219		580	
EXPECTED PEAK	6800		6800	
TOTAL MOVERS				
NUMBER	1419		198	
% TOTAL EMPLOYMENT	33		30	
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CARTHAGE-50 CASTALIAN SPRNG-51 GALLATIN-252 HARTSVILLE-193 HENDERSONVILLE-62 LAFAYETTE-122 LEBANON-156 DIXON SPRINGS-46		CARTHAGE-9 CASTALIAN SPRNG-10 GALLATIN-40 HARTSVILLE-38 HENDERSONVILLE-10 LAFAYETTE-15 LEBANON-23	
HOUSING TYPE SELECTED				
HOUSE-BOUGHT	615(43%)		85(40%)	
RENTED	287(20%)		40(20%)	
TOTAL		902 (63%)		125 (63%)
M. HOME BOUGHT	195(14%)		35(18%)	
RENTED	73 (5%)		9 (5%)	
TOTAL		268 (19%)		44 (23%)
APARTMENT		167 (12%)		15 (7%)
OTHER		82 (6%)		15 (7%)
GRAND TOTAL		1419(100%)		198(100%)
MOVERS				
WITH FAMILIES	1134(80%)		157(79%)	
WITHOUT FAMILIES	285(20%)		41(21%)	
CHILDREN				
SCHOOL-AGE	1168		141	
NUMBER PER FAMILY	1.0		0.9	
TOTAL	1688		202	
NUMBER PER FAMILY	1.5		1.3	

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	PHIPPS BEND MAY 1978	PHIPPS BEND NOV 1978	PHIPPS BEND MAY 1979	PHIPPS BEND NOV 1979	PHIPPS BEND MAY 1980
TOTAL EMPLOYEES	1100	1600	2000	2710	3350
EMPLOYEES SURVEYED	830	1200	1600	2070	2730
EXPECTED PEAK	3600	3600	3600	3600	3600
TOTAL MOVERS					
NUMBER	124	267	373	528	652
% TOTAL EMPLOYMENT	11	16	19	19	19
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CHURCH HILL-16 KINGSPORT-36 ROGERSVILLE-21 SURGOINSVILLE-24	CHURCH HILL-46 KINGSPORT-63 ROGERSVILLE-43 SURGOINSVILLE-35 MOUNT CARMEL-16	CHURCH HILL-67 KINGSPORT-74 ROGERSVILLE-71 SURGOINSVILLE-54 MOUNT CARMEL-19 JONESBORO-12	CHURCH HILL-97 KINGSPORT-106 ROGERSVILLE-96 SURGOINSVILLE-68 MOUNT CARMEL-28 JONESBORO-13 MORRISTOWN-13	CHURCH HILL-123 JOHNSON CITY-16 KINGSPORT-129 ROGERSVILLE-113 SURGOINSVILLE-88 MOUNT CARMEL-32 JONESBORO-15 MORRISTOWN-25
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	40(32%)	97(36%)	133(36%)	197(37%)	222(34%)
RENTED	20(16%)	43(16%)	71(19%)	105(20%)	141(21%)
TOTAL	60 (48%)	140 (52%)	204 (55%)	302 (57%)	363 (55%)
M. HOME BOUGHT	16(13%)	35(13%)	44(12%)	60(12%)	73(11%)
RENTED	12(10%)	18 (7%)	29 (8%)	49 (9%)	75(12%)
TOTAL	28 (23%)	53 (20%)	73 (19%)	109 (21%)	148 (23%)
APARTMENT	19 (15%)	55 (21%)	71 (19%)	89 (17%)	109 (17%)
OTHER	17 (13%)	19 (7%)	25 (7%)	28 (5%)	32 (5%)
GRAND TOTAL	124(100%)	267(100%)	373(100%)	528(100%)	652(100%)
MOVERS					
WITH FAMILIES	85(69%)	195(73%)	261(70%)	380(72%)	463(71%)
WITHOUT FAMILIES	39(31%)	72(27%)	112(30%)	148(28%)	189(29%)
CHILDREN					
SCHOOL-AGE	52	119	168	277	364
NUMBER PER FAMILY	0.6	0.6	0.6	0.7	0.8
TOTAL	79	200	276	436	574
NUMBER PER FAMILY	0.9	1.0	1.1	1.1	1.2

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	PHIPPS BEND NOV 1980	PHIPPS BEND MAY 1981	PHIPPS BEND SEPT 1981	PHIPPS BEND DEC 1981	PHIPPS BEND SEPT 1982
TOTAL EMPLOYEES	3250	3440	2061	671	227
EMPLOYEES SURVEYED	2780	2920	1838	582	164
EXPECTED PEAK	3600	3600	3600	3600	3600
TOTAL MOVERS					
NUMBER	652	715	423	148	64
% TOTAL EMPLOYMENT	20	21	21	22	28
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CHURCH HILL-113 KINGSPORT-110 ROGERSVILLE-107 SURGOINSVILLE-97 MOUNT CARMEL-34 MORRISTOWN-25 JOHNSON CITY-21	CHURCH HILL-125 KINGSPORT-123 ROGERSVILLE-128 SURGOINSVILLE-83 MOUNT CARMEL-43 MORRISTOWN-28 JOHNSON CITY-21	CHURCH HILL-71 KINGSPORT-78 ROGERSVILLE-63 SURGOINSVILLE-45 MOUNT CARMEL-31 MORRISTOWN-19 JOHNSON CITY-12	CHURCH HILL-31 KINGSPORT-20 ROGERSVILLE-27 SURGOINSVILLE-16 MOUNT CARMEL-14	CHURCH HILL-14 KINGSPORT-10 ROGERSVILLE-11 SURGOINSVILLE-7 MOUNT CARMEL-7
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	229(35%)	260(36%)	173(41%)	75(51%)	35(54%)
RENTED	136(21%)	144(20%)	76(18%)	22(15%)	11(17%)
TOTAL	365 (56%)	404 (56%)	249 (59%)	97 (66%)	46 (72%)
M. HOME BOUGHT	75(11%)	85(12%)	55(13%)	23(16%)	10(15%)
RENTED	80(12%)	76(11%)	30 (7%)	8 (5%)	1 (2%)
TOTAL	155 (23%)	161 (23%)	85 (20%)	31 (21%)	11 (17%)
APARTMENT	100 (15%)	115 (16%)	73 (17%)	17 (12%)	6 (9%)
OTHER	32 (5%)	35 (5%)	16 (4%)	2 (2%)	1 (2%)
GRAND TOTAL	652(100%)	715(100%)	423(100%)	148(100%)	64(100%)
MOVERS					
WITH FAMILIES	474(73%)	516(72%)	322(76%)	123(84%)	50(78%)
WITHOUT FAMILIES	178(27%)	198(28%)	101(24%)	24(16%)	14(22%)
CHILDREN					
SCHOOL-AGE	353	459	272	103	46
NUMBER PER FAMILY	0.9	0.9	0.8	0.8	0.9
TOTAL	634	670	390	148	57
NUMBER PER FAMILY	1.3	1.3	1.2	1.2	1.1

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	YELLOW CREEK JUNE 1978	YELLOW CREEK DEC 1978	YELLOW CREEK JUNE 1979	YELLOW CREEK DEC 1979	YELLOW CREEK JUN 1980
TOTAL EMPLOYEES	980	1668	2140	2830	3060
EMPLOYEES SURVEYED	760	1100	1590	2040	2211
EXPECTED PEAK	4300	4300	4300	4300	4300
TOTAL MOVERS					
NUMBER	158	301	406	492	540
% TOTAL EMPLOYMENT	16	18	19	17	18
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	FLORENCE-16 SHEFFIELD-6 CORINTH-10 IUKA-72 SAVANNAH-11	FLORENCE-23 SHEFFIELD-8 TUSCUMBIA-18 BURNSVILLE-10 CORINTH-26 IUKA-108 SAVANNAH-23 COUNCE-11	FLORENCE-31 MUSCLE SHOALS-12 TUSCUMBIA-22 BOONEVILLE-12 CORINTH-64 IUKA-135 SAVANNAH-34 COUNCE-11	CHEROKEE-17 FLORENCE-62 MUSCLE SHOALS-22 SHEFFIELD-28 TUSCUMBIA-26 CORINTH-54 IUKA-175 SAVANNAH-50	FLORENCE-43 MUSCLE SHOALS-22 SHEFFIELD-22 TUSCUMBIA-22 CORINTH-66 IUKA-163 SAVANNAH-36 COUNCE-21
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	32(21%)	95(32%)	147(36%)	211(34%)	173(32%)
RENTED	34(21%)	59(20%)	77(19%)	126(21%)	125(23%)
TOTAL	66 (42%)	154 (52%)	224 (55%)	337 (55%)	298 (55%)
M. HOME BOUGHT	35(22%)	55(18%)	75(19%)	121(20%)	104(19%)
RENTED	18(12%)	30(10%)	40(10%)	54 (9%)	35 (6%)
TOTAL	53 (34%)	85 (28%)	115 (29%)	175 (29%)	139 (25%)
APARTMENT	21 (13%)	38 (12%)	39 (10%)	54 (9%)	61 (11%)
OTHER	18 (11%)	25 (8%)	26 (6%)	48 (7%)	42 (8%)
GRAND TOTAL	158(100%)	301(100%)	406(100%)	492(100%)	560(100%)
MOVERS					
WITH FAMILIES	96(61%)	186(62%)	299(72%)	347(70%)	381(71%)
WITHOUT FAMILIES	62(39%)	115(38%)	112(28%)	145(30%)	159(29%)
CHILDREN					
SCHOOL-AGE	73	159	280	326	360
NUMBER PER FAMILY	0.8	0.9	1.0	0.9	0.9
TOTAL	105	263	417	506	518
NUMBER PER FAMILY	1.1	1.4	1.4	1.5	1.4

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	YELLOW CREEK DEC 1980	YELLOW CREEK JUN 1981	YELLOW CREEK NOV 1982
TOTAL EMPLOYEES	3002	3700	266
EMPLOYEES SURVEYED	2350	2467	174
EXPECTED PEAK	4300	4300	4300
TOTAL MOVERS			
NUMBER	539	658	61
% TOTAL EMPLOYMENT	18	18	23
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	FLORENCE-45 MUSCLE SHOALS-24 SHEFFIELD-31 TUSCUMBIA-22 CORINTH-49 IUKA-158 SAVANNAH-33 COUNCE-20	FLORENCE-55 MUSCLE SHOALS-34 SHEFFIELD-33 TUSCUMBIA-30 CORINTH-60 IUKA-197 SAVANNAH-40 COUNCE-25	FLORENCE-5 CORINTH-8 IUKA-20 BURNSVILLE-8
HOUSING TYPE SELECTED			
HOUSE-BOUGHT	184(34%)	224(34%)	35(58%)
RENTED	120(22%)	144(22%)	11(18%)
TOTAL	304 (56%)	368 (56%)	46 (75%)
M. HOME BOUGHT	98(18%)	123(19%)	5 (8%)
RENTED	34 (6%)	49 (8%)	2 (3%)
TOTAL	133 (25%)	172 (27%)	7 (11%)
APARTMENT	69 (13%)	79 (12%)	8 (12%)
OTHER	33 (6%)	39 (6%)	2 (2%)
GRAND TOTAL	539(100%)	658(100%)	61(100%)
MOVERS			
WITH FAMILIES	399(74%)	478(73%)	40(66%)
WITHOUT FAMILIES	141(26%)	179(23%)	21(34%)
CHILDREN			
SCHOOL-AGE	386	457	37
NUMBER PER FAMILY	1.0	1.0	0.9
TOTAL	541	628	50
NUMBER PER FAMILY	1.4	1.3	1.3

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

APPENDIX D

Comparison of Operational Employee Surveys*

*Table contains extrapolated survey results.

COMPARISON OF TVA OPERATIONAL EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	WATTS BAR JAN 1981	WATTS BAR JULY 1982	WATTS BAR APRIL 1984	WATTS BAR JULY 1986
TOTAL EMPLOYEES	554	742	1015	1022
EMPLOYEES SURVEYED	300	583	777	693
TOTAL MOVERS				
NUMBER	314	371	448	445
% TOTAL EMPLOYMENT	57	50	44	44
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	ATHENS-48 DAYTON-48 SPRING CITY-63	ATHENS-54 DAYTON-44 SPRING CITY-69 KINGSTON-24	ATHENS-61 DAYTON-50 DECATUR-27 KINGSTON-24 SPRING CITY-98 SWEETWATER-20	ATHENS-52 DAYTON-34 EVENSVILLE-22 KINGSTON-28 KNOXVILLE-31 SPRING CITY-100 SWEETWATER-21 TEN MILE-18
HOUSING TYPE SELECTED				
HOUSE-BOUGHT	196(62%)	189(51%)	244(55%)	266(60%)
RENTED	33(11%)	76(20%)	81(18%)	63(14%)
TOTAL	229 (73%)	265 (71%)	325 (73%)	329 (74%)
M. HOME BOUGHT	31(10%)	32 (9%)	34 (8%)	43(10%)
RENTED	6 (2%)	4 (1%)	8 (2%)	7 (2%)
TOTAL	37 (12%)	36 (10%)	42 (10%)	50 (12%)
APARTMENT	42 (13%)	57 (15%)	63 (14%)	47 (11%)
OTHER	6 (2%)	13 (4%)	18 (4%)	19 (4%)
GRAND TOTAL	314(100%)	371(100%)	448(100%)	445(100%)
MOVERS				
WITH FAMILIES	240(76%)	283(76%)	351(78%)	355(80%)
WITHOUT FAMILIES	74(24%)	88(24%)	97(22%)	90(20%)
CHILDREN				
SCHOOL-AGE	218	263	343	332
NUMBER PER FAMILY	0.9	0.9	1.0	0.9
TOTAL	355	399	483	492
NUMBER PER FAMILY	1.5	1.4	1.4	1.4

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA OPERATIONAL EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	SEQUOYAH JAN 1981	BELLEFONTE JAN 1981	BELLEFONTE JUNE 1982	BELLEFONTE APRIL 1984	BELLEFONTE JULY 1986
TOTAL EMPLOYEES	1327	114	392	413	162
EMPLOYEES SURVEYED	306	114	292	298	100
TOTAL MOVERS					
NUMBER	532	60	220	227	68
% TOTAL EMPLOYMENT	40	53	56	55	42
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CHATTANOOGA-97 HIXSON-223 SODDY DAISY-126	SCOTTSBORO-37 HOLLYWOOD-4	SCOTTSBORO-134 HOLLYWOOD-17	SCOTTSBORO-150 HOLLYWOOD-10	SCOTTSBORO-39
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	359(68%)	40(67%)	102(46%)	122(54%)	47(69%)
RENTED	45 (8%)	12(20%)	58(27%)	47(21%)	10(14%)
TOTAL	404 (76%)	52 (87%)	160 (73%)	169 (74%)	57 (83%)
M. HOME BOUGHT	21 (4%)		14 (6%)	12 (6%)	8(12%)
RENTED	10 (2%)	2 (3%)	4 (2%)	3 (1%)	
TOTAL	31 (6%)	2 (3%)	18 (8%)	15 (7%)	8 (12%)
APARTMENT	73 (14%)	5 (8%)	39 (18%)	36 (16%)	3 (5%)
OTHER	24 (4%)	1 (2%)	3 (1%)	7 (3%)	
GRAND TOTAL	532(100%)	60(100%)	220(100%)	227(100%)	68(100%)
MOVERS					
WITH FAMILIES	430(81%)	55(92%)	169(77%)	184(81%)	62(90%)
WITHOUT FAMILIES	102(19%)	5 (8%)	51(23%)	43(19%)	6(10%)
CHILDREN					
SCHOOL-AGE	411	56	144	175	65
NUMBER PER FAMILY	1.0	1.0	0.9	0.9	1.1
TOTAL	611	78	244	259	91
NUMBER PER FAMILY	1.4	1.4	1.4	1.4	1.5

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

TABLE B-8
FOLLOW UP SURVEY
WORKERS WHO MOVED INTO WATTS BAR NUCLEAR PLANT AREA PAGE 003

SPRING CITY
EMPLOYEES LIVING WITHIN THE CITY LIMITS
OPERATIONAL EMPLOYEES 07-31-86

RUN DATE 10/06/86
REPORT 1A
RUN TIME 110939

	MOVERS WITH FAMILY	WITH CHILDREN IN SCHOOL	TOTAL NUMBER OF CHILDREN	CHILDREN IN GRADE SCHOOL	CHILDREN IN HIGH SCHOOL	MOVERS WITHOUT FAMILY	TOTAL MOVERS
ANNUAL EMPLOYEES							
HOUSE OWNED	7	6	23	9	2	0	7
HOUSE RENTED	2	2	3	3	0	0	2
APARTMENT RENTED	0	0	0	0	0	1	1
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL	0	0	0	0	0	2	2
OTHER							
TOTAL	9	8	26	12	2	3	12
HOURLY EMPLOYEES							
HOUSE OWNED	0	0	0	0	0	2	2
HOUSE RENTED	2	2	6	3	0	0	2
APARTMENT RENTED	0	0	0	0	0	1	1
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL							
OTHER							
TOTAL	2	2	6	3	0	3	5
ALL EMPLOYEES							
HOUSE OWNED	7	6	23	9	2	2	9
HOUSE RENTED	4	4	9	6	0	0	4
APARTMENT RENTED	0	0	0	0	0	2	2
MOBILE HOME RENTED							
MOBILE HOME OWNED							
SLEEPING ROOM							
MOTEL	0	0	0	0	0	2	2
OTHER							
TOTAL	11	10	32	15	2	6	17

APPENDIX C

Comparison of Construction Employee Surveys*

*Table contains extrapolated survey results.

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	PARADISE JAN 1968	CUMBERLAND SEPT 1968	CUMBERLAND SEPT 1969	CUMBERLAND MAY 1971	CUMBERLAND APRIL 1973
TOTAL EMPLOYEES	2000	564	1450	2900	725
EMPLOYEES SURVEYED	2000	564	1100	1500	625
EXPECTED PEAK	2000	2900	2900	2900	2900
TOTAL MOVERS					
NUMBER	643	158	435	1035	340
% TOTAL EMPLOYMENT	32	29	30	36	47
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	DRAKESBORO CENTRAL CITY GREENVILLE MADISONVILLE	ERIN-66 CLARKSVILLE-22 CUMBERLAND CTY-31 TENNESSEE RDG-16 WAVERLY-11	ERIN-140 CLARKSVILLE-69 CUMBERLAND CTY-97 TENNESSEE RDG-31 WAVERLY-23	ERIN-294 CLARKSVILLE-212 CUMBERLAND CTY-230 TENNESSEE RDG-76 WAVERLY-51 DOVER-41	ERIN-99 CLARKSVILLE-69 CUMBERLAND CTY-76 TENNESSEE RDG-28 WAVERLY-13 DOVER-12
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	36 (5%)	25(16%)	65(15%)	155(15%)	75(22%)
RENTED	181(28%)	50(32%)	144(33%)	300(29%)	75(22%)
TOTAL	215 (33%)	75 (48%)	209 (48%)	455 (44%)	150 (44%)
M. HOME BOUGHT	66(10%)	23(14%)	100(23%)	228(22%)	78(23%)
RENTED	55 (9%)	11 (7%)	30 (7%)	155(15%)	45(13%)
TOTAL	121 (19%)	34 (21%)	130 (30%)	383 (37%)	123 (36%)
APARTMENT	113 (18%)	10 (6%)	26 (6%)	73 (7%)	36 (11%)
OTHER	194 (30%)	39 (25%)	70 (16%)	124 (12%)	31 (9%)
GRAND TOTAL	643(100%)	158(100%)	435(100%)	1035(100%)	340(100%)
MOVERS					
WITH FAMILIES	317(49%)	90(57%)	296(68%)	683(66%)	224(66%)
WITHOUT FAMILIES	326(51%)	68(43%)	139(32%)	352(34%)	116(34%)
CHILDREN					
SCHOOL-AGE	410	94	330	668	147
NUMBER PER FAMILY	1.3	1.0	1.1	1.0	0.6
TOTAL	NA	NA	477	982	251
NUMBER PER FAMILY	NA	NA	1.6	1.4	1.1

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	SEQUOYAH OCT 1970	SEQUOYAH JULY 1972	SEQUOYAH AUG 1974	SEQUOYAH FEB 1977	SEQUOYAH SEPT 1978
TOTAL EMPLOYEES	1100	2200	1600	2800	3900
EMPLOYEES SURVEYED	847	1477	1300	1900	3000
EXPECTED PEAK	4100	4100	4100	4100	4100
TOTAL MOVERS					
NUMBER	187	513	474	1142	1689
% TOTAL EMPLOYMENT	17	23	30	41	43
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CHATTANOOGA-29 HIXSON-65 SODDY-DAISY-83	CHATTANOOGA-73 HIXSON-113 RED BANK-15 SODDY-DAISY-216	CHATTANOOGA-63 DAYTON-12 HIXSON-107 RED BANK-21 SODDY-DAISY-192	CHATTANOOGA-221 DAYTON-25 HIXSON-360 RED BANK-113 SODDY-DAISY-312	CHATTANOOGA-336 DAYTON-29 HIXSON-488 RED BANK-139 SODDY-DAISY-593
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	56(30%)	95(19%)	128(27%)	296(26%)	504(30%)
RENTED	28(15%)	76(14%)	48(10%)	135(12%)	203(12%)
TOTAL	84 (45%)	171 (33%)	176 (37%)	431 (38%)	707 (42%)
M. HOME BOUGHT	46(25%)	130(25%)	130(28%)	159(14%)	194(12%)
RENTED	25(13%)	102(20%)	59(12%)	176(15%)	302(18%)
TOTAL	71 (38%)	232 (45%)	189 (40%)	335 (29%)	496 (30%)
APARTMENT	30 (16%)	77 (15%)	84 (18%)	213 (31%)	427 (25%)
OTHER	2 (1%)	33 (7%)	25 (5%)	20 (2%)	59 (3%)
GRAND TOTAL	187(100%)	513(100%)	474(100%)	1142(100%)	1689(100%)
MOVERS					
WITH FAMILIES	138(73%)	376(73%)	349(74%)	784(69%)	1180(70%)
WITHOUT FAMILIES	49(27%)	137(27%)	125(26%)	358(31%)	509(30%)
CHILDREN					
SCHOOL-AGE	104	276	216	586	1006
NUMBER PER FAMILY	0.8	0.7	0.6	0.7	0.9
TOTAL	169	459	365	1040	1568
NUMBER PER FAMILY	1.2	1.2	1.0	1.3	1.3

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	SEQUOYAH JAN 1981	SEQUOYAH JUNE 1982	BROWNS FERRY OCT 1969	BROWNS FERRY APRIL 1971	BROWNS FERRY JULY 1973
TOTAL EMPLOYEES	1548	768	2500	3200	2100
EMPLOYEES SURVEYED	731	542	1700	2500	1800
EXPECTED PEAK	4100	4100	3200	3200	3200
TOTAL MOVERS					
NUMBER	494	180	425	795	410
% TOTAL EMPLOYMENT	32	23	17	25	20
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	CHATTANOOGA-78 HIXSON-178 RED BANK-17 SODDY-DAISY-110	CHATTANOOGA-27 HIXSON-43 SODDY DAISY-37	ATHENS-225 DECATUR-46 TANNER-31 HUNTSVILLE-16 ROGERSVILLE-12 FLORENCE-10 MOULTON-10	ATHENS-436 DECATUR-130 TANNER-45 HUNTSVILLE-34 ROGERSVILLE-19 FLORENCE-18 KILLEN-10	ATHENS-154 DECATUR-67 TANNER-20 HUNTSVILLE-24 ROGERSVILLE-14 FLORENCE-19 KILLEN-16 TUSCUMBIA-13
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	265(54%)	102(57%)	81(19%)	100(13%)	172(42%)
RENTED	64(13%)	24(13%)	157(37%)	146(18%)	93(23%)
TOTAL	329 (67%)	126 (70%)	238 (56%)	246 (31%)	265 (65%)
M. HOME BOUGHT	61(12%)	23(13%)	68(16%)	155(19%)	83(20%)
RENTED	15 (3%)	4 (2%)	43(10%)	157(20%)	22 (5%)
TOTAL	76 (15%)	27 (15%)	111 (26%)	312 (39%)	105 (25%)
APARTMENT	59 (12%)	14 (8%)	51 (12%)	116 (15%)	25 (6%)
OTHER	30 (6%)	13 (7%)	25 (6%)	121 (15%)	15 (4%)
GRAND TOTAL	494(100%)	180(100%)	425(100%)	795(100%)	410(100%)
MOVERS					
WITH FAMILIES	375(76%)	146(81%)	340(80%)	506(64%)	347(85%)
WITHOUT FAMILIES	119(24%)	34(19%)	85(20%)	289(36%)	63(15%)
CHILDREN					
SCHOOL-AGE	290	135	294	384	223
NUMBER PER FAMILY	0.8	0.9	0.9	0.8	0.6
TOTAL	506	194	477	709	407
NUMBER PER FAMILY	1.4	1.3	1.4	1.4	1.2

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	WATTS BAR MARCH 1973	WATTS BAR JULY 1974	WATTS BAR MAY 1976	WATTS BAR OCT 1977	WATTS BAR JAN 1981
TOTAL EMPLOYEES	475	1700	2800	3429	2550
EMPLOYEES SURVEYED	400	1500	2500	3129	1831
EXPECTED PEAK	3900	3900	3900	3900	3900
TOTAL MOVERS					
NUMBER	95	420	860	1070	785
% TOTAL EMPLOYMENT	20	25	31	31	31
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	SPRING CITY-35 DECATUR-12	SPRING CITY-147 TEN MILE-44 KINGSTON-35 DECATUR-29 ATHENS-27 HARRIMAN-18 DAYTON-16	SPRING CITY-253 ATHENS-87 DECATUR-84 TEN MILE-63 KINGSTON-60 DAYTON-45 SWEETWATER-34 HARRIMAN-29	SPRING CITY-318 DECATUR-111 ATHENS-102 TEN MILE-94 DAYTON-67 KINGSTON-66 SWEETWATER-64 ROCKWOOD-33	SPRING CITY-157 DECATUR-57 ATHENS-53 ROCKWOOD-50 TEN MILE-50 KINGSTON-46 DAYTON-42 SWEETWATER-39
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	25(26%)	122(29%)	233(27%)	310(29%)	303(39%)
RENTED	14(14%)	61(15%)	122(14%)	151(14%)	152(19%)
TOTAL	39 (40%)	183 (44%)	355 (41%)	461 (43%)	455 (58%)
M. HOME BOUGHT	21(22%)	109(26%)	165(19%)	160(15%)	104(13%)
RENTED	22(23%)	67(16%)	151(18%)	216(20%)	50(6%)
TOTAL	43 (45%)	176 (42%)	316 (37%)	376 (35%)	154 (19%)
APARTMENT	5 (6%)	40 (9%)	140 (16%)	151 (14%)	96 (12%)
OTHER	8 (9%)	21 (5%)	49 (6%)	82 (8%)	79 (12%)
GRAND TOTAL	95(100%)	420(100%)	860(100%)	1070(100%)	784(100%)
MOVERS					
WITH FAMILIES	66(70%)	311(74%)	592(69%)	686(64%)	567(72%)
WITHOUT FAMILIES	29(30%)	109(26%)	268(31%)	384(36%)	218(28%)
CHILDREN					
SCHOOL-AGE	27	191	439	590	490
NUMBER PER FAMILY	0.4	0.6	0.7	0.9	0.9
TOTAL	55	345	763	861	746
NUMBER PER FAMILY	0.8	1.1	1.3	1.3	1.3

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	WATTS BAR JULY 1982	WATTS BAR APRIL 1984	WATTS BAR JULY 1986
TOTAL EMPLOYEES	3900	3150	2103
EMPLOYEES SURVEYED	2579	2635	1196
EXPECTED PEAK	3900	3900	3900
TOTAL MOVERS			
NUMBER	1388	1251	758
% TOTAL EMPLOYMENT	36	40	36
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	SPRING CITY-311 DECATUR-138 TEN MILE-113 ATHENS-101 DAYTON-85 KINGSTON-62 ROCKWOOD-60 KNOXVILLE-48	SPRING CITY-282 DECATUR-90 ATHENS-88 TEN MILE-85 DAYTON-80 KINGSTON-65 KNOXVILLE-54 SWEETWATER-47	SPRING CITY-158 DECATUR-46 ATHENS-62 TEN MILE-46 DAYTON-53 KINGSTON-51 KNOXVILLE-51 ROCKWOOD-46
HOUSING TYPE SELECTED			
HOUSE-BOUGHT	414(30%)	405(32%)	338(45%)
RENTED	299(22%)	280(22%)	151(20%)
TOTAL	713 (52%)	685 (54%)	489 (65%)
M. HOME BOUGHT	175(13%)	168(13%)	79(10%)
RENTED	184(13%)	125(10%)	37 (5%)
TOTAL	359 (26%)	293 (23%)	116 (15%)
APARTMENT	189 (14%)	166 (13%)	88 (12%)
OTHER	125 (9%)	106 (9%)	65 (9%)
GRAND TOTAL	1388(100%)	1251(100%)	758(100%)
MOVERS			
WITH FAMILIES	898(65%)	846(68%)	572(75%)
WITHOUT FAMILIES	490(35%)	405(32%)	186(25%)
CHILDREN			
SCHOOL-AGE	836	827	543
NUMBER PER FAMILY	0.9	1.0	1.0
TOTAL	1187	1142	728
NUMBER PER FAMILY	1.3	1.4	1.3

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

COMPARISON OF TVA CONSTRUCTION EMPLOYEE SURVEYS

PROJECT NAME DATE OF SURVEY	BELLEFONTE APRIL 1975	BELLEFONTE MAY 1976	BELLEFONTE AUG 1977	BELLEFONTE MAY 1978	BELLEFONTE JAN 1981
TOTAL EMPLOYEES	900	2200	3500	3980	4111
EMPLOYEES SURVEYED	650	1350	2100	3255	2461
EXPECTED PEAK	4200	4200	4200	4200	4200
TOTAL MOVERS					
NUMBER	279	736	1167	1168	1383
% TOTAL EMPLOYMENT	31	33	34	29	34
PRIMARY TOWNS IMPACTED AND NUMBER OF EMPLOYEES MOVING THERE	SCOTTSBORO-167 HOLLYWOOD-34 HUNTSVILLE-15 STEVENSON-10	SCOTTSBORO-433 HOLLYWOOD-89 HUNTSVILLE-37 DUTTON-23 SECTION-18 GUNTERSVILLE-13 BRIDGEPORT-11 STEVENSON-10	SCOTTSBORO-636 HOLLYWOOD-127 HUNTSVILLE-67 SECTION-30 STEVENSON-30 CHATTANOOGA-23	SCOTTSBORO-604 HOLLYWOOD-132 HUNTSVILLE-78 SECTION-37 STEVENSON-35 GUNTERSVILLE-20	SCOTTSBORO-610 HOLLYWOOD-109 HUNTSVILLE-63 STEVENSON-38 SECTION-35 GUNTERSVILLE-28 DUTTON-27
HOUSING TYPE SELECTED					
HOUSE-BOUGHT	30(11%)	158(22%)	269(23%)	279(24%)	429(31%)
RENTED	51(18%)	112(15%)	157(13%)	165(14%)	286(21%)
TOTAL	81 (29%)	270 (37%)	426 (36%)	444 (38%)	715 (52%)
M. HOME BOUGHT	71(25%)	177(24%)	302(26%)	275(24%)	234(17%)
RENTED	66(24%)	155(21%)	196(17%)	210(18%)	124 (9%)
TOTAL	137 (49%)	332 (45%)	498 (43%)	485 (42%)	358 (26%)
APARTMENT	40 (14%)	99 (13%)	196 (17%)	186 (16%)	155 (11%)
OTHER	21 (8%)	35 (5%)	47 (4%)	53 (4%)	155 (11%)
GRAND TOTAL	279(100%)	736(100%)	1167(100%)	1168(100%)	1383(100%)
MOVERS					
WITH FAMILIES	144(52%)	517(70%)	822(70%)	788(67%)	944(68%)
WITHOUT FAMILIES	135(48%)	219(30%)	345(30%)	380(33%)	439(32%)
CHILDREN					
SCHOOL-AGE	108	348	574	803	783
NUMBER PER FAMILY	0.8	0.7	0.7	1.0	0.8
TOTAL	184	670	991	1185	1159
NUMBER PER FAMILY	1.3	1.3	1.2	1.5	1.2

NOTE-COLUMNS MAY NOT SUM TO TOTAL DUE TO ROUNDING
NA-NOT AVAILABLE

September 1996

USER'S MANUAL FOR CORMIX: A HYDRODYNAMIC MIXING ZONE MODEL AND DECISION SUPPORT SYSTEM FOR POLLUTANT DISCHARGES INTO SURFACE WATERS

by

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Abstract

The Cornell Mixing Zone Expert System (CORMIX, Version 3.0 or higher) is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone -- including compliance with regulatory constraints--, but the system also predicts the behavior of the discharge plume at larger distances. The highly user-interactive CORMIX system is implemented on microcomputers (IBM-PC, or compatible), and consists of three integrated subsystems:

---CORMIX1 for submerged single port discharges,
---CORMIX2 for submerged multiport diffuser discharges,
---CORMIX3 for buoyant surface discharges.

While CORMIX was originally developed under the assumption of steady ambient conditions, Version 3.0 also allows application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, two post-processing models are linked to the CORMIX system, but can also be used independently. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, and FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments.

This user's manual gives a comprehensive description of the CORMIX system; it provides guidance for assembly and preparation of required input data for the three subsystems; it delineates ranges of applicability; it provides guidance for interpretation and graphical display of system output; and it illustrates practical system application through several case studies.

Acknowledgments

An earlier version of this user's manual covering the three separate CORMIX subsystems (Version 1.0) before they were integrated into a comprehensive single system was developed under support form the National Council of the Paper Industry for Air and Stream Improvement Inc. (NCASI) and was published as Technical Bulletin No. 624 of NCASI (Jirka and Hinton, 1992). With the permission of NCASI, that user's guide has up until recently also been distributed by the USEPA-Center for Environmental Assessment Modeling (CEAM), Athens, GA, as part of the modeling support for CORMIX.

With the completion of CORMIX Version 3.0 and its many new program features, the present revision and update of the user's manual has become necessary. This work was conducted at the DeFrees Hydraulics Laboratory, Cornell University, as a Cooperative Agreement with the United States Environmental Protection Agency. The authors would like to extend their appreciation to Dr. Hiranmay Biswas, Project Officer, for his guidance of the project.

Additional support for the development, testing and evaluation of CORMIX system elements was provided by the State of Delaware Department of Natural Resources (Mr. Rick Greene, Project Officer) during 1991, by the Austrian Verbundgesellschaft (Dr. Gerhard Schiller, Project Officer) during 1991/92, and by the State of Maryland Department of Natural Resources (Dr. Paul Miller, Project Officer) during 1992 to 1995.

Cameron Wilkens, Electronics Technician, in the DeFrees Hydraulics Laboratory, generously assisted with solutions for computer hardware and software problems.

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Glossary

Actual Water Depth (HD) - the actual water depth at the submerged discharge location. It is also called local water depth. For surface discharges it is the water depth at the channel entry location.

Alignment Angle (GAMMA) - the angle measured counterclockwise from the ambient current direction to the diffuser axis.

Allocated Impact Zone - see mixing zone.

Alternating Diffuser - a multi-port diffuser where the ports do not point in a nearly single horizontal direction.

Ambient Conditions - the geometric and dynamic characteristics of a receiving water body that impact mixing zone processes. These include plan shape, vertical cross sections, bathymetry, ambient velocity, and density distribution.

Ambient Currents - A velocity field within the receiving water which tends to deflect a buoyant jet into the current direction.

Ambient Discharge (QA) - the volumetric flow rate of the receiving water body.

Average Diameter (D0) - the average diameter of the discharge ports or nozzles for a multi-port diffuser.

Average Depth (HA) - the average depth of the receiving water body determined from the equivalent cross sectional area during schematization.

Bottom Slope (SLOPE) - the slope of the bottom that extends from a surface discharge into the receiving water body.

Buoyant Jet - a discharge where turbulent mixing is caused by a combination of initial momentum flux and buoyancy flux. It is also called a forced plume.

Buoyant Spreading Processes - far-field mixing processes which arise due to the buoyant forces caused by the density difference between the mixed flow and the ambient receiving water.

Buoyant Surface Discharge - the release of a positively or neutrally buoyant effluent into a receiving water through a canal, channel, or near-surface pipe.

Coanda Attachment - a dynamic interaction between the effluent plume and the water bottom that results from the entrainment demand of the effluent jet itself and is due to low pressure effects.

Cumulative Discharge - refers to the volumetric flow rate which occurs between the bank/shoreline and a given position within the water body.

Cumulative Discharge Method - an approach for representing transverse plume mixing in river or estuary flow by describing the plume centerline as being fixed on a line of constant cumulative discharge and by relating the plume width in terms of a cumulative discharge increment

Darcy-Weisbach Friction Factor - a measure of the roughness characteristics in a channel.

Deep Conditions - see near-field stability.

Density Stratification - the presence of a vertical density profile within the receiving water.

Diffuser Length (LD) - The distance between the first and last port of a multi-port diffuser line. See diffuser line.

Diffuser Line - a hypothetical line between the first and last ports of a multi-port diffuser.

Discharge Velocity (U0) - the average velocity of the effluent being discharged from the outfall structure.

Discharge from Shore (DISTB) - the average distance between the outfall location (or diffuser mid-point) and the shoreline. It is also specified as a cumulative ambient discharge divided by the product UA times HA.

Distance from Shore (YB1, YB2) - the distance from the shore line to the first and last ports of a multi-port diffuser.

Discharge Flow Rate (Q0) - the volumetric flow rate from the discharge structure.

Discharge Channel Width (B0) - the average width of a surface discharging channel.

Discharge Channel Depth (H0) - the average depth of a surface discharging channel.

Discharge Conditions - the geometric and flux characteristics of an outfall installation that effect mixing processes. These include port area, elevation above the bottom and orientation, effluent discharge flow rate, momentum flux, and buoyancy flux.

Far-field - the region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume.

Far-field Processes - physical mixing mechanisms that are dominated by the ambient receiving water conditions, particularly ambient current velocity and density differences between the mixed flow and the ambient receiving water.

FAST-CORMIX - a version of CORMIX data entry with short questions and without help sections; can be chosen in main menu; for advanced users.

Flow Classification - the process of identifying the most appropriate generic qualitative description of the discharge flow undergoing analysis. This is accomplished by examining known relationships between flow patterns and certain calculated physical parameters.

Flux Characteristics - the properties of effluent discharge flow rate, momentum flux and buoyancy flux for the effluent discharge.

Forced Plume - see buoyant jet.

Generic Flow Class - a qualitative description of a discharge flow situation that is based on known relationships between flow patterns and certain physical parameters.

Height of Port (H0) - the average distance between the bottom and the average nozzle centerline.

High Water Slack (HWS) - the time of tidal reversal nearest to MHW

Horizontal Angle (SIGMA) - the angle measured counterclockwise from the ambient current direction to the plane projection of the port center line.

Hydrodynamic Mixing Processes - the physical processes that determine the fate and distribution of effluent once it is discharged.

Input Data Sequence - a group of questions from one of four topical areas.

Intermediate-field Affects - induced flows in shallow waters which extend beyond the strictly near-field region of a multi-port diffuser.

Iteration Menu - the last menu (red panel) the user can choose after completion of a design case; allows iteration with different ambient/discharge/regulatory conditions.

Jet - see pure jet.

Laterally Bounded - refers to a water body which is constrained on both sides by banks such as rivers, streams, estuaries and other narrow water courses.

Laterally Unbounded - a water body which for practical purposes is constrained on at most one side. This would include discharges into wide lakes, wide estuaries and coastal areas.

Legal Mixing Zone (LMZ) - see regulatory mixing zone.

Length Scale - a dynamic measure of the relative influence of certain hydrodynamic processes on effluent mixing.

Length Scale Analysis - an approach which uses calculated measures of the relative influence of certain hydrodynamic processes to identify key aspects of a discharge flow so that a generic flow class can be identified.

Local Water Depth (HD) - see actual water depth.

Low Water Slack (LWS) - the time of tidal reversal nearest to MLW

Main Menu - the first menu (red panel) the user can choose from when entering CORMIX.

Manning's n - a measure of the roughness characteristics in a channel.

Maximum Tidal Velocity (Uamax) - the maximum velocity occurring within the tidal cycle

Mean Ambient Velocity (UA) - the average velocity of the receiving water body's flow.

Mean High Water (MLW) - the highest water level (averaged over many tidal cycles) in estuarine or coastal flows.

Mean Low Water (MLW) - the lowest water level (averaged over many tidal cycles) in estuarine or coastal flows.

Merging - the physical interaction of the discharge plumes from adjacent ports of a multi-port diffuser.

Mixing Zone - an administrative construct which defines a limited area or volume of the receiving water where the initial dilution of a discharge is allowed to occur. In practice, it may occur within the near-field or far-field of a hydrodynamic mixing process and therefore depends on source, ambient, and regulatory constraints.

Mixing Zone Regulations - The administrative construct that intends to prevent any harmful impact of a discharged effluent on the aquatic environment and its designated uses.

Momentum Jet - see pure jet.

Multi-port Diffuser - a structure with many closely spaced ports or nozzles that inject more than one buoyant jet into the ambient receiving water body.

Near-field - the region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of an effluent discharge.

Near-Field Region (NFR) - a term used in the CORMIX printout for describing the zone of strong initial mixing where the so called near-field processes occur. It is the region of the receiving water where outfall design conditions are most likely to have an impact on in-stream concentrations.

Near-field Stability - the amount of local recirculation and re-entrainment of already mixed water back into the buoyant jet region. Stable discharge conditions are associated with weak momentum and deep water and are also sometimes called deep water conditions. Unstable discharge conditions have localized recirculation patterns and are also called shallow water conditions.

Negative Buoyancy - the measure of the tendency of an effluent discharge to sink in a receiving water.

Non-buoyant Jet - see pure jet.

Open Format - data input which does not require precise placement of numerical values in fixed fields and which allows character strings to be entered in either upper or lower case letters.

Passive Ambient Diffusion Processes - far-field mixing processes which arise due to existing turbulence in the ambient receiving water flow.

Plume - see buoyant jet.

Positive Buoyancy - the measure of the tendency of an effluent discharge to rise in the receiving water.

Post-Processor - several options available within CORMIX (main menu or iteration menu) for additional computation or data display, including a graphics package, a near-field buoyant jet model, and a far-field plume delineator.

Pure Jet - a discharge where only the initial momentum flux in the form of a high velocity injection causes turbulent mixing. It is also called momentum jet or non-buoyant jet.

Pure Plume - a discharge where only the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing.

Pycnocline - a horizontal layer in the receiving water where a rapid density change occurs.

Pycnocline Height (HINT) - the average distance between the bottom and a horizontal layer in the receiving water body where a rapid density change occurs.

Region Of Interest (ROI) - a user defined region of the receiving water body where mixing conditions are to be analyzed.

Regulatory Mixing Zone (RMZ) - the region of the receiving water where mixing zone regulations are applied. It is sometimes referred to as the legal mixing zone.

Relative Orientation Angle (BETA) - the angle measured either clockwise or counterclockwise from the average plan projection of the port centerline to the nearest diffuser axis.

Schematization - the process of describing a receiving water body's actual geometry with a rectangular cross section.

Shallow Water Conditions - see near-field stability.

Stable Discharge - see near-field stability.

Staged Diffuser - a multi-port diffuser where all ports point in one direction, generally following the diffuser line.

Stagnant Conditions - the absence of ambient receiving water flow. A condition which rarely occurs in actual receiving water bodies.

Submerged Multi-port Diffuser - an effluent discharge structure with more than one efflux opening that is located substantially below the receiving water surface.

Submerged Single Port Discharge - an effluent discharge structure with a single efflux opening that is located substantially below the receiving water surface.

Surface Buoyant Jets - positively or neutrally buoyant effluent discharges occurring horizontally at the water surface from a latterly entering channel or pipe.

Surface Width (BS) - the equivalent average surface width of the receiving water body determined from the equivalent rectangular cross sectional area during schematization.

Tidal cycle - the variation of ambient water depth and velocity as a function of time occurring due to tidal (lunar and solar) influences.

Tidal period (PERIOD) - the duration of the tidal cycle (on average 12.4 hours).

Tidal reversal - the two instances in the tidal cycle when the ambient velocity reverses its direction.

Toxic Dilution Zone (TDZ) - the region of the receiving water where the concentration of a toxic chemical may exceed the acute effects concentration.

Unidirectional Diffuser - a multi-port diffuser with all ports pointing to one side of the diffuser line and all ports oriented more or less normally to the diffuser line.

Unstable Discharge - see near-field stability.

Vertical Angle (THETA) - the angle between the port centerline and the horizontal plane.

Wake Attachment - a dynamic interaction of the effluent plume with the bottom that is forced by the receiving water crossflow.

Zone of Initial Dilution - a term sometimes used to describe the mixing zone for the discharge of municipal wastewater into the coastal ocean, limited to the extent of near-field mixing processes.

Metric Conversion Factors for Dimensions Used in CORMIX

Length:	1 m	= 3.281 ft = 39.37 in = 0.0006214 mile
Velocity:	1 m/s	= 3.281 ft/s (fps) = 2.237 miles/hr (mph) = 1.943 knots
Discharge:	1 m^3/s	= 35.31 ft^3/s (cfs) = 22.82 million-gal/day (mgd)
Density:	1000 kg/m^3	= 62.43 lb/ft^3
Temperature:	°C	= (°F - 32.0) * 0.5556

I Introduction

The Cornell Mixing Zone Expert System (CORMIX) is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It was developed under several cooperative funding agreements between U.S. EPA and Cornell University during the period 1985-1995. It is a recommended analysis tool in key guidance documents (1,2,3) on the permitting of industrial, municipal, thermal, and other point source discharges to receiving waters. Although the system's major emphasis is on predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be judged, the system also predicts the behavior of the discharge plume at larger distances.

The highly user-interactive CORMIX system is implemented on IBM-DOS compatible microcomputers, utilizes a rule-based systems approach to data input and processing, and consists of three subsystems. These are: (a) CORMIX1 for the analysis of submerged single port discharges, (b) CORMIX2 for the analysis of submerged multiport diffuser discharges and (c) CORMIX3 for the analysis of buoyant surface discharges. Without specialized training in hydrodynamics, users can make detailed predictions of mixing zone conditions, check compliance with regulations and readily investigate the performance of alternative outfall designs. The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for the application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, several post-processing options are available. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments, and CMXGRAPH, a graphics package for plume plotting.

Several factors provided the original impetus for system development including: (a) the considerable complexity of mixing processes in the aquatic environment, resulting from the great diversity of discharge and site conditions and requiring advanced knowledge in a specialized field of hydrodynamics; (b) the failure of previously existing models (e.g. the U.S. EPA plume models (4) originally developed for municipal discharges in deep coastal waters) to adequately predict often routine discharge situations, especially for more shallow inland sites; (c) the issuance in 1985 by the U.S. EPA of additional guidelines (1) for the permitting of toxic aqueous discharges, placing yet another burden on both applicants and regulators in delineating special zones for the initial mixing of these substances; and (d) the availability of new computer methods, so-called expert systems, for making accessible to the user, within a simple personal computing environment, the expert's knowledge and experience in dealing with complex engineering problems.

Four separate publications (5,6,7,8) describe the scientific basis for the CORMIX system and demonstrate comparison and validation with field and laboratory data. The results of these works are summarized in the peer-reviewed literature (9,10,11,12,13,14,15, 16,17). The CORMIX systems approach and its performance relative to the earlier U.S. EPA plume models in the context of estuarine applications is also described in EPA's technical guidance manual for performing waste load allocations in estuaries (3).

EPA's established policy is to make the CORMIX system freely available to all potential users through its modeling software distribution facility at the U.S. EPA Center for Environmental Assessment Modeling (CEAM) in Athens, Georgia. Some of the CORMIX subsystems have been available to the industrial and regulatory user communities since December 1989 when distribution of CORMIX1 was commenced by Cornell University for the purpose of identifying subtle programming errors through application to actual mixing zone analysis problems by a controlled users group. After this testing was deemed complete, CEAM commenced the distribution of CORMIX1 in November 1990. A similar approach was used to introduce CORMIX2 which began CEAM distribution in October 1991. In 1992, CORMIX1, CORMIX2, and CORMIX3 were integrated a single program and distributed by USEPA-CEAM as CORMIX Version 2.1 as of 1993.

Additional development of the post-processor modules, including plume graphics, the jet-integral model, and the far-field locator, were added to the system and distributed as CORMIX Version 3.0 as of 1994.

This manual describes the operation of a revised version, including a special routine for unsteady tidal applications, denoted as CORMIX Version 3.1 that has been distributed by Cornell as of June 1995. A slightly updated Version 3.2 will be distributed by USEPA-CEAM as of September 1996.

The objectives of this user's guide are as follows: (a) to provide a comprehensive description of the CORMIX system; (b) to provide guidance for assembly and preparation of required input data for all three subsystems as well as the post-processor models; (c) to delineate ranges of applicability of the subsystems; (d) to provide guidance for the interpretation and graphical display of system output; and (e) to illustrate practical system application through several case studies.

This manual is organized to meet the informational needs of two distinctly different groups of readers: 1) personnel in environmental management positions desiring an overview of the CORMIX systems capabilities, and 2) technical staff needing assistance in actual applications. Chapter II provides a summary of the physical processes of effluent mixing, as well as an overview of the regulatory background and practice on mixing zone applications. The general features of the CORMIX system are explained in Chapter III including summaries of: (a) predictive capabilities and limitations, (b) overall system structure and method of processing information, (c) user interaction, and (d) individual computational elements. Detailed guidance on the preparation and entry of input data, as required by the three CORMIX subsystems, is given in Chapter IV. Chapter V provides a description of system output, containing descriptive, quantitative, and graphical information on the predicted effluent flow. Chapter VI describes the background, input and output features of the CORJET jet integral model and the far-field plume locator program FFLOCATR. The closing remarks in Chapter VII contain information on system availability and user support, and on possible future developments and enhancements.

Appendices to this guide present four case studies on the application of all three CORMIX subsystems and its post-processor models. These are adapted from actual situations and illustrate the complete input requirements and output capabilities of the system. In addition, some of the assumptions on data schematization, problem simplification, and output interpretation, and construction graphical displays are discussed in a context typical of many mixing zone model applications.

II Background: Mixing Processes and Mixing Zone Regulations

When performing design work and predictive studies on effluent discharge problems, it is important to clearly distinguish between the physical aspects of **hydrodynamic mixing processes** that determine the effluent fate and distribution, and the administrative construct of **mixing zone regulations** that intend to prevent any harmful impact of the effluent on the aquatic environment and associated uses.

2.1 Hydrodynamic Mixing Processes

The mixing behavior of any wastewater discharge is governed by the interplay of ambient conditions in the receiving water body and by the discharge characteristics.

The **ambient conditions** in the receiving water body, be it stream, river, lake, reservoir, estuary or coastal waters, are described by the water body's geometric and dynamic characteristics. Important geometric parameters include plan shape, vertical cross-sections, and bathymetry, especially in the discharge vicinity. Dynamic characteristics are given by the velocity and density distribution in the water body, again primarily in the discharge vicinity. In many cases, these conditions can be taken as steady-state with little variation because the time scale for the mixing processes is usually of the order of minutes up to perhaps one hour. In some cases, notably tidally influenced flows, the ambient conditions can be highly transient and the assumption of steady-state conditions may be inappropriate. In this case, the effective dilution of the discharge plume may be reduced relative to that under steady state conditions.

The **discharge conditions** relate to the geometric and flux characteristics of the submerged outfall installation. For a single port discharge the port diameter, its elevation above the bottom and its orientation provide the geometry; for multiport diffuser installations the arrangement of the individual ports along the diffuser line, the orientation of the diffuser line, and construction details represent additional geometric features; and for surface discharges the cross-section and orientation of the flow entering the ambient watercourse are important. The **flux characteristics** are given by the effluent discharge flow rate, by its momentum flux and by its buoyancy flux. The buoyancy flux represents the effect of the relative density difference between the effluent discharge and ambient conditions in combination with the gravitational acceleration. It is a measure of the tendency for the effluent flow to rise (i.e. **positive buoyancy**) or to fall (i.e. **negative buoyancy**).

The hydrodynamics of an effluent continuously discharging into a receiving water body can be conceptualized as a mixing process occurring in two separate regions. In the first region, the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influence the jet trajectory and mixing. This region will be referred to as the "**near-field**", and encompasses the buoyant jet flow and any surface, bottom or terminal layer interaction. In this near-field region, outfall designers can usually affect the initial mixing characteristics through appropriate manipulation of design variables.

As the turbulent plume travels further away from the source, the source characteristics become less important. Conditions existing in the ambient environment will control trajectory and dilution of the turbulent plume through buoyant spreading motions and passive diffusion due to ambient turbulence. This region will be referred to here as the "**far-field**". It is stressed at this point that the distinction between near-field and far-field is made purely on hydrodynamic grounds. It is unrelated to any regulatory mixing zone definitions.

2.1.1 Near-Field Processes

Three important types of near-field processes are submerged buoyant jet mixing, boundary interactions and surface buoyant jet mixing as described in the following paragraphs.

Submerged Buoyant Jet Mixing: The effluent flow from a submerged discharge port provides a velocity discontinuity between the discharged fluid and the ambient fluid causing an intense shearing action. The shearing flow breaks rapidly down into a turbulent motion. The width of the zone of high turbulence intensity increases in the direction of the flow by incorporating ("entraining") more of the outside, less turbulent fluid into this zone. In this manner, any internal concentrations (e.g. fluid momentum or pollutants) of the discharge flow become diluted by the entrainment of ambient water. Inversely, one can speak of the fact that both fluid momentum and pollutants become gradually diffused into the ambient field.

The initial velocity discontinuity may arise in different fashions. In a **"pure jet"** (also called "momentum jet" or "non-buoyant jet"), the initial momentum flux in the form of a high-velocity injection causes the turbulent mixing. In a **"pure plume,"** the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing. In the general case of a **"buoyant jet"** (also called a "forced plume"), a combination of initial momentum flux and buoyancy flux is responsible for turbulent mixing.

Thus, buoyant jets are characterized by a narrow turbulent fluid zone in which vigorous mixing takes place. Furthermore, depending on discharge orientation and direction of buoyant acceleration, curved trajectories are generally established in a stagnant uniform-density environment as illustrated in Figure 2.1a.

Buoyant jet mixing is further affected by ambient currents and density stratification. The role of **ambient currents** is to gradually deflect the buoyant jet into the current direction as illustrated in Figure 2.1b and thereby induce additional mixing. The role of ambient **density stratification** is to counteract the vertical acceleration within the buoyant jet leading ultimately to trapping of the flow at a certain level. Figure 2.1c shows a typical buoyant jet shape at the trapping or terminal level.

Finally, in case of multiport diffusers, the individual round buoyant jets behave independently until they interact, or merge, with each other at a certain distance from the efflux ports. After **merging**, a two-dimensional buoyant jet plane is formed as illustrated in Figure 2.1d. Such plane buoyant jets resulting from a multiport diffuser discharge in deep water can be further affected by ambient currents and by density stratification as discussed in the preceding paragraph.

Boundary Interaction Processes and Near-Field Stability: Ambient water bodies always have vertical boundaries. These include the water surface and the bottom, but in addition, "internal boundaries" may exist at pycnoclines. **Pycnoclines** are layers of rapid density change. Depending on the dynamic and geometric characteristics of the discharge flow, a variety of interaction phenomena can occur at such boundaries, particularly where flow trapping may occur.

In essence, boundary interaction processes provide a transition between the buoyant jet mixing process in the near-field, and between buoyant spreading and passive diffusion in the far-field. They can be gradual and mild, or abrupt leading to vigorous transition and mixing processes. They also can significantly influence the stability of the effluent discharge conditions.

The assessment of **near-field stability**, i.e. the distinction of stable or unstable conditions, is a key aspect of effluent dilution analyses. It is especially important for understanding the behavior of the two-dimensional plumes resulting from multiport diffusers, as shown by some examples in Figure 2.2. **"Stable discharge"** conditions, usually occurring for a combination of strong buoyancy, weak momentum and deep water, are often referred to as **"deep water"** conditions (Figures 2.2a,c). **"Unstable discharge"** conditions, on the other hand, may be considered synonymous to **"shallow water"** conditions (Figure 2.2b,d). Technical discussions on discharge stability are presented elsewhere (18,19).

A few important examples of boundary interaction for a single round buoyant jet are illustrated in Figure 2.3. If a buoyant jet is bent-over by a cross-flow, it will gradually approach the surface, bottom or terminal level and will undergo a smooth transition with little additional mixing impingement point can take on one of the following forms: (a) If the flow has sufficient buoyancy it will ultimately form a stable layer at the **surface** (Figure **2.3b**). In the presence of **weak** ambient flow this will lead to an upstream intrusion against the ambient current. (b) If the buoyancy of the effluent flow is weak or its momentum very high, unstable recirculation phenomena can occur in the discharge vicinity (Figure **2.3c**). This local recirculation leads to **re**-entrainment of already mixed water back into the buoyant jet region. (c) In the intermediate case, a combination of localized vertical mixing and upstream spreading may result (Figure **2.3d**).

Another type of interaction process concerns submerged buoyant jets discharging in the vicinity of the water bottom into a stagnant or flowing ambient. **Two** types of dynamic interaction processes can occur that lead to rapid attachment of the effluent plume to the water bottom as illustrated in Figure 2.4. These are wake attachment forced by the receiving water's crossflow or **Coanda attachment** forced by the entrainment demand of the effluent jet itself. The latter is due to low pressure effects as the jet **periphery** is close to the water bottom.

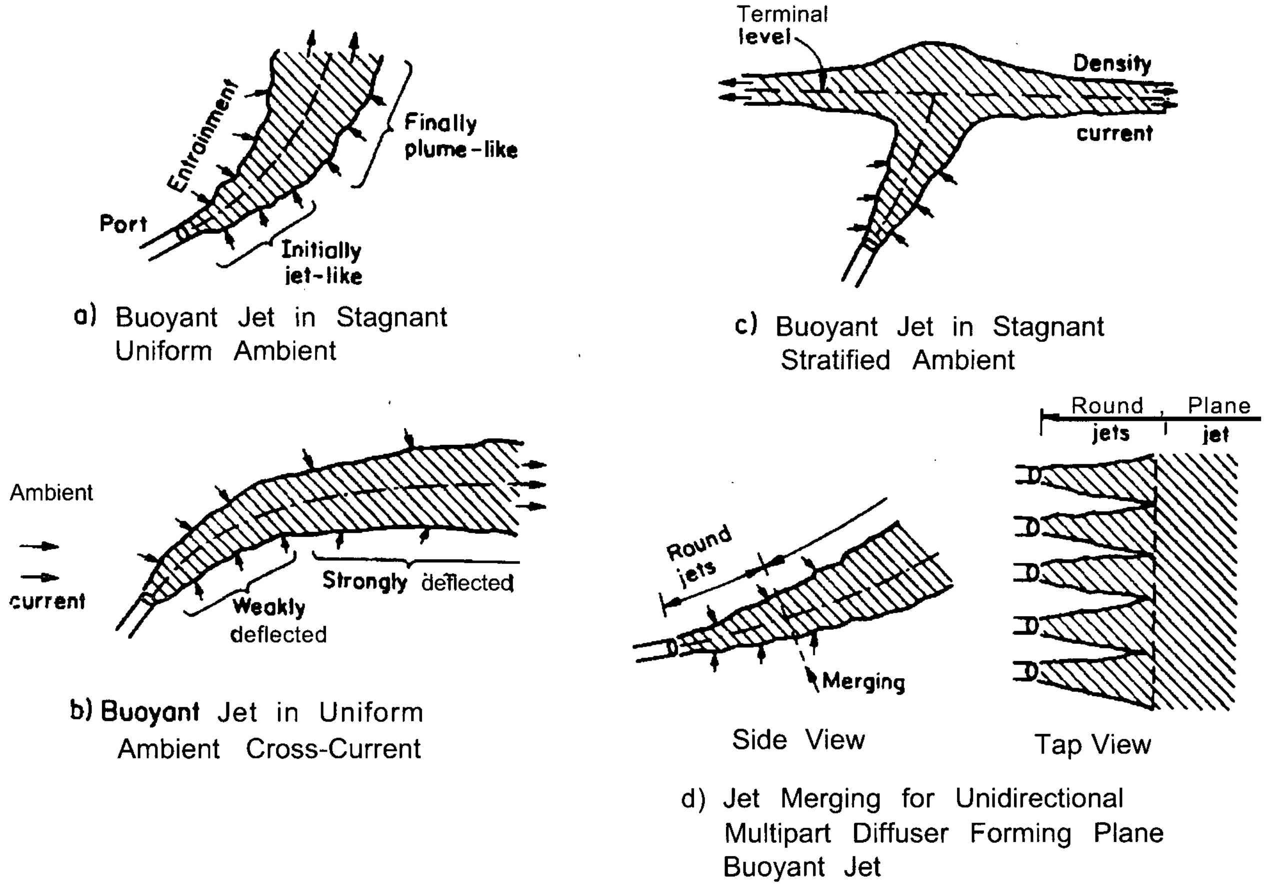
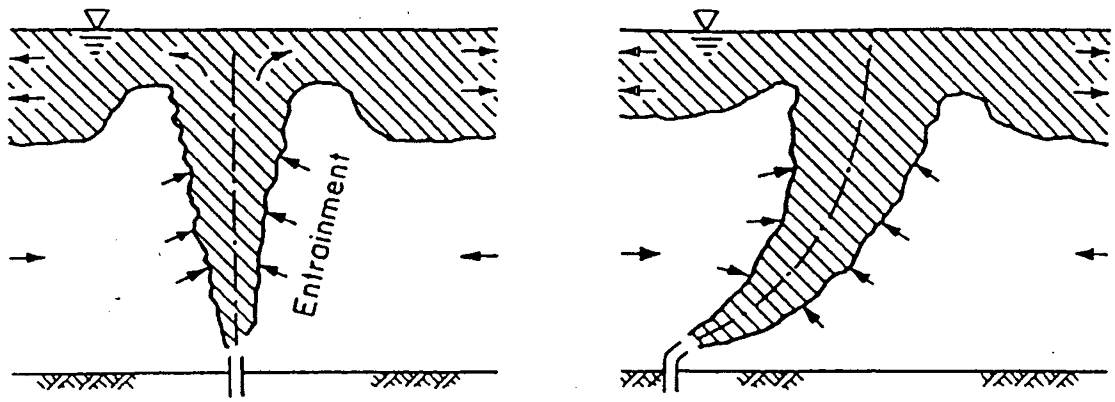
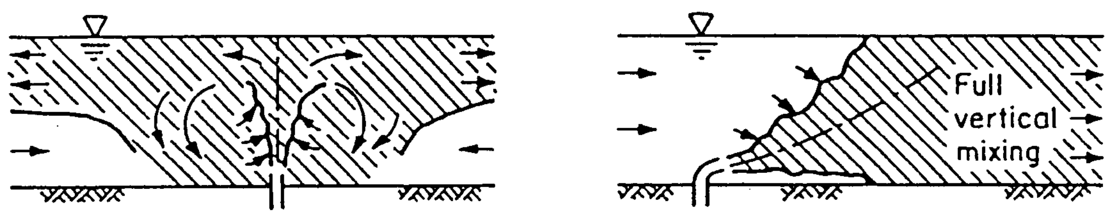


Figure 2.1: Typical buoyant jet mixing flow patterns under different ambient conditions



a) Deep Water, High Buoyancy, Vertical: Stable Near-Field

c) Deep Water, High Buoyancy, Near-Horizontal: Stable Near-Field



b) Shallow Water, Low Buoyancy, Vertical: Unstable Near-Field with Local Mixing and Restratification

d) Shallow Water, Low Buoyancy, Near-Horizontal: Unstable Near-Field with Full Vertical Mixing

Figure 2.2: Examples of near-field stability and instability conditions for submerged discharges in limited water depth

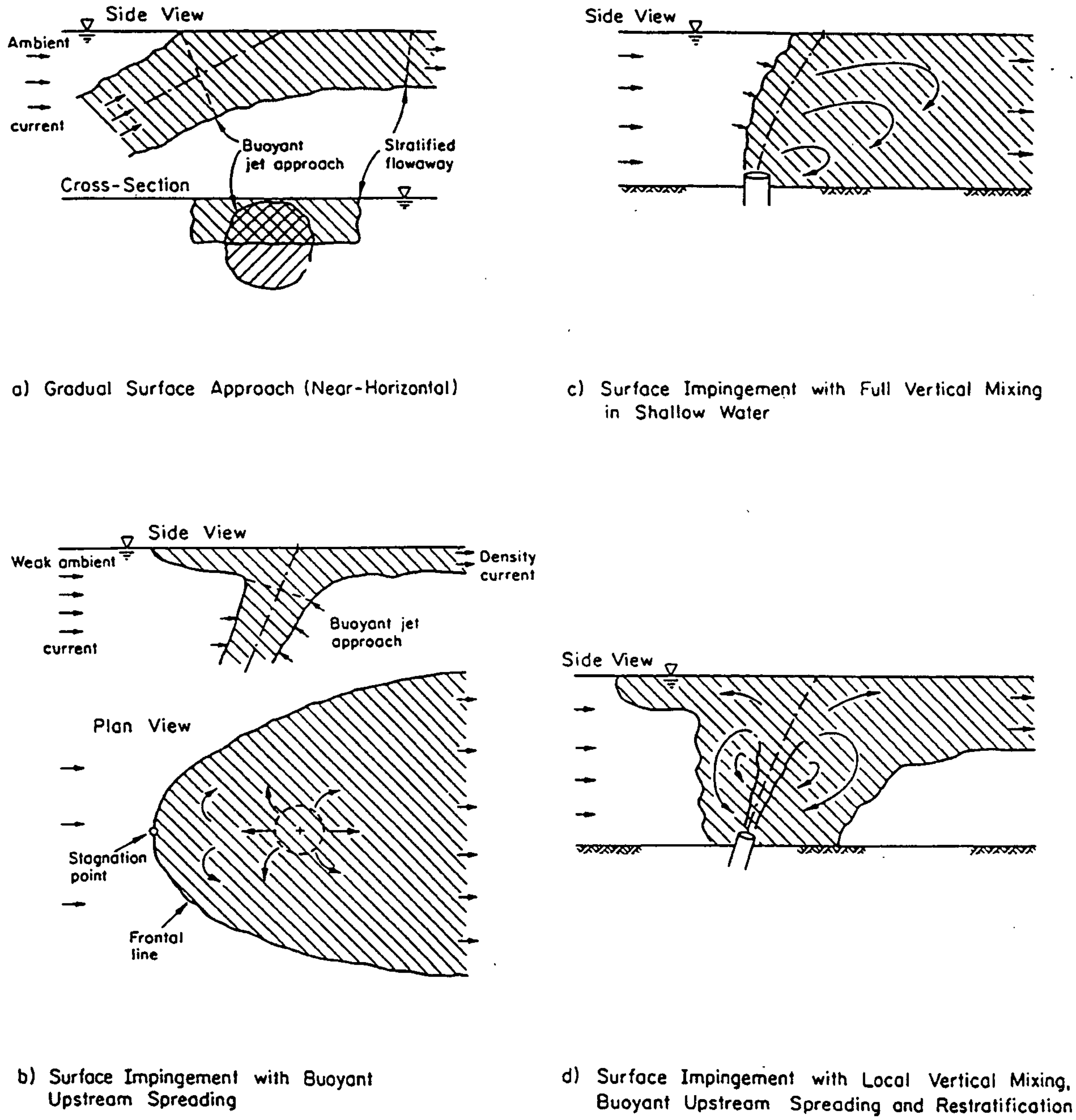


Figure 2.3: Examples of boundary interactions for submerged jets in finite depth

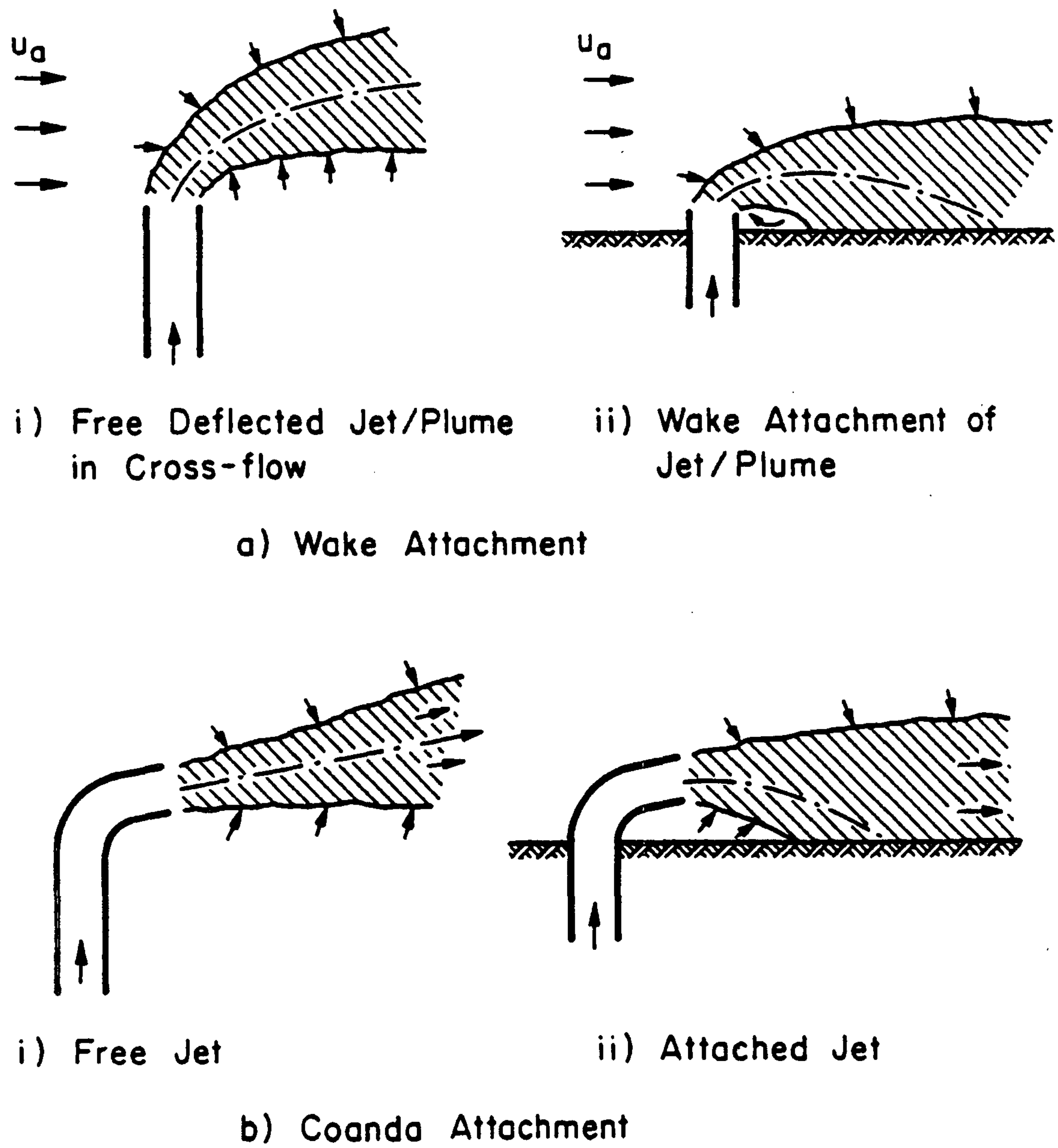
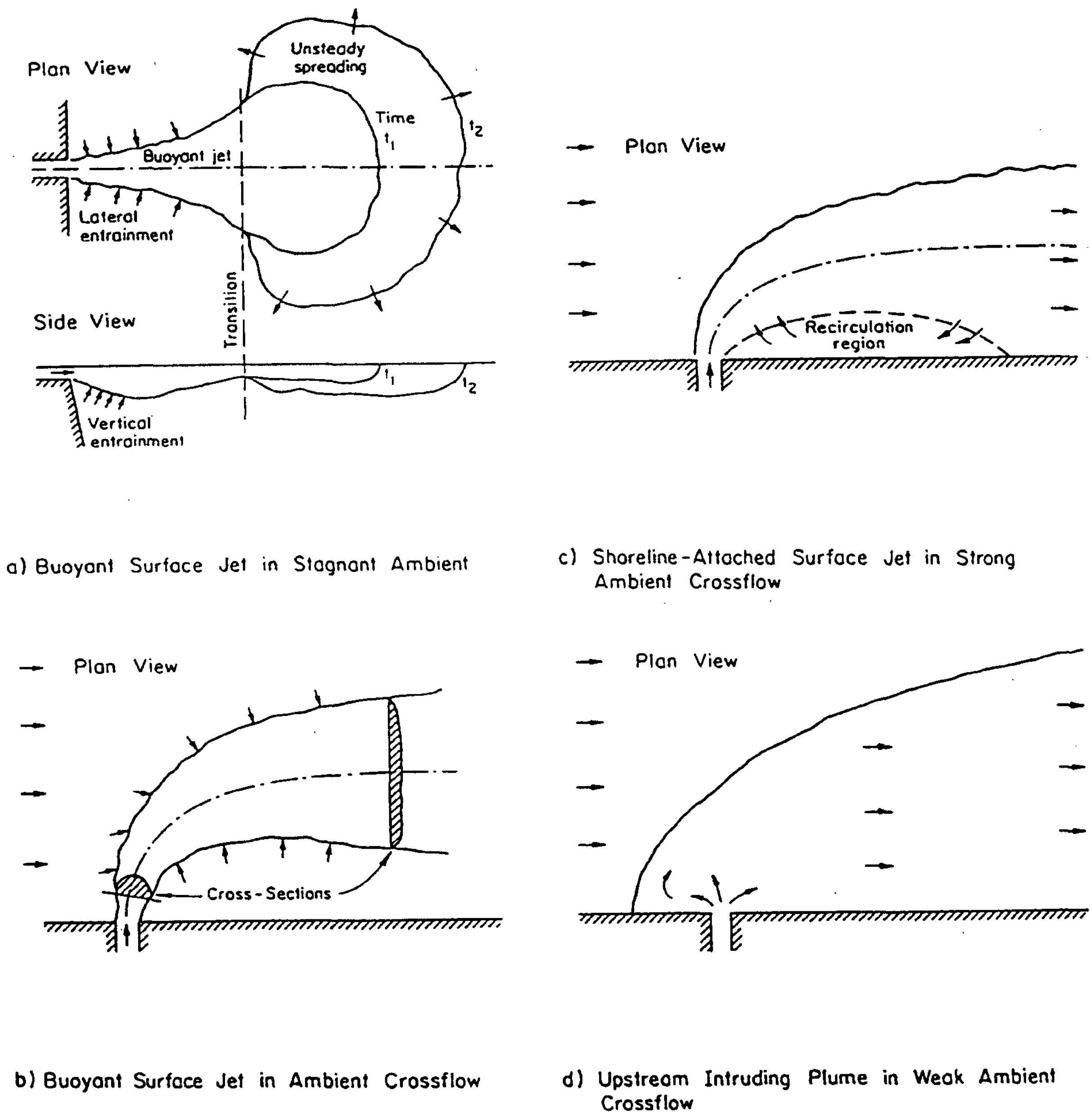


Figure 2.4: Examples of wake (crossflow induced) attachment and Coanda attachment conditions for jets discharging near boundaries

Surface Buoyant Jet Mixing: Positively buoyant jets discharged horizontally along the water surface from a laterally entering channel or pipe (Figure 2.5) bear some similarities to the more classical submerged buoyant jet. For a relatively short initial distance, the effluent behaves like a momentum jet spreading both laterally and vertically due to turbulent mixing. After this stage, vertical entrainment becomes inhibited due to buoyant damping of the turbulent motions, and the jet experiences strong lateral spreading. During stagnant ambient conditions, ultimately a reasonably thin layer may be formed at the surface of the receiving water; that layer can undergo the transient buoyant spreading motions depicted in Figure2.5a.



2.5: Typical buoyant surface jet mixing flow patterns under stagnant or flowing ambient conditions

In the presence of ambient crossflow, buoyant surface jets may exhibit any one of following three types of flow features: They may form a weakly deflected jet that does not interact with the shoreline (Figure 2.5b). When the crossflow is strong, they may attach to the downstream boundary forming a shore-hugging plume (Figure 2.5c). When a high discharge buoyancy flux combines with a weak crossflow, the buoyant spreading effects can be so strong that an upstream intruding plume is formed that also stays close to the shoreline (Figure 2.5d).

Intermediate-Field Effects for Multiport Diffuser Discharges: Some multiport diffuser installations induce flows in shallow water which extend beyond the strict near-field region. The resulting plumes are sometimes referred to as the "intermediate-field" (18) because they interact with the receiving water at distances that are substantially greater than the water depth; the order of magnitude of the water depth is typically used to define the dimensions of the near-field region. Intermediate fields may occur when a multiport diffuser represents a large source of momentum with a relatively weak buoyancy effect. Such a diffuser will have an unstable near-field with shallow water conditions. For certain diffuser geometries (e.g. unidirectional & staged diffuser types; see Section V) strong motions can be induced in the shallow water environment in the form of vertically mixed currents that laterally entrain ambient water and may extend over long distances before they re-stratify or dissipate their momentum.

Another type of interaction process concerns submerged buoyant jets discharging in the vicinity of the water bottom into a stagnant or flowing ambient. Two types of dynamic interaction processes can occur that lead to rapid attachment of the effluent plume to the water bottom as illustrated in Figure 2.4. These are **wake attachment** forced by the receiving water's crossflow or **Coanda attachment** forced by the entrainment demand of the effluent jet itself. The latter is due to low pressure effects as the jet periphery is close to the water bottom.

2.1.2 <u>Far-Field Processes</u>

Far-field mixing processes are characterized by the longitudinal advection of the mixed effluent by the ambient current velocity.

Buoyant Spreading Processes: These are defined as the horizontally transverse spreading of the mixed effluent flow while it is being advected downstream by the ambient current. Such spreading processes arise due to the buoyant forces caused by the density difference of the mixed flow relative to the ambient density. They can be effective transport mechanisms that can quickly spread a mixed effluent laterally over large distances in the transverse direction, particularly in cases of strong ambient stratification. In this situation, effluent of considerable vertical thickness at the terminal level can collapse into a thin but very wide layer unless this is prevented by lateral boundaries. If the discharge is non-buoyant, or weakly buoyant, and the ambient is unstratified, there is no buoyant spreading region in the far-field, only a passive diffusion region.

Depending on the type of near-field flow and ambient stratification, several types of buoyant spreading may occur. These include: (a) spreading at the water surface, (b) spreading at the bottom, (c) spreading at a sharp internal interface (pycnocline) with a density jump, or (d) spreading at the terminal level in continuously stratified ambient fluid. As an example, the definition diagram and structure of surface buoyant spreading processes somewhat downstream of the discharge in unstratified crossflow is shown in Figure 2.6.

The laterally spreading flow behaves like a density current and entrains some ambient fluid in the "head region" of the current. During this phase, the mixing rate is usually relatively small, the layer thickness may decrease, and a subsequent interaction with a shoreline or bank can impact the spreading and mixing processes.

Passive Ambient Diffusion Processes: The existing turbulence in the ambient environment becomes the dominating mixing mechanism at sufficiently large distances from the discharge point. In general, the passively diffusing flow grows in width and in thickness until it interacts

The strength of the ambient diffusion mechanism depends on a number of factors relating mainly to the geometry of the ambient shear flow and the amount of ambient stratification. In the context of classical diffusion theory (20), gradient diffusion processes in the bounded flows of rivers or narrow estuaries can be described by constant diffusivities in the vertical and horizontal direction that depend on turbulent intensity and on channel depth or width as the length scales. In contrast, wide "unbounded" channels or open coastal areas are characterized by plume size dependent diffusivities leading to accelerating plume growth described, for example, by the "4/3 law" of diffusion. In the presence of a stable ambient stratification, the vertical diffusive mixing is generally strongly damped.

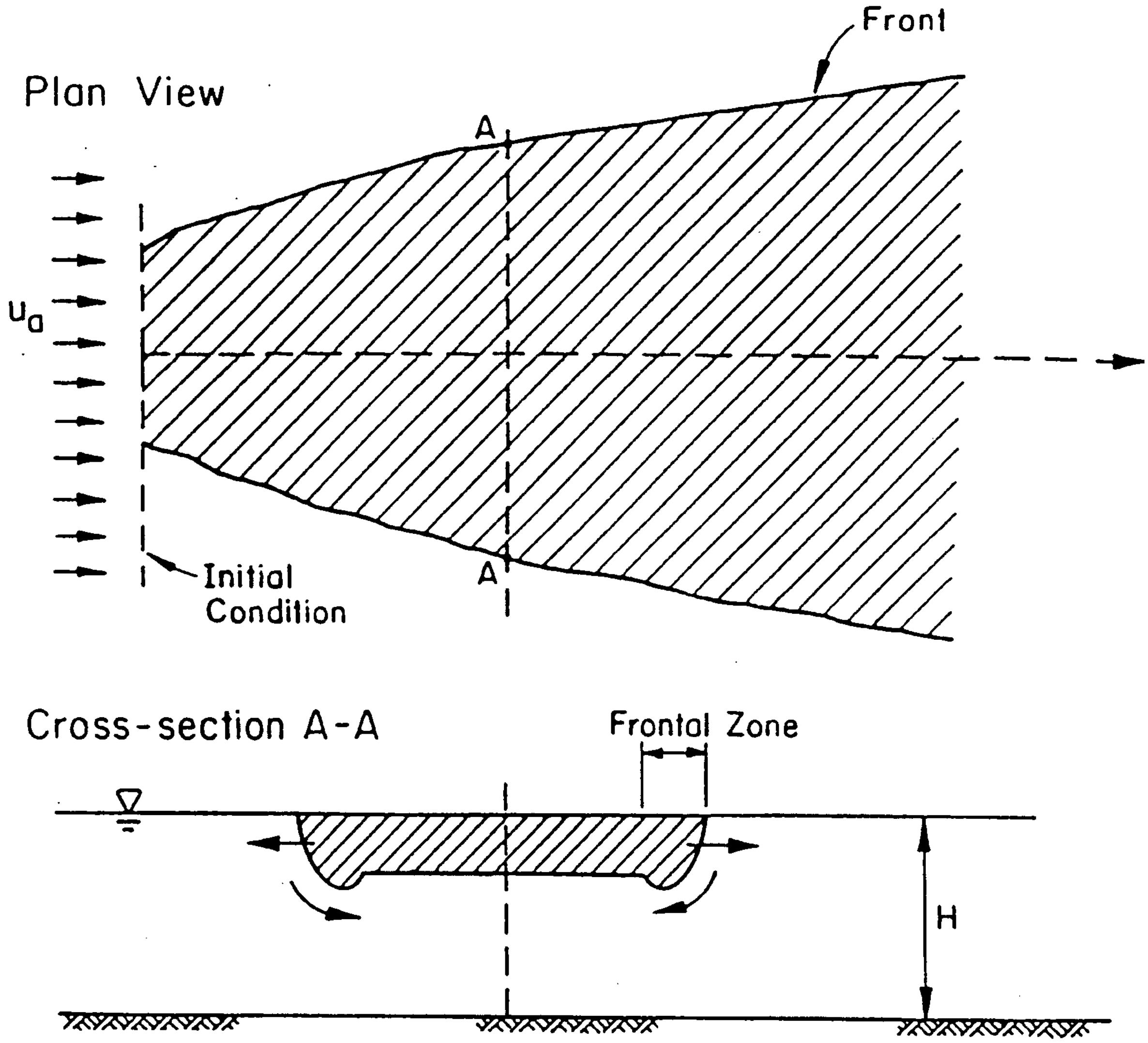


Figure 2.6: Buoyant spreading processes downstream of the near-field region (example of spreading along the water surface)

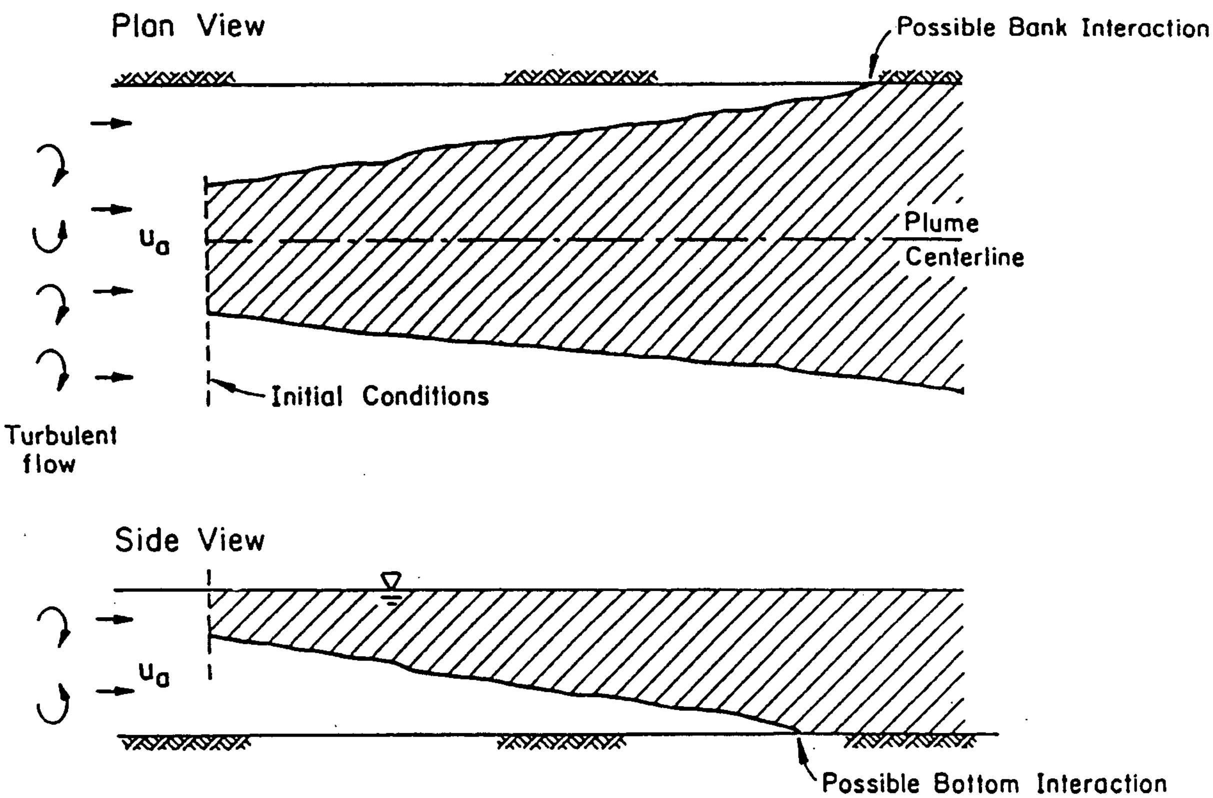


Figure 2.7: Passive ambient diffusion process with advection in the far-field

2.2 Mixing Zone Regulations

The discharge of waste water into a water body can be considered from two vantage points regarding its impact on ambient water quality. On a larger scale, seen over the entire receiving water body, care must be taken that water quality conditions that protect designated beneficial uses are achieved. This is the realm of the general waste load allocation (WLA) procedures and models.

On a local scale, or in the immediate discharge vicinity, additional precautions must be taken to insure that high initial pollutant concentrations are minimized and constrained to small zones, areas, or volumes. The generic definition of these zones, commonly referred to as "**mixing zones**", is embodied in federal water quality regulations and often cited in the regulations of permit granting authorities. As stated previously, mixing zones are administrative constructs that are independent of hydrodynamic mixing processes.

2.2.1 Legal Background

The Clean Water Act of 1977 defines five general categories of pollutants. These are: (a) conventional, (b) nonconventional, (c) toxics, (d) heat, and (e) dredge and fill spoil. The Act distinguishes between new and existing sources for setting effluent standards. Pollutants designated as "conventional" would be "generally those pollutants that are naturally occurring, biodegradable, oxygen demanding materials and solids. In addition, compounds which are not toxic and which are similar in characteristics to naturally occurring, biodegradable substances are to be designated as conventional pollutants for the purposes of the provision." Examples of conventional pollutants are: biochemical oxygen demand (BOD), total suspended solids, and fecal coliform bacteria. Pollutants designated as "nonconventional" would be "those which are not toxic or conventional", and some examples are: chemical oxygen demand (COD), fluoride, and ammonia. "Toxic" pollutants are those that cause harmful effects, either acute or chronic, at very low concentrations; examples of some designated toxic substances are: nickel, chloroform, or benzidine.

2.2.2 Mixing Zone Definitions

The mixing zone is defined as an "**allocated impact zone**" where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented. A mixing zone can be thought of as a limited area or volume where the initial dilution of a discharge occurs (21). Water quality standards apply at the boundary of the mixing zone, not within the mixing zone itself. The U.S. EPA and its predecessor agencies have published numerous documents giving guidance for determining mixing zones. Guidance published by U.S. EPA in the 1984 Water Quality Standards Handbook (21) supersedes these sources.

In setting requirements for mixing zones, U.S. EPA (22) requires that "the area or volume of an individual zone or group of zones be limited to an area or volume as small as practicable that will not interfere with the designated uses or with the established community of aquatic life in the segment for which the uses are designated," and the shape be "a simple configuration that is easy to locate in the body of water and avoids impingement on biologically important areas," and "shore hugging plumes should be avoided."

The U.S. EPA rules for mixing zones recognize the State has discretion whether or not to adopt a mixing zone and to specify its dimensions. The U.S. EPA allows the use of a mixing zone in permit applications except where one is prohibited in State regulations. A previous review (5) of individual State mixing zone policies (1,22) found that 48 out of 50 States make use of a mixing zone in some form; the exceptions are Arizona and Pennsylvania. State regulations dealing with streams or rivers generally limit mixing zone widths or cross-sectional areas, and allow lengths to be determined on a case by case basis.

In the case of lakes, estuaries and coastal waters, some states specify the surface area that can be affected by the discharge. The surface area limitation usually applies to the underlying water column and benthic area. In the absence of specific mixing zone dimensions, the actual shape and size is determined on a case-by-case basis.

Special mixing zone definitions have been developed for the discharge of municipal wastewater into the coastal ocean, as regulated under Section 301(h) of the Clean Water Act (23). Frequently, these same definitions are used also for industrial and other discharges into coastal waters or large lakes, resulting in a plurality of terminology. For those discharges, the mixing zone was labeled as the "**zone of initial dilution**" in which rapid mixing of the waste stream (usually the rising buoyant fresh water plume within the ambient saline water) takes place. EPA requires that the "zone of initial dilution" be a regularly shaped area (e.g. circular or rectangular) surrounding the discharge structure (e.g. submerged pipe or diffuser line) that encompasses the regions of high (exceeding standards) pollutant concentrations under design conditions (23). In practice, limiting boundaries defined by dimensions equal to the water depth measured horizontally from any point of the discharge structure are accepted by the EPA provided they do not violate other mixing zone restrictions (23).

2.2.3 Special Mixing Zone Requirements for Toxic Substances

The U.S. EPA maintains two water quality criteria for the allowable concentration of toxic substances: a criterion maximum concentration

(CMC) to protect against acute or lethal effects; and a criterion continuous concentration (CCC) to protect against chronic effects (1). The CMC value is greater than or equal to the CCC value and is usually more restrictive. The CCC must be met at the edge of the same regulatory mixing zone specified for conventional and nonconventional discharges.

Lethality to passing organisms within the mixing zone can be prevented in one of four ways:

The first alternative is to meet the CMC criterion within the pipe itself.

The second alternative is to meet the CMC within a short distance from the outfall. If dilution of the toxic discharge in the ambient environment is allowed, a **toxic dilution zone (TDZ)**, which is usually more restrictive than the legal mixing zone for conventional and nonconventional pollutants, may be used. The revised 1991 Toxics TSD document (1) recommends for new discharges a minimum exit velocity of 3 meters per second (10 feet per second) in order to provide sufficiently rapid mixing that would minimize organism exposure time to toxic material. The TSD does not set a requirement in this regard, recognizing that the restrictions listed in the following paragraph can in many instances also be met by other designs, especially if the ambient velocity is large.

As the third alternative, the outfall design must meet the most restrictive of the following geometric restrictions for a TDZ:

--- The CMC must be met within 10% of the distance from the edge of the outfall structure to the edge of the regulatory mixing zone in any spatial direction.

--- The CMC must be met within a distance of 50 times the discharge length scale in any spatial direction. The discharge length scale is defined as the square-root of the cross-sectional area of any discharge outlet. This restriction is intended to ensure a dilution factor of at least 10 within this distance under all possible circumstances, including situations of severe bottom interaction and surface interaction.

--- The CMC must be met within a distance of 5 times the local water depth in any horizontal direction. The local water depth is defined as the natural water depth (existing prior to the installation of the discharge outlet) prevailing under mixing zone design condition (e.g. low flow for rivers). This restriction will prevent locating the discharge in very shallow environments or very close to shore, which would result in significant surface and bottom concentrations (1).

A fourth alternative is to show that a drifting organism would not be exposed more than 1-hour to average concentrations exceeding the CMC.

2.2.4 <u>Current Permitting Practice on Mixing Zones</u>

It is difficult to generalize the actual practice in implementing the mixing zone regulations, given the large number and diverse types of jurisdictions and permit-granting authorities involved. By and large, however, current procedure falls into one of the following approaches, or may involve a combination thereof.

(i) The mixing zone is defined by some numerical dimension, as discussed above. The applicant must then demonstrate that the existing or proposed discharge meets all applicable standards for conventional pollutants or for the CCC of toxic pollutants at the edge of the specified mixing zone.

(ii) No numerical definition for a mixing zone may apply. In this case a mixing zone dimension may be proposed by the applicant. To do so the applicant generally uses actual concentration measurements for existing discharges, dye dispersion tests or model predictions to show at what plume distance, width, or region, the applicable standard will be met. The applicant may then use further ecological or water use-oriented arguments to demonstrate that the size of that predicted region provides reasonable protection. The permitting authority may evaluate that proposal, or sometimes pursue its own independent proposal for a mixing zone.

This approach resembles a negotiating process with the objective of providing optimal protection of the aquatic environment consistent with other uses.

As regards the acute, or CMC, criterion for toxic pollutants, the spatial restrictions embodied in the Toxics TSD document (1) call for very specific demonstrations of how the CMC criterion is met at the edge of the "toxic dilution zone". Again, field tests for existing discharges or predictive models may be used.

2.2.5 Relationship Between Actual Hydrodynamic Processes and Mixing Zone Dimensions

The spatial requirements in mixing zone regulations are not always correlated with the actual hydrodynamic processes of mixing. With few exceptions, the toxic dilution criteria apply to the near-field of most discharges since the TDZ criteria (2) are spatially highly restrictive. The regular mixing zone boundaries, however, may be located in the near-field or the far-field of the actual effluent discharge flow since they are administratively determined by the permit-granting authority. Thus, the analyst must have tools at his disposal with the capability to address both the near and far-field situations.

III General Features of the CORMIX System

This section provides a general description of common features of CORMIX. CORMIX Version 3.1 has three different subsystem modules for diverse discharge conditions. The subsystems are CORMIX1, CORMIX2, and CORMIX3 for the analysis of submerged single port, submerged multiport, and buoyant surface outfall configurations, respectively. Furthermore, two post-processor models CORJET, a near-field jet integral model, and FFLOCATR, a far-field plume locator in non-uniform channels, are included. The following two sections give a detailed guidance for developing the required input data and for understanding program output. Reference is made throughout this document to CORMIX Version 3.1 dated June 1995 or Version 3.2 dated September 1996; other versions may differ somewhat.

3.1 Overview

The CORMIX system represents a robust and versatile computerized methodology for predicting both the qualitative features (e.g. flow classification) and the quantitative aspects (e.g. dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations and in all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters. The methodology: (a) has been extensively verified by the developers through comparison of simulation results to available field and laboratory data on mixing processes (5,6,7,8), (b) has undergone independent peer review in journal proceedings (9,10,11,12,13, 14,15,16,17) and (c) is equally applicable to a wide range of problems from a simple single submerged pipe discharge into a small stream with rapid cross-sectional mixing to a complicated multiport diffuser installation in a deeply stratified coastal water.

System experience suggests that CORMIX1 applies to better than 95% of submerged single-port designs, CORMIX2 to better than 80% of multiport diffusers, and CORMIX3 to better than 90% of surface discharges. Lack of applicability is usually given by highly non-uniform ambient flow conditions that are prone to locally recirculating flows. Other non-applicable cases may arise to complicated discharge geometries in which case CORMIX advises the user not to proceed with the analysis. Whenever the model is applicable extensive comparison with available field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations, with associated plume geometries, are accurate to within ± 50 % (standard deviation).

The methodology provides answers to questions that typically arise during the application of mixing zone regulations for both conventional and toxic discharges. More importantly, this is accomplished by utilizing the customary approaches often used in evaluating and implementing mixing zones, thereby providing a common framework for both applicants and regulatory personnel to arrive at a consensus view of the available dilution and plume trajectory for the site and effluent discharge characteristics.

The methodology also provides a way for personnel with little or no training in hydrodynamics to investigate improved design solutions for aquatic discharge structures. To limit misuse, the system contains limits of applicability that prevent the simulation of situations for which no safe predictive methodology exists, or for discharge geometries that are undesirable from a hydrodynamic viewpoint. Furthermore, warning labels, data screening mechanisms, and alternative design recommendations are furnished by the system. The system is not fool proof, however, and final results should always be examined for reasonableness.

Finally, CORMIX is an educational tool that intends to make the user more knowledgeable and appreciative about effluent discharge and mixing processes. The system is not simply a black box that produces a final numerical or graphical output, but contains an interactive menu of user guidance, help options, and explanatory material of the relevant physical processes. These assist users in understanding model predictions and exploring the sensitivity of model predictions to assumptions.

3.2 Capabilities and Major Assumptions of the Three Subsystems and the Post-Processor Models

3.2.1 CORMIX Subsystems

CORMIX1 predicts the geometry and dilution characteristics of the effluent flow resulting from a **submerged single port diffuser discharge**, of arbitrary density (positively, neutrally, or negatively buoyant) and arbitrary location and geometry, into an ambient receiving water body that may be stagnant or flowing and have ambient density stratification of different types.

CORMIX2 applies to three commonly used types of **submerged multiport diffuser discharges** under the same general effluent and ambient conditions as CORMIX1. It analyzes unidirectional, staged, and alternating designs of multiport diffusers and allows for arbitrary alignment of the diffuser structure within the ambient water body, and for arbitrary arrangement and orientation of the individual ports. For complex hydrodynamic cases, CORMIX2 uses the "equivalent slot diffuser" concept and thus neglects the details of the individual jets issuing from each diffuser port and their merging process, but rather assumes that the flow arises from a long slot discharge with equivalent dynamic characteristics. Hence, if details of the effluent flow behavior in the immediate diffuser vicinity are needed, an additional CORMIX1 simulation for an equivalent partial effluent flow may be recommended.

CORMIX3 analyzes **buoyant surface discharges** that result when an effluent enters a larger water body laterally, through a canal, channel, or near-surface pipe. In contrast to CORMIX1 and 2, it is *limited to positively or neutrally buoyant effluents.* Different discharge geometries and orientations can be analyzed including flush or protruding channel mouths, and orientations normal, oblique, or parallel to the bank.

Additional major assumptions include the following:

--- All subsystems require that the actual cross-section of the water body be described as a rectangular straight uniform channel that may be bounded laterally or unbounded. The ambient velocity is assumed to be uniform within that cross-section.

--- In addition to a uniform ambient density possibility, CORMIX allows for three generic types of ambient stratification profiles to be used for the approximation of the actual vertical density distribution (see Section 4.3).

--- All CORMIX subsystems are in principle **steady-state models**, however recent developments (beginning with Version 3.1) allow the analysis of **unsteady mixing in tidal environments**.

--- All CORMIX systems can predict mixing for both conservative and first-order decay processes, and can simulate heat transfer from thermal plumes.

3.2.2 Post-Processor Models CORJET and FFLOCATR

CORJET, the Cornell Buoyant Jet Integral Model, is a **buoyant jet integral model** that predicts the jet trajectory and dilution characteristics of a single round jet or of a series of merging jets from a multiport diffuser with arbitrary discharge direction and positive, neutral or negative buoyancy in a general ambient environment. The ambient conditions can be highly non-uniform with both ambient current magnitude, current direction, and density a function of vertical distance. In general, CORJET can be used as an enhancement to the near-field predictions provided by CORMIX1 or 2 in order to investigate local details that have been simplified within the CORMIX representation. The major limitation of CORJET lies in the assumption of an *infinite receiving water body*, similar to all other available jet integral type models. Thus, CORJET should only be used after an initial CORMIX classification has shown that the single or multiple port discharge is indeed of the deep water type, i.e. hydrodynamically stable, without boundary interactions.

FFLOCATR, the Far-Field Plume Locator, uses the **cumulative discharge method** to delineate the CORMIX predicted far-field plume within the actual irregular (meandering or winding) river or estuary channel geometry with uneven distribution of the ambient flow.

3.3 System Processing Sequence and Structure

The general CORMIX layout appears in Figure 3.1, which shows the overall structure and the execution sequence of the program elements. The system has overall common data input features for the three different discharge elements. During program execution, the elements are loaded automatically and sequentially by the system. Each element provides user interaction and prompting in response to displayed information. This may somewhat extend the total time required for a single CORMIX session, but has offsetting benefit of allowing the user to gain process knowledge and insight on design sensitivity.

The user has numerous options with the **Main Menu** at start-up. Option 1 is to start a new CORMIX session. Option 2 is to re-run and modify a former case. Option 3 is to simply re-display (without new computation) results of a former design case. Option 4 is to use the Post-Processor, which includes the CORJET near-field jet integral model, the FFLOCATR far-field locator, and the plume display graphics which will be discussed in Section V of this document. Option 5 is the file manager which lists all files from previous simulations. Option 6 is to set/change CORMIX system speed. Here the user can select REGULAR CORMIX, complete with detailed queries and user help, or FAST-CORMIX, which has terse questions and limited user help. Option 7 contains system information and reference material. Option 7 is to quit the CORMIX system and return to DOS.

The common program elements of CORMIX are composed of DATIN, PARAM, CLASS, HYDRO, and SUM (Figure 3.1). DATIN is the program element for the entry of data and initialization of other program elements. PARAM uses the input data to compute a number of important physical parameters and length scales, as precursor to CLASS which performs the hydrodynamic classification of the given discharge/ambient situation into one of many possible generic flow configurations. HYDRO performs the actual detailed numerical prediction of the effluent plume characteristics. Finally, SUM summarizes the results from the classification and prediction, interprets them as regards mixing zone regulations, suggests design alternatives, and allows sensitivity analysis to be conveniently conducted using the current input data. At this point the **iteration menu** allows the user to perform an iteration with different ambient/discharge/regulatory conditions, or start a new design case, or make use of the post-processor options.

Due to its diverse programming requirements, CORMIX is written in two programming languages: VP-Expert, an "expert systems shell", and Fortran. The former is powerful in knowledge representation and logical reasoning, while the latter is adept at mathematical computations. Program elements DATIN, PARAM, CLASS, and SUM are written exclusively in VP-Expert. HYDRO is written in VP-Expert, but uses three Fortran executables HYDRO1, 2 and 3 for the actual detailed computation of plume characteristics. Finally, C++ is used in the specially developed graphics package CMXGRAPH.

3.4 CORMIX Data Input Features

All data is entered interactively in response to the CORMIX system prompts generated by the data input program element DATIN. DATIN queries the user for a complete specification of the physical environment of the discharge, as well as the applicable regulatory considerations for the situation undergoing analysis. A CORMIX session commences with questions on four topics which are asked sequentially in this order: site/case descriptions, ambient conditions, discharge characteristics, and regulatory mixing zone definitions. Data entry is entirely guided by the system and the available advice menu options provide expanded descriptions of the questions, if clarification is needed.

Chapter IV provides complete details on input specification for the three CORMIX discharge subsystems. Chapter VI deals with the input features of the post-processor models CORJET and FFLOCATR.

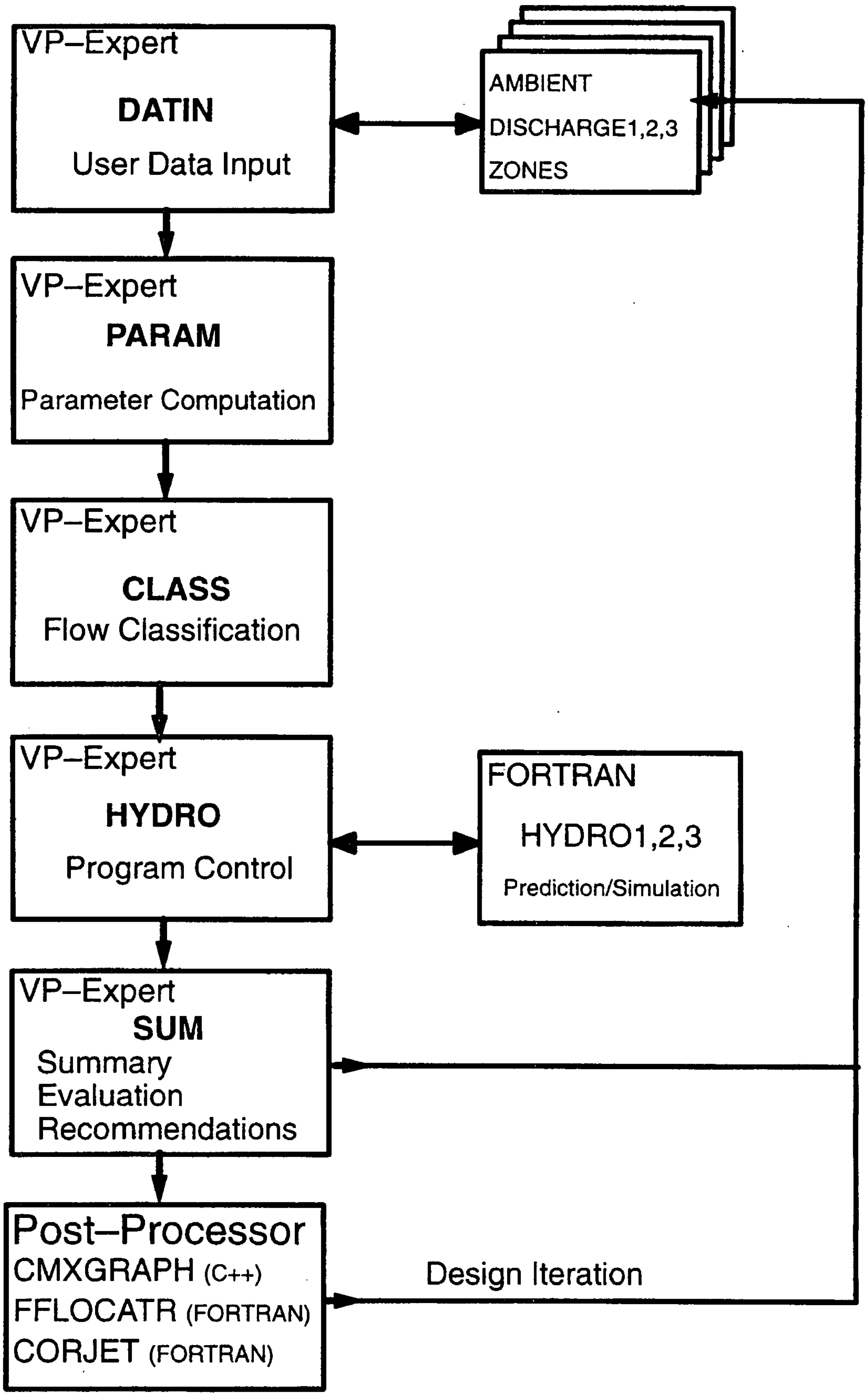


Figure 3.1: CORMIX system elements and processing sequence

3.5 Logic Elements of CORMIX: Flow Classification

To make predictions of an effluent discharge's dilution and plume trajectory, CORMIX typically combines the solutions of several simple flow patterns to provide a complete analysis from the efflux location all the way into the far-field.

The logic processing elements of CORMIX identify which solutions should be combined to provide the complete analysis. This process, called **flow classification**, develops a generic qualitative description of the discharge flow and is based on known relationships between flow patterns and certain calculated physical parameters.

PARAM is the program element that computes relevant physical parameters including: the various length scales, fluxes, and other values needed for the execution of other program elements. Length scales are calculated measures of the length of dynamic influence of various physical processes (see Chapters IV and V).

At the heart of CORMIX is a flow classification system contained in the program element CLASS. It provides a rigorous and robust expert knowledge base that carefully distinguishes among the many hydrodynamic flow patterns that a discharge may exhibit. As examples, these possibilities include discharge plumes attaching to the bottom, plumes vertically mixing due to instabilities in shallow water, plumes becoming trapped internally due to density stratification, and plumes intruding upstream against the ambient current due to buoyancy, and many others. Theoretically based hydrodynamic criteria using length scale analysis and empirical knowledge from laboratory and field experimentation, are applied in a systematic fashion to identify the most appropriate flow classification for a particular analysis situation. For all three subsystems, a total of about 80 generic flow configurations or classes can be distinguished.

The classification procedure of CORMIX is based on technical principles and has been verified by the developers through repeated testing and data comparison. It has also undergone independent peer review and the four documentation manuals (5,6,7,8) give the detailed scientific background for the classification scheme, in form of a number of criteria. The actual criteria constants are listed in the technical reports with comments on their sources and degree of reliability. Experienced users, especially those involved in research applications, may want to inspect these data values contained in the source code and occasionally vary some constant values within certain limits in order to examine improved prediction fits with available high-quality data. Extreme caution must be exercised when doing that as some values are interdependent; furthermore, if changes are made, they should be carefully documented.

When CLASS has executed, a description of the particular flow class is available to the user in the form of on-screen or hardcopy computer output; these description are also contained in the documentation reports (5,6,7). It is recommended that the novice or intermediate user review these to gain an appreciation of the involved hydrodynamic mixing processes.

3.6 Simulation Elements of CORMIX: Flow Prediction

Once a flow has been classified, CORMIX assembles and executes a sequence of appropriate hydrodynamic simulation modules in the program element HYDRO1, 2 or 3. HYDRO consists of: (a) control programs or "protocols" for each hydrodynamic flow classification and (b) a large number of subroutines or "simulation modules" corresponding to the particular flow processes, and their associated spatial regions, that occur within a given flow classification. The simulation modules are based on buoyant jet similarity theory, buoyant jet integral models, ambient diffusion theory, and stratified flow theory, and on simple dimensional analysis, as described elsewhere (5,6,7,8). The basic tenet of the simulation methodology is to arrange a sequence of relatively simple simulation modules which, when executed together, predict the trajectory and dilution characteristics of a complex flow. Each of the simulation models uses the final values of the previous module as "initial conditions".

3.7 CORMIX Output Features: Design Summary and Iterations

In addition to the narrative feedback during user input, the CORMIX system provides three types of output on-screen or in print: a) CORMIX Session Report that is a narrative summary, mostly for regulatory evaluation, of all discharge input data and global plume features, including compliance with mixing zone regulations, b) CORMIX1, 2 or 3 Prediction File that is a detailed listing of all plume properties as predicted by the Fortran program, and c) CMXGRAPH Plots representing plan, side, and trajectory views and concentration distribution of the predicted plume.

3.7.1 CORMIX Session Report

SUM is the final program element that summarizes the hydrodynamic simulation results for the case under consideration. The output in the CORMIX Session Report is arranged in four groups:

(1) Site summary gives the site identifier information, discharge and ambient environment data, and discharge length scales.

(2) Hydrodynamic simulation and mixing zone summary lists conditions at the end of the near-field region (NFR), regulatory mixing zone (RMZ) conditions, toxic dilution zone (TDZ) conditions, region of interest (ROI) conditions, upstream intrusion information, bank attachment locations, and a passive diffusion mixing summary. Users should be cognizant of the four major zone definitions, and associated acronyms, introduced above and defined as follows:

Near-Field Region (NFR): The NFR is simply the zone of strong initial mixing, corresponding to the "near-field" processes discussed in Chapter II. It has no regulatory implication whatsoever. However, the information on size and mixing conditions at the edge of the NFR is given as a useful guide to the discharge designer because mixing in the NFR is usually sensitive to design conditions, and therefore somewhat controllable. A notable exception is the effluent discharge into very shallow flow-limited streams where the actual discharge port design detail may have little bearing on instream concentrations.

Regulatory Mixing Zone (RMZ): The RMZ corresponds to either: (1) the applicable mixing zone regulation with specified size dimensions, or (2) a preliminary proposal for a mixing zone (see Section 2.2.4 (ii)).

Toxic Dilution Zone (TDZ): The TDZ corresponds to the EPA's definition of where toxic chemical concentrations may exceed the CMC value (see Section 2.2.3).

Region of Interest (ROI): The ROI is a user defined region of the receiving water body where mixing conditions are to be analyzed. It is specified as the maximum analysis distance in the direction of mixed effluent flow and is particularly important when legal mixing zone restrictions do not exist or when information over a larger area is of interest.

(3) Data analysis section presents further details on toxic dilution zone criteria, regulatory mixing zone criteria, stagnant ambient environment information, and region of interest criteria.

(4) Design recommendations section contains design suggestions in three general areas for improving initial dilution. These include: (a) geometry variations in discharge port design, (b) sensitivity to ambient conditions, and (c) process variations in discharge flow characteristics. The user is given guidance on the potential changes in mixing conditions from varying parameter values within these groups.

Finally, SUM is also used as an interactive loop to guide the user back to DATIN to alter design variables and perform sensitivity studies. Different options for iteration exist on the **iteration menu** depending on what input data changes are to be made. The importance of performing an ample number of CORMIX iterations cannot be sufficiently stressed. To obtain a design that adequately meets water quality and engineering construction objectives, it is necessary to get a feel for the physical situation and its sensitivity to design changes through repeated system use.

3.7.2 CORMIX1, 2 or 3 Prediction File

The CORMIX1, 2 or 3 Prediction File is a detailed listing of all simulation input data as well as the predicted plume properties (plume shapes and concentration distributions) arranged by the individual flow modules that form part of the simulation. Additional information, such as encounter of local mixing zone regulations, plume contact with bottom or shoreline, etc., are listed in the output. Detailed output features are discussed in Chapter V.

3.7.3 CMXGRAPH Plots

The post-processing graphics package CMXGRAPH can be exercised flexibly by the user at different stages: directly after a CORMIX case prediction for an initial evaluation of the design case, or later to inspect or prepare plots for an earlier design case, or outside the CORMIX system to plot any plume predicted by CORMIX or CORJET. The user can view different views of the plume, with scaling and zooming possibilities. Finally, hardcopy printouts can be prepared through a direct print-screen option or by writing to a Postscript file. Details of the graphics feature are discussed in Chapter V.

3.8 Post-Processor Models CORJET and FFLOCATR: Input and Output Features

The near-field jet integral model CORJET and the far-field plume locator model FFLOCATR can be exercised both within the CORMIX system, with guided input data assembly, or separately, with a simple Fortran input file. In both cases, only limited data are needed. Chapter VI provides a detailed discussion of the data requirements.

The output from these models is displayed on-screen or as a printed file. Furthermore, CORJET output can also be plotted with the CMXGRAPH program (see Section 5.3).

3.9 Equipment Requirements, System Installation and Run Times

The minimum recommended hardware configuration required for CORMIX is an IBM-DOS compatible microcomputer with: (a) a minimum of 550Kb of available RAM memory, (b) approximately 3Mb of hard disk space, (c) DOS 3.3 or higher operating system, and (d) a minimum 80386 with math co-processor to provide acceptable performance, especially with plume graphics display. The system will run on systems with less advanced processors, however simulation times can be long.

The RAM memory requirement of CORMIX may present an obstacle to many users because the configuration requirements of many commercial applications packages and the installation of memory resident software, or running DOS from windows, frequently reduce available RAM memory to less than 550Kb. The amount of available RAM memory can be determined with the DOS command CHKDSK. Although there are numerous approaches for increasing the size of a computer's available RAM memory, the simplest way is "boot" the computer from a floppy "system" disk that contains no AUTOEXEC.BAT or CONFIG.SYS files which consume additional memory. This should be done just prior to beginning an analysis session since it will temporary disable programs that consume RAM memory. The CONFIG.SYS file should allow the number of open files to be set to at least 20 by including the line statement "files=20". At the completion of the analysis session, the computer should be "booted" from the hard drive to restore normal operations. A bootable floppy system disk can be created with the DOS command FORMAT a:/S.

The CORMIX must be installed on a hard disk drive. The directory structure of CORMIX (Table 3.1) is fixed; it gets set up during the installation process; and it consists of a subsystem root directory, called "CORMIX", and six sub-directories. Complete installation instructions are available with the CORMIX distribution diskette.

Depending on computer configuration, a typical CORMIX session for one discharge/ambient condition may take less than 5 minutes for an Pentium-based computer to about 20 minutes for an 80286-based computer if all necessary input data is at hand. In some unusual cases (such as attached flow classes, e.g. H1A5) the numerical simulation routines in HYDROn may take up to 10 minutes to converge on Pentium-based systems.

Table 3.1
Directory Structure

CORMIX
Version 3.1 June 1995, Version 3.2 September 1996

Directory Name	Comments
CORMIX	system root directory; contains VP-Expert system files, the knowledge base program CORMIX.kmp or kbs (system driver), and the start-up batch file CMX.bat, and several other batch files to be used for starting up CORJET, CMXGRAPH, and FFLOCATR when used independently
CORMIX\DATA	contains cache "fact" files exported from knowledge base programs
CORMIX\EXE	contains Fortran hydrodynamic simulation programs HYDROn and file manipulation programs (*.exe)
CORMIX\KBS	contains all knowledge base programs (*.kmp or *.kbs)
CORMIX\POST	contains three post-processor programs CORJET, CMXGRAPH, and FFLOCATR
CORMIX\POST\CJ	contains CORJET numerical prediction files (fn.CJT) and graphical postscript files (fn.Pvn, where v = view type, and n = 0 to 9)
CORMIX\POST\FF	contains FFLOCATR cumulative discharge input data files (*.FFI) and prediction files (fn.FFX)
CORMIX\SIM	contains simulation results (Fortran files "fn.CXn", where n = 1,2,3, and fn = user designated filenames) and graphical postscript files (fn.Pvn, where v = view type, and n = 0 to 9)
CORMIX\SIM\CXn	contains simulation data files for each subsystem n (cache files "fn.CXC" and record keeping file "summary")
CORMIX\TEXT	contains all user-requested advice files and flow descriptions (*.txt)

IV CORMIX Data Input

4.1 General Aspects of Interactive Data Input

All CORMIX data input occurs interactively in response to system prompts and is entirely guided by the system. The user is automatically prompted for a complete specification of: site/case descriptions, ambient conditions, discharge characteristics, and regulatory definitions. The data for each of these four topical areas are called **input data sequences** herein. Questions are asked in plain English. Advice menu options within the program are available to provide help on how to prepare and enter data values when clarification of the system prompts is needed. The contents of these are also available in the documentation reports (5,6,7).

Regular CORMIX versus **FAST-CORMIX:** Upon in its initial installation the CORMIX system speed is set to "Regular CORMIX". In this mode the user will see detailed input questions with ample explanations for each variable. Also there will be opportunities to consult advice sections. It is recommended that the *novice user* employ this mode for about a dozen or so CORMIX sessions until he/she has become thoroughly familiar with the system. The *advanced user* can switch to the "FAST-CORMIX" mode in which only short questions are asked, thereby greatly accelerating data input and compacting it on screen. Certain advice section are not available. The differences are illustrated in the following:

Examples of three questions asked in **Regular CORMIX**:

1)
```
Do you want detailed ADVICE on how to specify the ambient density
stratification?
      [no]  [yes]
```

2)
```
Can the ambient density be considered 'UNIFORM' throughout the water column,
or
is there a 'NON-UNIFORM' vertical density stratification?
As practical guideline, uniformity can be assumed if the vertical density
variation between top and bottom is limited to 0.1 kg/m^3 or the  temperature
variation to 1 degC.
      [uniform]  [non-uniform]
```

3)
```
What is the WIDTH of the channel in the vicinity of the discharge (m)?
```

Corresponding questions in **FAST-CORMIX**:

1) <Question not asked>

2)
```
AMBIENT DENSITY?
      [uniform]  [non-uniform]
```

3)
```
Channel WIDTH (m)?
```

Data can be entered in an **open format** without concern for letter case or decimal placement. The only constraint is that <u>the following characters may not be entered</u> in response to any question:

+ = { } , < > ' " / \ ;

The system checks data entries for consistency with question type (e.g. an alphabetic character for water depth), obvious physical errors (e.g. a negative length), possible inconsistencies with previous entries (e.g. an angular value implying that a port points directly back to the shoreline) and situations outside the ranges of model applicability. Inconsistency with question type and obvious physical errors require immediate re-entry while possible inconsistencies with previous entries lead to a warning label and the opportunity for later correction. Entries specifying situations outside the ranges of model applicability usually require the re-entry of the entire data segment.

Warning: No attempt should be made to alter input data by manipulating any of the data files that are used by the HYDROn Fortran programs and execute these programs separately without using the VP-Expert segments DATIN, PARAM, and CLASS. Because of the inherent error and compatibility checking of input data within these program segments, unreliable prediction may result if they are by-passed!

As discussed in Chapter III, data input occurs in three or four program segments that load automatically. At the end of each data sequence (usually of the order of 5 to 20 items long) the entire sequence is displayed and the user is requested to accept or not accept the sequence. If it is not accepted, i.e. an error has been made, the user has another opportunity for entering the sequence. If an error is detected earlier there is no way of correcting immediately, it is best then to give a short answer (e.g. the value of 1) to all remaining questions and thus quickly move to the end of the sequence for the re-start opportunity.

Due to the similarity of data entry, a common description is given for all input data sequences, except discharge data to which a separate subsection for each CORMIXn subsystem is devoted below. Further guidance on data specification can be obtained from examining the case studies in the Appendices and from the documentation manuals (5,6,7). Following the discussion of input data sequences, units of measure conversion factors and checklists for input preparation are presented.

All the data input requirements of CORMIX are included in the **Checklist for Data Preparation** (see following page) that can be photocopied by the reader for future multiple use. The checklist aids in the assembly and preparation of this data prior to beginning an analysis to verify that all necessary data are available.

4.2 Site/Case Identifier Data

The first input data sequence determines basic information needed for the program to operate. These include: a two-part identifier for labeling output and a computer file name.

It is necessary to specify three site/case labels that facilitate the rapid identification of printed output and aid in good record-keeping. The system provides for one label called SITE NAME (e.g. Blue River), another called DESIGN CASE (e.g. 7Q10-low-flow, or High-velocity-port).

The user needs to supply a DOS-compatible FILE NAME, up to eight characters long, and without extension (e.g. sdif7q10). CORMIX will use that user-specified file name *fn*, and create, transfer, or store intermediate or final data files with that same file name, but with different extensions. The most important of these are the two output data files, SIM*fn*.CXn and SIM\CXn*fn*.CXC, where n = 1, 2 or 3, which are discussed further in Chapter V.

4.3 Ambient Data

Ambient conditions are defined by the geometric and hydrographic conditions in the vicinity of the discharge. Due to the significant effect of boundary interactions on mixing processes, the ambient data requirements for the **laterally bounded** and **unbounded** analysis situations are presented separately in the discussions below. CORMIX analyses, as all mixing zone evaluations, are usually carried out under the assumption of **steady-state** ambient conditions. Even though the actual water environment is never in a true steady-state, this assumption is usually adequate since mixing processes are quite rapid relative to the time scale of hydrographic variations. In highly **unsteady tidal reversing flows** the assumption is no longer valid and significant concentration build-up can occur. CORMIX will assess this situation and compute some re-entrainment effects on plume behavior. The data requirements for that purpose are discussed in the Section 4.3.3. Following are discussions on ambient

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.00-3.20

SITE Name ______________________ Date:
Design **CASE** ______________________ Prepared by:
DOS **FILE NAME** ______________________ (w/o extension)

AMBIENT DATA:

Water body depth	________ m	Water body is	bounded/unbounded	
Depth at discharge	________ m	If bounded: Width	________	m
		Appearance	1/2/3	
If steady: Ambient flowrate	________ m^3/s or:	Ambient velocity	________	m/s
If tidal: Tidal period	________ hr	Max. tidal velocity	________	m/s
At time ________ hr before/at/after slack		Tidal velocity at this time	________	m/s
Manning's n	________ or:	Darcy-Weisbach f	________	
Wind speed	________ m/s			

Density data: UNITS: Density...kg/m^3 / Temperature...°C

Water body is	fresh/salt water	If fresh: Specify as	density/temp.	values
If uniform:		Average density/temp.	________	
If stratified:		Density/temp. at surface	________	
Stratification type	A/B/C	Density/temp. at bottom	________	
If B/C: Pycnocline height	________ m	If C: Density/temp. jump	________	

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1

Nearest bank is on	left/right	Distance to nearest bank	________	m
Vertical angle THETA	________ °	Horizontal angle SIGMA	________	°
Port diameter	________ m or:	Port area	________	m^2
Port height	________ m			

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2

Nearest bank is on	left/right	Distance to one endpoint	________	m
Diffuser length	________ m	to other endpoint	________	m
Total number of openings	________ m	Port height	________	m
Port diameter	________ m with	contraction ratio	________	
Diffuser arrangement/type	unidirectional / staged / alternating or vertical			
Alignment angle GAMMA	________ °	Horizontal angle SIGMA	________	°
Vertical angle THETA	________ °	Relative orientation BETA	________	°

BUOYANT SURFACE DISCHARGE -- CORMIX3

Discharge located on	left/right bank	Configuration	flush/protruding/co-flowing	
Horizontal angle SIGMA	________ °	If protruding: Dist. from bank	________	m
Depth at discharge	________ m	Bottom slope	________	°
If rectangular Width	________ m or:	If circular Diameter	________	m
discharge channel: Depth	________ m	pipe: Bottom invert depth	________	m

Effluent: Flow rate	________ m^3/s or:	Effluent velocity	________	m/s
Effluent density	________ kg/m^3 or:	Effluent temperature	________	°C
Heated discharge?	yes/no	If yes: Heat loss coefficient	________	W/m^2,°C
Concentration units	________	Effluent concentration	________	
Conservative substance?	yes/no	If no: Decay coefficient	________	/day

MIXING ZONE DATA:

Is effluent toxic?	yes/no	If yes: CMC ________	CCC ________	
WQ stand./conventional poll.?	yes/no	If yes: value of standard	________	
Any mixing zone specified?	yes/no	If yes: distance ________ m	or width ________	% or m
			or area ________	% or m^2
Region of interest	________ m	Grid intervals for display	________	

density specification and on wind effects.

CORMIX requires that the actual cross-section of the ambient water body be described by a rectangular channel that may be bounded laterally or unbounded. Furthermore, that channel is assumed to be uniform in the downstream direction, following the mean flow of the actual water body that may be non-uniform or meandering. The process of describing a receiving water body's geometry with a rectangular cross-section is herein called **schematization.**

Additional aids exist for the CORMIX user for interpreting plume behavior in the far-field of actual non-uniform (winding or meandering) flows in rivers or estuaries (see Section 6.2 for the post-processor option FFLOCATR).

The first step towards specifying the ambient conditions is to determine whether a receiving water body should be considered "bounded" or "unbounded." To do this, as well as answer other questions on the ambient geometry, it is usually necessary to have access to cross-sectional diagrams of the water body. These should show the area normal to the ambient flow direction at the discharge site and at locations further downstream. If the water body is constrained on both sides by banks such as in rivers, streams, narrow estuaries, and other narrow watercourses, then it should be considered "bounded." However, in some cases the discharge is located close to one bank or shore while the other bank is for practical purposes very far away. When interaction of the effluent plume with that other bank or shore is impossible or unlikely, then the situation should be considered "unbounded." This would include discharges into wide lakes, wide estuaries, and coastal areas.

4.3.1 Bounded Cross-Section

Both geometric (bathymetric) and hydrographic (ambient discharge) data should be used for defining the appropriate rectangular cross-section. This schematization may be quite evident for well-channeled and regular rivers or artificial channels. For highly irregular cross-sections, it may require more judgment and perhaps several iterations of the analysis to get a better feel on the sensitivity of the results to the assumed cross-sectional shape.

In any case, the user is advised to consider the following comments:

a) Be aware that a particular flow condition such as a river discharge is usually associated with a certain water surface elevation or "stage." Data for a stage-discharge relationship is normally available from a USGS office; otherwise it can be obtained from a separate hydraulic analysis or from field measurements.

In the simplest case of a river flow, if river depth is known for a certain flow condition (subscript 1 in the following) corresponding perhaps to the situation at the time of a field study, then the depth for a given design (e.g. low) flow (subscript 2) can be predicted from Manning's equation

$$HA_2 = HA_1 \left[\frac{QA_2}{QA_1} \right]^{\frac{3}{5}}$$

in which QA is the ambient river flow and HA the mean ambient depth. This approach assumes that the both the ambient width and frictional characteristics of the channel (i.e. Manning's n) remain approximately the same during such a stage change.

b) For the given stage/river discharge combination to be analyzed, assemble plots showing the cross-sections at the discharge and several downstream locations. Examine these to determine an "equivalent rectangular cross-sectional area." Very shallow bank areas or shallow floodways may be neglected as unimportant for effluent transport. Also, more weight should be given to the cross-sections at, and close to, the discharge location since these will likely have the greatest effect on near-field processes. Figure 4.1a provides an example of the schematization process for a river or estuary cross-section.

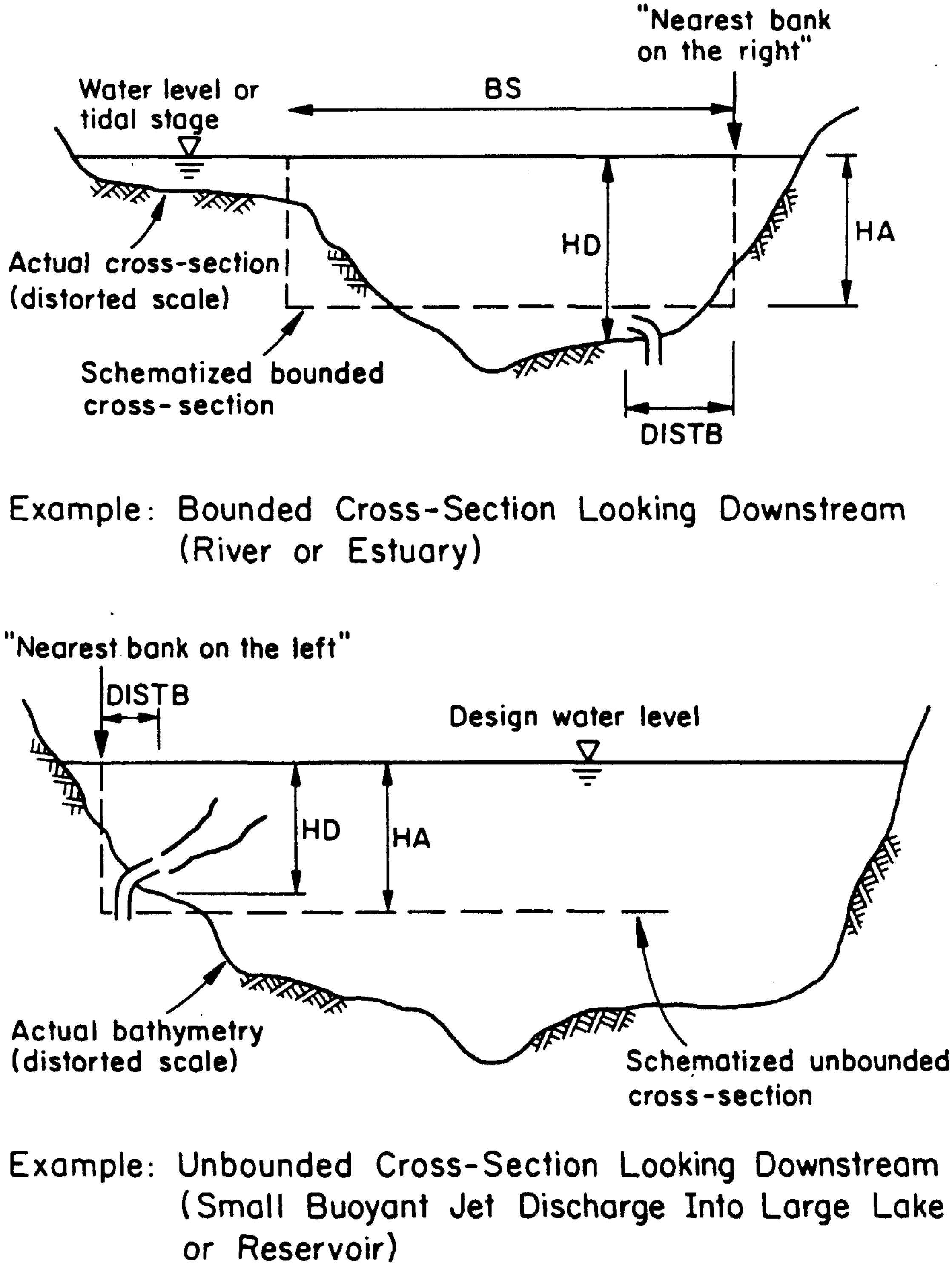


Figure 4.1: Examples of the schematization process for preparing CORMIX input data on ambient cross-sectional conditions

c) The input data values for **surface width (BS)** and **(average) depth (HA)** should be determined from the equivalent rectangular cross-sectional area. When ambient discharge and ambient velocity data are available, the reasonableness of the schematization should be checked with the continuity relation. It specifies that ambient discharge equals velocity times cross-sectional area, where the area is given by the product of average width and depth.

The discussion of the cumulative discharge method (see Section 6.2 and Figure 6.2 for an illustration) will provide further perspective on the choice of these variables.

d) CORMIX also requires specification of the **actual water depth (HD)** in the general discharge location to describe local bathymetric features. A check is built in allowing the local depth HD not to differ from the schematized average depth HA by more than +/- 30%. This restriction is included to prevent CORMIX misuse in several discharge/ambient combinations involving strongly non-uniform channels. Alternative schematizations can be explored by the user to work around the restriction. The choice for these alternatives may be influenced somewhat by the expected plume pattern. As an example, Figure 4.1b illustrates a small buoyant discharge that is located on the side slope of a deep reservoir and that is rising upward. In this situation, the correct representation of the deeper mean reservoir depth is irrelevant for plume predictions. Although the illustration is for an unbounded example, the comments on choice of HA apply here, too.

When schematizing HA and HD in highly non-uniform conditions, HD is the variable that usually influences near-field mixing, while HA is important for far-field transport and never influences the near-field.

e) The **ambient discharge (QA)** or **mean ambient velocity (UA)** may be used to specify the ambient flow condition. Depending which is specified, the program will calculate and display the other. The displayed value should be checked to see whether it is consistent with schematizations and continuity principles discussed above.

The simulation of **stagnant conditions** should usually be avoided. If zero or a very small value for ambient velocity or discharge is entered, CORMIX will label the ambient environment as stagnant. In this case, CORMIX will predict only the near-field of the discharge, since steady-state far-field processes require a mean transport velocity. Although stagnant conditions often, but not necessarily always, represent the extreme limiting case for a dilution prediction, a real water body never is truly stagnant. Therefore, a more realistic assumption for natural water bodies would be to consider a small, but finite ambient crossflow.

f) As a measure of the roughness characteristics in the channel the value of **Manning's n**, or alternatively of the **Darcy-Weisbach friction factor f**, must be specified. Friction values are useful for applications in laboratory studies. If Manning's n is given, as is preferable for field cases, CORMIX internally converts it to an f friction value using the following equation

$$f = 8\,g\,\frac{n^2}{HA^{1/3}}$$

in which g = 9.81 m/s^2.

The friction parameters influence the mixing process only in the final far-field diffusion stage, and do not have a large impact on the predictions. Generally, if these values can be estimated within +/-30%, the far-field predictions will vary by +/-10% at the most. The following list is a brief guide for specification of Manning's n values; additional details are available in hydraulics textbooks (e.g. 24).

g) The **channel appearance** can have an effect on the far field mixing by increasing turbulent diffusivity for the passive mixing process, but will not significantly affect near-field mixing. Three channel appearance types are allowed in CORMIX. Type 1 are fairly straight and uniform channels. Type 2 have moderate downstream meander with a non-uniform channel. Type 3 are strongly winding and have highly irregular downstream cross-sections.

Channel type	Manning's n
Smooth earth channel, no weeds	0.020
Earth channel, some stones and weeds	0.025
Clean and straight natural rivers	0.025 - 0.030
Winding channel, with pools and shoals	0.033 - 0.040
Very weedy streams, winding, overgrown	0.050 - 0.150
Clean straight alluvial channels (d = 75% sediment grain size in feet)	0.031 $d^{1/6}$

4.3.2 Unbounded Cross-section

Both hydrographic and geometric information are closely linked in this case. The following comments apply:

a) From lake or reservoir elevation or tidal stage data, determine the water depth(s) for the receiving water condition to be analyzed.

b) For the given receiving water condition to be analyzed, assemble plots showing water depth as a function of distance from the shore for the discharge location and for several positions downstream along the ambient current direction.

c) If detailed hydrographic data from field surveys or from hydraulic numerical model calculations are available, determine the **"cumulative ambient discharge"** from the shore to the discharge location for the discharge cross-section. For each of the subsequent downstream cross-sections, determine the distance from the shore at which the same cumulative ambient discharge has been attained. Mark this position on all cross-sectional profiles. Examine the vertically averaged velocity and the depth at these positions to determine typical values for the **ambient depth (HA)** and **ambient velocity (UA)** input specifications. The conditions at, and close to, the discharge location should be given the most weight. The **distance from the shore (DISTB)** for the outfall location is typically specified as the cumulative ambient discharge divided by the product UA times HA.

When detailed hydrographic data are unavailable, data or estimates of the vertically averaged velocity at the discharge location can be used to specify HA, UA, and DISTB. First, determine the cumulative cross-sectional area from the shore to the discharge location for the discharge cross-section. For each of the subsequent downstream cross-sections, mark the position where the cumulative cross-sectional area has the same value as at the discharge cross-section. Then proceed as discussed in the preceding paragraph.

d) The specification of the **actual water depth at the submerged discharge location (HD)** in CORMIX1 and 2 is governed by considerations that are similar to those discussed earlier for bounded flow situations discussed above. Figure 4.1b shows an illustration of the schematization for a small buoyant discharge located on the side slope of a deep reservoir. The plume is expected to rise upward and stay close to one shore, with bottom contact and vertical mixing not expected. In this situation, no emphasis on replicating the mean reservoir depth and the actual width is necessary. However, care must still be taken to specify an ambient mean velocity that is: (a) characteristic of the actual reservoir and (b) not determined using the reduced depth assumption.

The specification of HD for CORMIX3 is dictated by the depth condition some distance offshore from the discharge exit. It does not describe the conditions immediately in front of the discharge channel exit. When in doubt, set HD simply equal to HA in the CORMIX3 case.

e) Either **Manning's n** or the **Darcy-Weisbach friction factor f** can be specified for the ambient roughness characteristics as described previously for the bounded case (see above). If the unbounded case represents a large lake or coastal area, it is often preferable to use the friction factor f. Typical f values for such open water bodies range from 0.020 to 0.030, with larger values for rougher conditions.

4.3.3 Tidal Reversing Ambient Conditions

When predictions are desired in an unsteady ambient flow field, information on the tidal cycle must be supplied. In general, estuaries or coastal waters can exhibit considerable complexity with variations in both velocity magnitude, direction and water depth. As an example, Figure 4.2 shows the time history of tidal velocities and tidal height for a mean tidal cycle at some site in Long Island Sound. The tidal height varies between mean Low Water (MLW) and Mean High water (MHW).

The tidal velocity changes its direction twice during the tidal cycle at times called slack tide. One of these times occurs near, but is not necessarily coincident with, the time MLW and is referred to as Low Water Slack (LWS). The slack period near MHW is referred to as High Water Slack (HWS). The rate reversal (time gradient of the tidal velocity) near these slack tides is of considerable importance for the concentration build-up in the transient discharge plume, as tidal reversals will reduce the effective dilution of a discharge by re-entraining the discharge plume remaining from the previous tidal cycle (8). Hence, CORMIX needs some information on the ambient design conditions relative to any of the two slack tides.

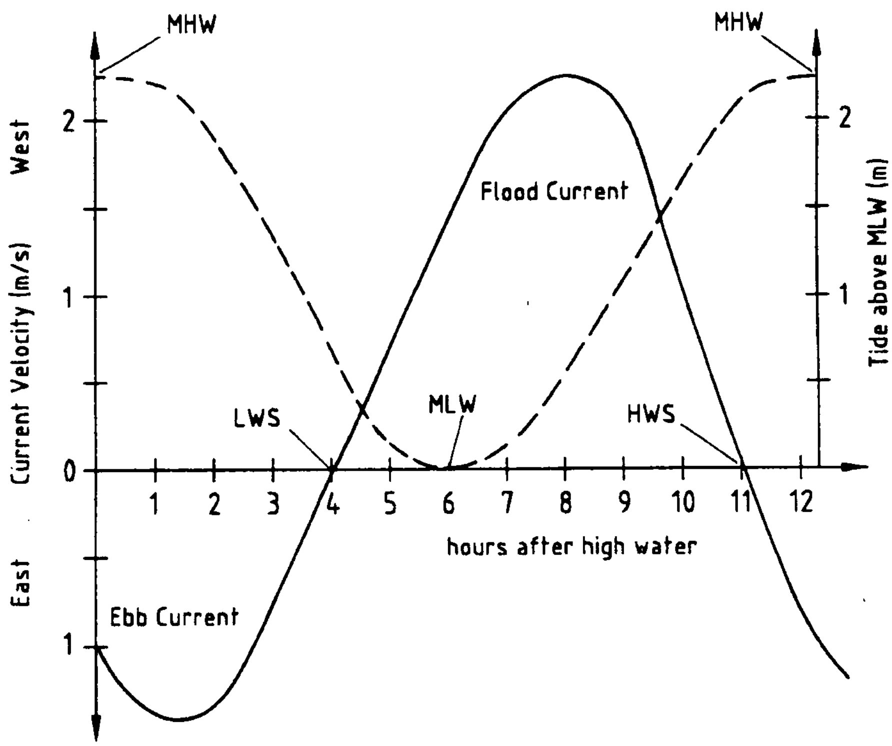


Figure 4.2: Example of tidal cycle, showing stage and velocity as a function of time after Mean High Water (MHW)

The **tidal period (PERIOD)** must be supplied; in most cases it is 12.4 hours, but in some locations it may vary slightly. The **maximum tidal velocity (UAmax)** for the location must be specified; this can usually be taken as the average of the absolute values of the two actual maxima, independent of their direction. A CORMIX design case consists then of an instantaneous ambient condition, before, at or after one of the two slack tides. Hence, the analyst must specify the **time** (in hours) **before, at, or after slack** that defines the design condition, followed by the actual **tidal ambient velocity (UA)** at that time. The ambient depth conditions are then those corresponding to that time.

In general, tidal simulations should be repeated for several time intervals (usually hourly or two-hourly intervals will suffice) before and after slack time to determine plume characteristics in unsteady ambient conditions.

Strongly unsteady conditions can also occur in other environments, such as in wind-induced current reversals in shallow lakes or coastal areas. In this case, any typical reversal period can be analyzed following an approach similar to the above.

4.3.4 Ambient Density Specification

Information about the density distribution in the ambient water body is very important for the correct prediction of effluent discharge plume behavior. CORMIX first inquires whether the ambient water is **fresh water** or **non-fresh** (i.e. brackish or saline). If the ambient water is fresh and above 4 °C, the system provides the option of entering ambient temperature data so that the ambient density values can be internally computed from an equation of state. This is the recommended option for specifying the density of fresh water, even though ambient temperature per se is not needed for the analysis of mixing conditions. In the case of salt water conditions, Figure 4.3 is included as a practical guide for specifying the density if "salinity values" in parts-per-thousand (ppt) are available for the water body. Typical open ocean salinities are in the range 33 - 35 ppt.

The user then specifies whether the ambient density (or temperature) can be considered as **uniform** or as **non-uniform** within the water body, and in particular within the expected plume regions. As a practical guide, vertical variation in density of less than 0.1 kg/m^3 or in temperature of less than 1 °C can be neglected. For uniform conditions, the **average ambient density** or **average temperature** must be specified.

When conditions are non-uniform, CORMIX requires that the actual measured vertical density distribution be approximated by one of three schematic stratification profile types illustrated in Figure 4.4. These are: Type A, linear density profile; Type B, two-layer system with constant densities and density jump; Type C, constant density surface layer with linear density profile in bottom layer separated by a density jump. Corresponding profile types exist for approximating a temperature distribution when it is used for specifying the density distribution.

Note: When in doubt about the specification of the ambient density values it is reasonable to first simplify as much as possible. The sensitivity of a given assumption can be explored in subsequent CORMIX simulations. Furthermore, if CORMIX indicates indeed a flow configuration (flow class) with near-field stability, additional studies with the post-processor option CORJET (see Section 6.1) can be performed to investigate *any arbitrary density distribution.*

After selecting the stratification approximation to be used, the user then enters all appropriate density (or temperature) values and **pycnocline heights (HINT)** to fully specify the profiles. The pycnocline is defined as zone or level of strong density change that separates the upper and lower layers of the water column. The program checks the density specification to insure that stable ambient stratification exists (i.e. the density at higher elevations must not exceed that at lower elevations).

Note that a dynamically correct approximation of the actua ldensity distribution should keep a balance between over-and under-estimationof the actual data similar to a best-fit in regression analysis. If simulation results indicate internal plume trapping, then it is

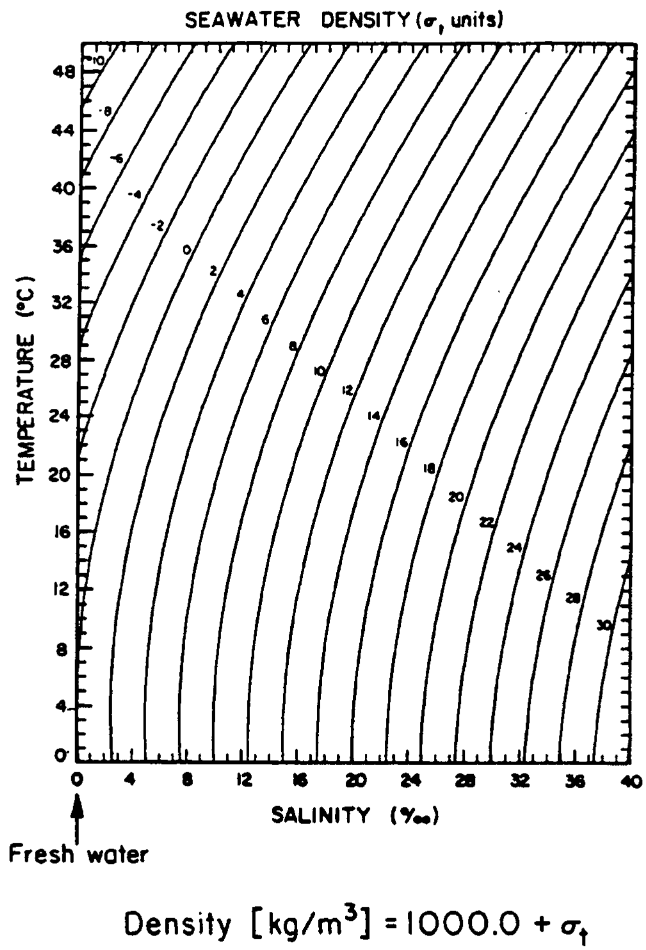


Figure 4.3: Diagram for density of seawater as a function of temperature and salinity

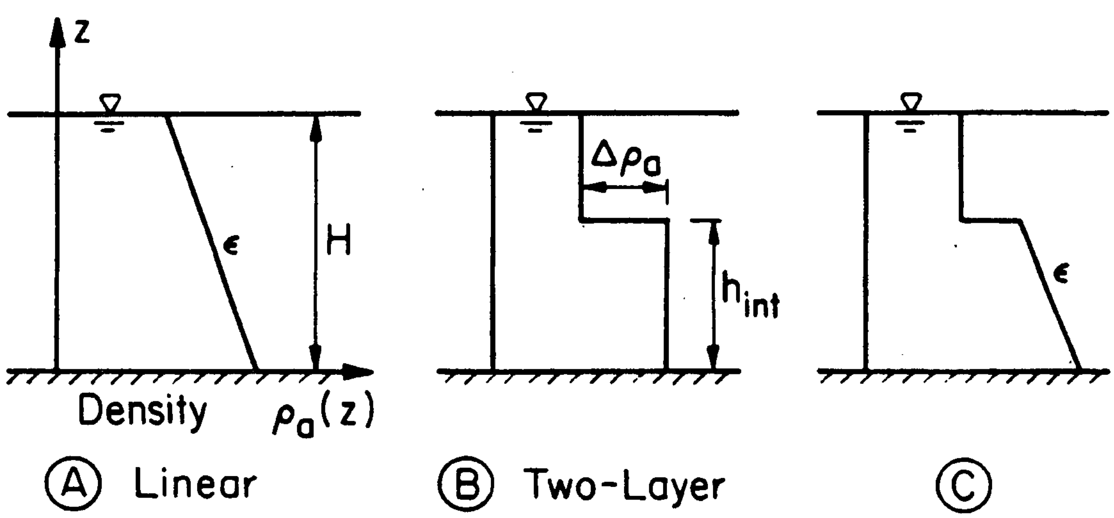


Figure 4.4: Different approximations for representing the ambient density stratification

desirable to test --through repeated use of CORMIX-- different approximations (i.e. with different stratification types and/or parameter values) in order to evaluate the sensitivity of the resulting model predictions.

4.3.5 Wind speed

When specifying the **wind speed (UW)** at design conditions, it should be kept in mind that the wind is unimportant for near-field mixing, but may critically affect plume behavior in the far-field. This is especially important for heated discharges in the buoyant spreading regions. Wind speed data from adjacent meteorological stations is usually sufficient for that purpose.

The following guidelines are useful when actual measured data are not available. The typical wind speed categories measured at the 10 m level are:

--- breeze (0-3 m/s)
--- light wind (3-15 m/s)
--- strong wind (15-30 m/s)

If field data are not available, consider using the recommended value of 2 m/s to represent conservative design conditions. An extreme low value of 0 m/s is usually unrealistic for field conditions, but useful when comparing to laboratory data. A wind speed of 15 m/s is the maximum value allowed in CORMIX.

4.4. Discharge Data: CORMIX1

Figure 4.5a is a definition sketch giving the geometry and flow characteristics for a submerged single port discharge within the schematized cross-section.

4.4.1 Discharge Geometry

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX1 requires the specification of 6 data entries. These specifications are illustrated in Figure 4.5a and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) **distance to the nearest bank (DISTB)**, (c) port **radius** (or **cross-sectional area** for non-circular shaped ports) (*Note:* The specification of the port dimension should account for any contraction effects that the effluent jet may experience upon leaving the port/nozzle!) , (d) **height of the port (H0)** center above the bottom, (e) **vertical angle of discharge (THETA)** between the port centerline and a horizontal plane, and (f) **horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerline. Angle THETA may range between -45° and 90°. As examples, the vertical angle is 90° for a discharge pointing vertically upward, and it is 0° for a horizontal discharge. Angle SIGMA may range between 0° and 360 °. As examples, the horizontal angle is 0° (or 360 °) when the port points downstream in the ambient flow direction, and it is 90°, when the port points to the left of the ambient flow direction.

In order to prevent an inappropriate system application, CORMIX1 checks the specified geometry for compliance with the three criteria illustrated in Figure 4.5b. These are: (a) the port height (H0) value must not exceed one-third of the local water depth (HD) value, (b) the port diameter value must not exceed HD's value for near-vertical designs, and one-third of HD's value for near-horizontal designs, and (c) the pycnocline value must be within the 40 to 90 percent range of HD's value. The port height restriction results from the fact that CORMIX1 only applies to submerged discharge applications.

In ordinary design practice, submerged implies a discharge close to the bottom, and not anywhere within the main water column or near the water surface. The port diameter restriction excludes very large discharge diameters relative to the actual water depth since these are unrealistic and/or undesirable. The distance separating the upper and lower layers of the ambient density profile type B or C is restricted in order to prevent: (a) discharges into the upper layer or (b) an unrealistically thick plume relative to a thin upper layer. For those few extreme situations that would normally be limited by the above restrictions, Section 7.4 of Doneker and Jirka (5) contains a number of hints on how to conduct these difficult analyses; <u>only advanced users should attempt these techniques</u>.

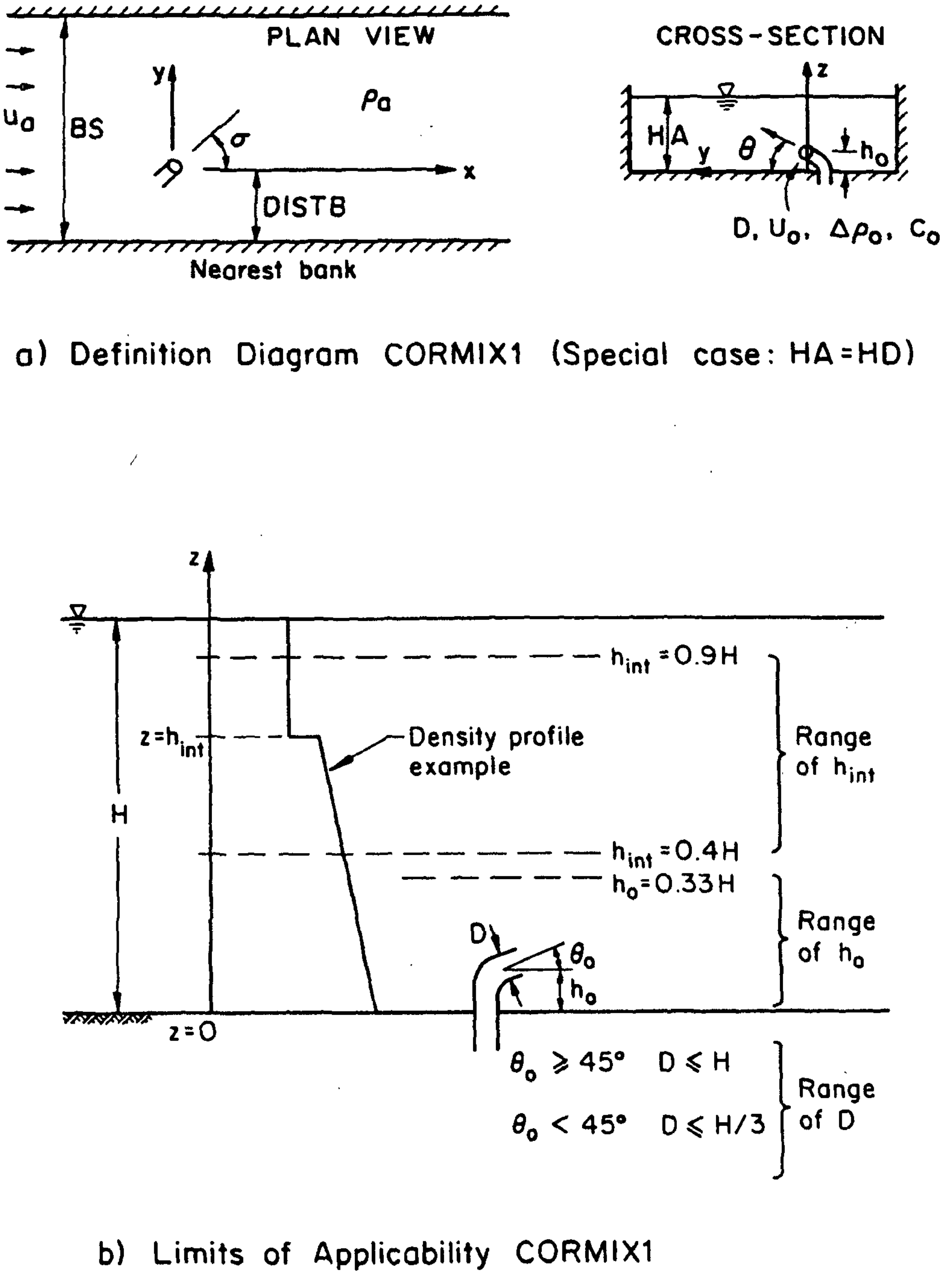


Figure 4.5: CORMIX1 discharge geometry and restrictions

4.4.2 Port Discharge Flow

For discharge characteristics, CORMIX1 requires the specification of 3 data entries. These specifications include: (a) the **discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the port cross-sectional area and the program computes and displays the alternate value allowing for user inspection and verification. For a freshwater discharge, discharge density can be directly related to temperature via an equation of state since the addition of any pollutant or tracer has negligible effect on density.

The specification of the pollutant in the effluent is described in Section 4.7 below.

4.5 Discharge Data: CORMIX2

A generalized definition sketch showing the geometry and flow characteristics for a typical multiport diffuser installation is provided in Figure 4.6a. Due to the great number of complexities which may rise in describing an existing or proposed diffuser design, a few definitions are introduced prior to discussing actual data requirements of CORMIX2.

A **multiport diffuser** is a linear structure consisting of many more or less closely spaced ports or nozzles which inject a series of turbulent jets at high velocity into the ambient receiving water body. These ports or nozzles may be connected to vertical risers attached to an underground pipe or tunnel or they may simply be openings in a pipe lying on the bottom.

The **diffuser line** (or axis) is a line connecting the first port or nozzle and the last port or nozzle. Generally, the diffuser line will coincide with the connecting pipe or tunnel. CORMIX2 will assume a straight diffuser line. If the actual diffuser pipe has bends or directional changes it must be approximated by a straight diffuser line.

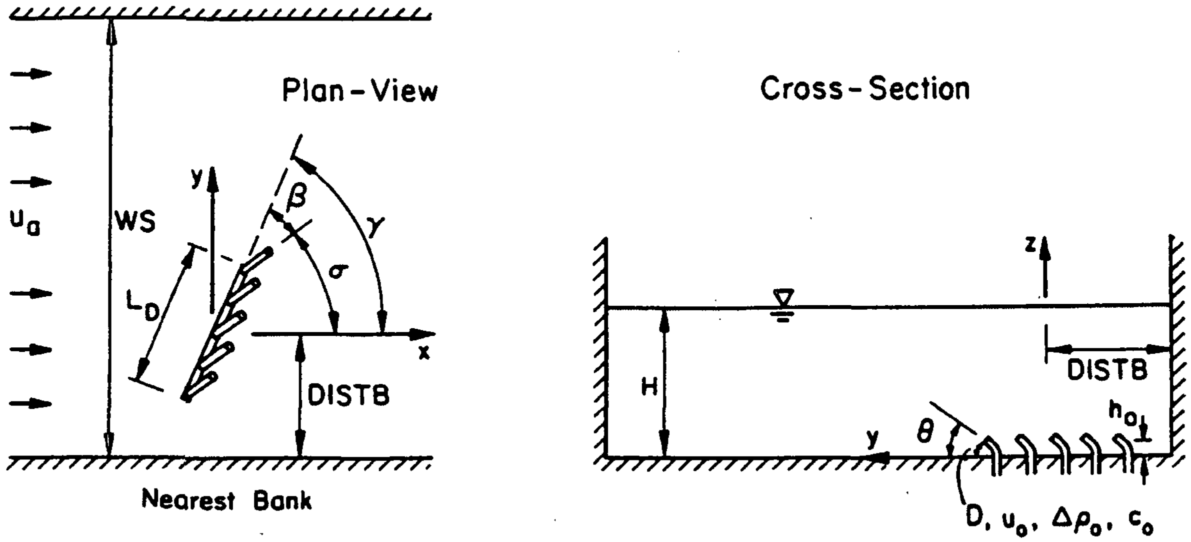
The **diffuser length** is the distance from the first to the last port or nozzle. The origin of the coordinate system used by CORMIX2 is located at the center (mid-point) of the diffuser line. The only exception is when the diffuser line starts at the shore; then the origin is located directly at the shore.

CORMIX2 can analyze discharges from the three major diffuser types used in common engineering practice. These are illustrated in Figure 4.7 and include: (a) the **unidirectional diffuser** where all ports (or nozzles) point to one side of the diffuser line and are oriented more or less normally to the diffuser line and more or less horizontally; (b) the **staged diffuser** where all ports point in one direction generally following the diffuser line with small deviations to either side of the diffuser line and are oriented more or less horizontally; and (c) the **alternating diffuser** where the ports do not point in a nearly single horizontal direction. In the latter case, the ports may point more or less horizontally in an alternating fashion to both sides of the diffuser line or they may point upward, more or less vertically.

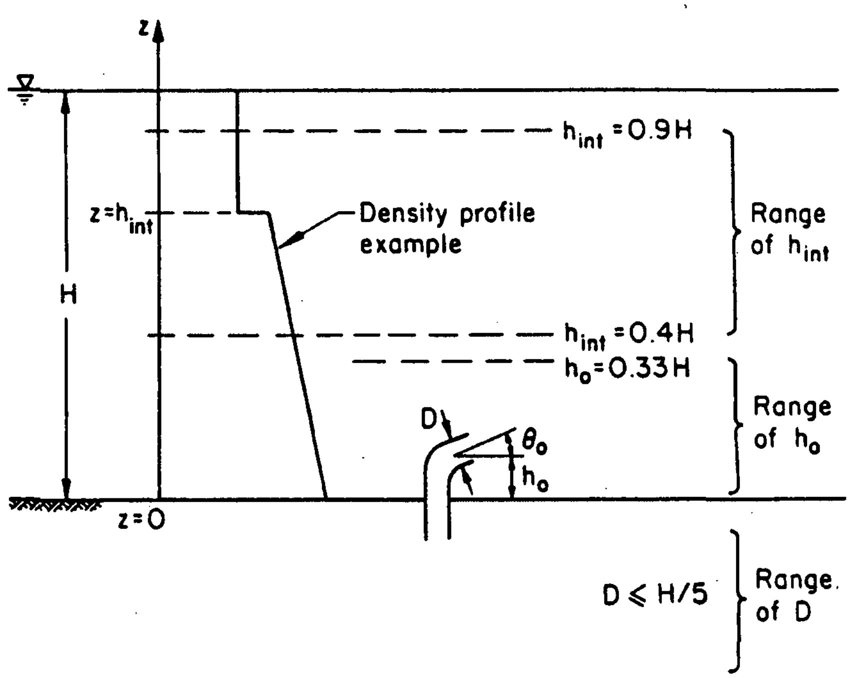
4.5.1 Diffuser Geometry

CORMIX2 assumes uniform discharge conditions along the diffuser line. This includes the local ambient receiving water depth (HD) and discharge parameters such as port size, port spacing and discharge per port, etc. If the actual receiving water depth is variable (e.g. due to an offshore slope), it should be approximated by the mean depth along the diffuser line with a possible bias to the more shallow near-shore conditions. Similarly, mean values should be used to specify variable diffuser geometry when it occurs.

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX2 requires the specification of 13 data entries. These specifications are illustrated in Figure 4.6a and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) average **distance to the nearest bank (DISTB)**, (c) **average diameter (D0)** of the discharge ports or nozzles, (d) **contraction ratio** for the port/nozzle is required (This can range from 1 for well rounded ports --usual value-- down to 0.6 for sharp-edged orifices), (e) average



a) Definition Diagram CORMIX2



b) Limits of Applicability CORMIX2

Figure 4.6: CORMIX2 discharge geometry and restrictions

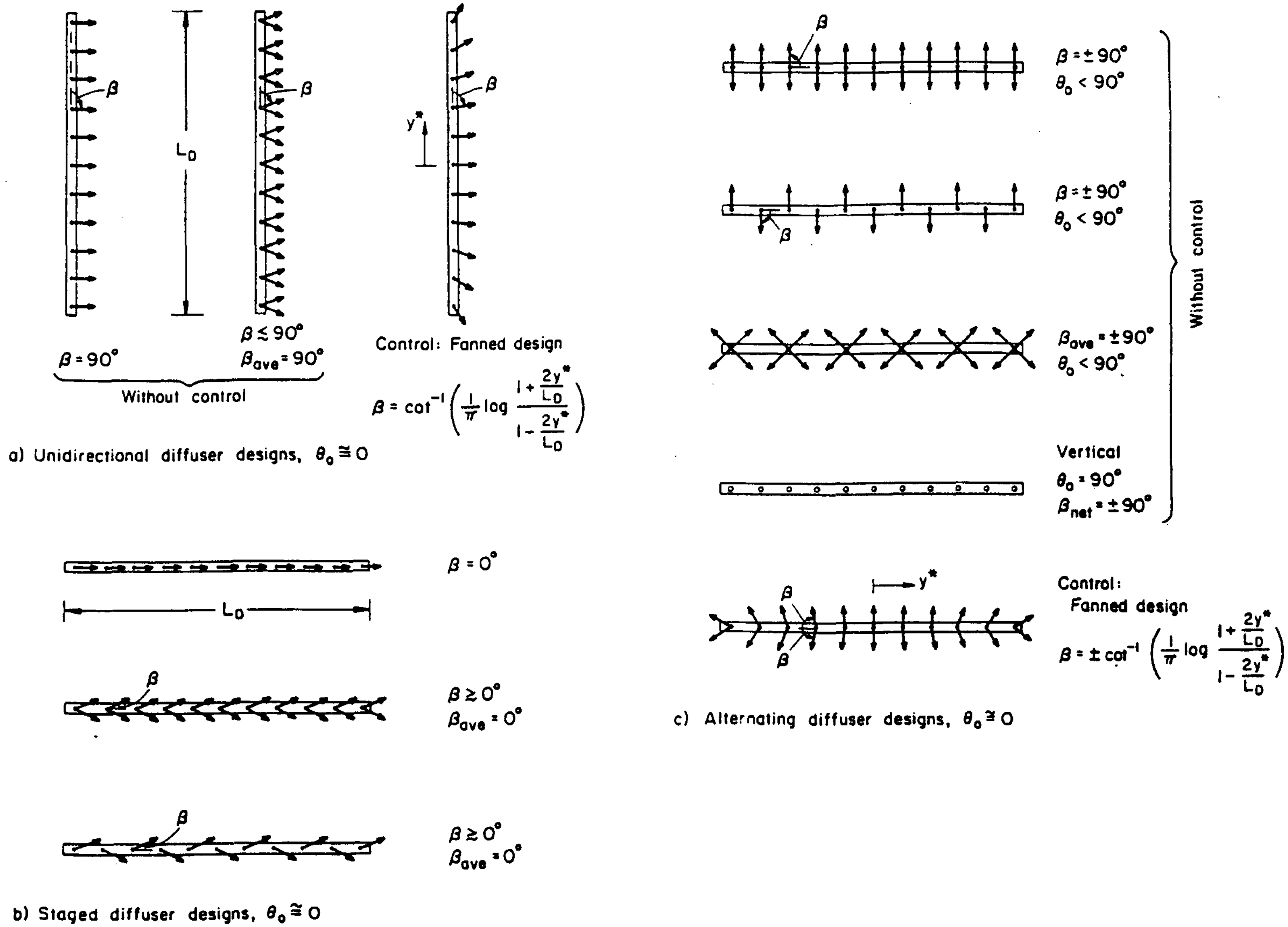


Figure 4.7: Configurations of common multiport diffuser types

height of the port centers (H0) above the bottom, (f) average **vertical angle of discharge (THETA)** between the port centerlines and a horizontal plane (-45 and 90°), (g)for the unidirectional and staged diffusers only, the average **horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerlines (0 to 360°), (h) approximate straight-line **diffuser length (LD)** between the first and last ports or risers, (I) **distance from the shore to the first and last ports or risers (YB1, YB2)** of the diffuser line, (j) number of ports or risers and the number of ports per riser if risers are present, (k) average **alignment angle (GAMMA)** measured counterclockwise from the ambient current direction (x-axis) to the diffuser axis (0 to 180 °), and (I) for the unidirectional and staged diffusers only, **relative orientation angle (BETA)** measured either clockwise or counterclockwise from the average plan projection of the port centerlines to the nearest diffuser axis (0 to 90°). Note that CORMIX2 always assumes a uniform spacing between risers or between ports, and a round port cross-sectional shape.

As examples of angle specifications, THETA is 0 degrees for a horizontal discharge and it is +90 degrees for a vertically upward discharge, SIGMA is 0 degrees (or 360°) when the ports point downstream in the ambient flow direction and it is 90 degrees when the ports point to the left of the ambient flow direction, GAMMA is 0 degrees (or 180°) for a parallel diffuser and it is 90 degrees for a perpendicular diffuser, and BETA is 0 degrees for a staged diffuser and it is 90 degrees for a unidirectional diffuser.

CORMIX2 performs a number of consistency checks to ensure the user does not make arithmetical errors when preparing and entering the above data and it also checks the specified geometry for compliance with three criteria to prevent an inappropriate system application. Figure 4.6b shows the imposed limits of system application for CORMIX2 which are: (a) the port height (H0) value must not exceed one-third of the local water depth (HD) value, (b) the port diameter value must not exceed one-fifth of HD's value, and (c) the pycnocline value must be within the 40 to 90 percent range of HD's value. The restrictions are similar to those shown in Figure 4.5b for CORMIX1 with the exception of the diameter limit for each port.

4.5.2 Diffuser Discharge Flow

For discharge characteristics, CORMIX2 requires the specification of 3 data entries. These specifications include: (a) the **total discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the total cross-sectional area of all diffuser ports and the program computes and displays the alternate value allowing for user inspection and verification.

The specification of the pollutant in the diffuser effluent is described in Section 4.7 below.

4.6 Discharge Data: CORMIX3

A definition sketch for the discharge geometry and flow characteristics for a buoyant surface discharge is provided in Figure 4.8. In general, CORMIX3 allows for different types of inflow structures, ranging from simple rectangular channels to horizontal round pipes that may be located at or near the water surface. In addition, three different configurations relative to the bank are allowed as illustrated in Figure 4.9. Discharge structures can be: (a) **flush** with the bank/shore, (b) **protruding** from the bank or (c) **co-flowing** along the bank.

4.6.1 Discharge Geometry

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX3 requires the specification of up to 7 data entries. These specifications are illustrated in Figure 4.8 and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) **discharge channel width (B0)** of the **rectangular channel**, (c)**discharge channel depth (H0)**, (d) **actual receiving water depth at the channel entry (HD0)** and (e) **bottom slope (SLOPE)** in the receiving water body in the vicinity of the discharge channel, and (f)**horizontal angle of discharge (SIGMA)** measured counterclock-wise from the ambient current direction (x-axis) to

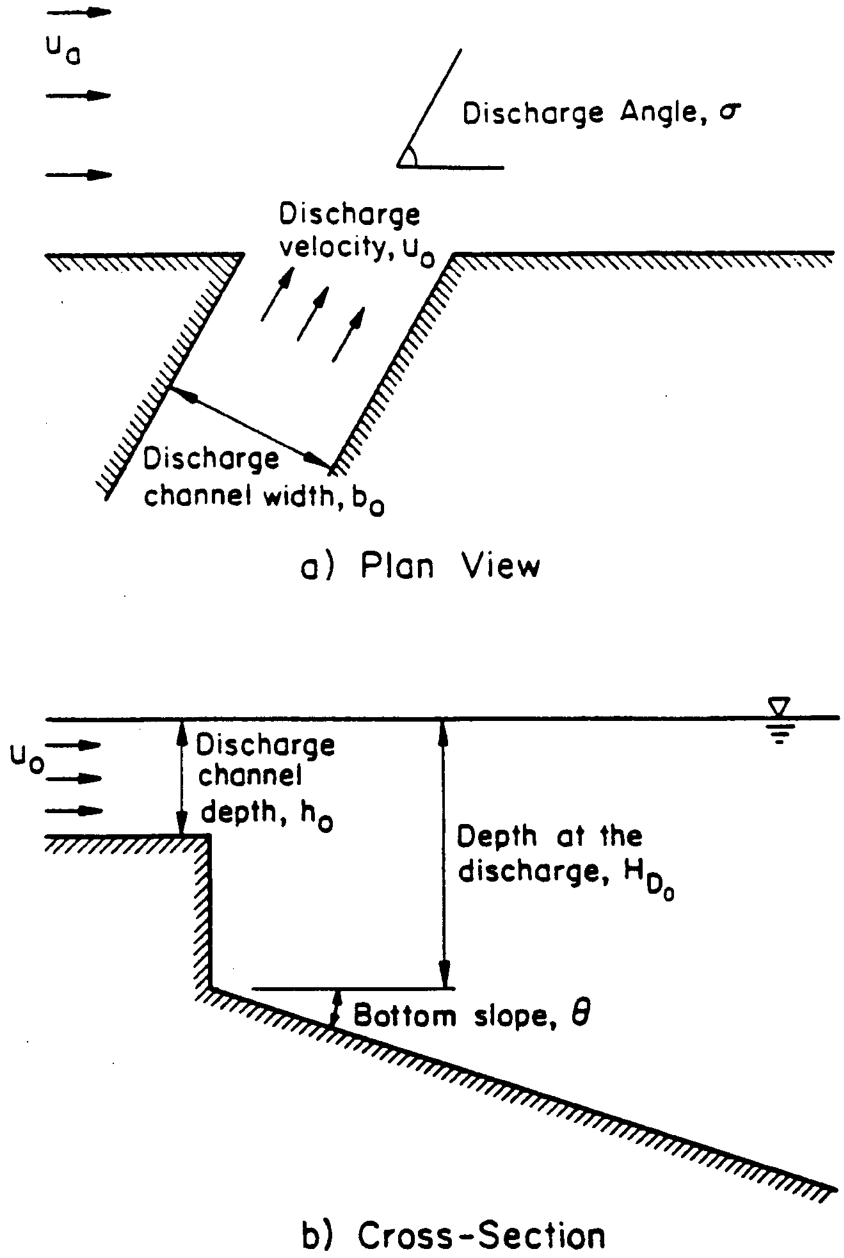


Figure 4.8: CORMIX3 discharge channel geometry

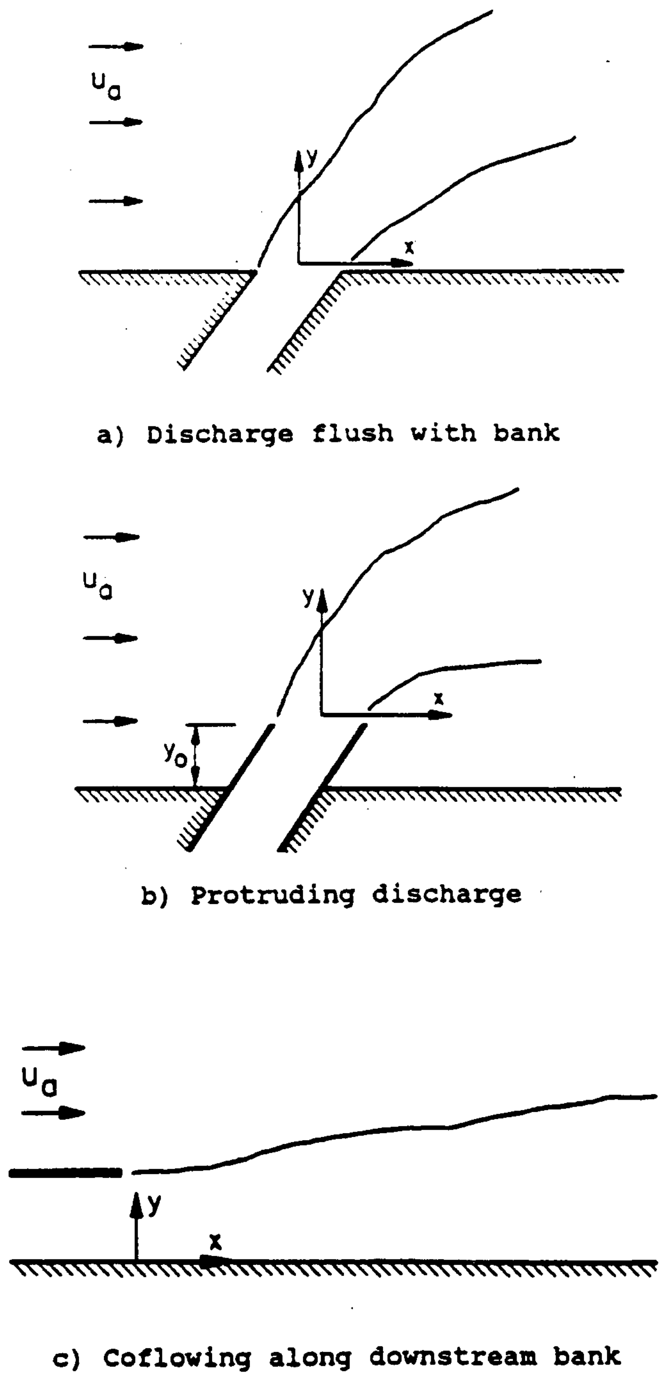


Figure 4.9: Possible CORMIX3 discharge configurations of discharge channel relative to bank/shoreline

the plan projection of the port centerline. In the case of a **circular discharge pipe**, the (b) **pipe diameter** and (c) **depth of bottom invert** below the water surface (water surface to bottom edge of pipe) must be specified, respectively. In all cases, CORMIX3 assumes the discharge is being issued horizontally.

CORMIX3 uses the variable HD0 for the actual water depth just in front of the channel exit and requires an additional specification for the receiving water bottom slope, again in front of the exit, extending into the receiving water body. These details are important for identifying cases where plume attachment to the bottom can occur.

In the case of a circular pipe discharge CORMIX3 assumes the outlet is flowing full and that it is not submerged under the water surface by more than ½ of the outlet diameter. If the discharge outlet has an odd cross-sectional shape (e.g. a pipe flowing partially full) then it should be represented schematically as a rectangular outlet of the same cross-sectional area and similar channel depth.

For open channel discharges, considerable care should be exercised when specifying discharge channel depth since this parameter is directly linked to the ambient receiving water depth (stage). This is especially important for tidal situations.

To prevent an inappropriate system application, CORMIX3 only allows for a discharge channel depth-to-width aspect ratio of 0.05 to 5. This prohibits the use of extremely oblong discharge geometry.

4.6.2 Discharge Flow

For discharge characteristics, CORMIX3 requires the specification of 3 data entries. These specifications include: (a) the **total discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the channel cross-sectional area; the program computes and displays the alternate value allowing for user inspection and verification.

The discharge concentration of the material of interest (pollutant, tracer, or temperature) is defined as the excess concentration above any ambient concentration of that same material. The user can specify this quantity in any units. CORMIX1 predictions should be interpreted as computed excess concentrations in these same units. If no specific pollutant is under consideration, simply specify a discharge concentration of 100%.

4.7 Pollutant Data

CORMIX allows three types of pollutant discharges:

(a) Conservative Pollutant:
The pollutant does not undergo any decay/growth processes.

(b) Non-conservative Pollutant:
The pollutant undergoes a first order decay or growth process. One needs to specify the **coefficient of decay** (positive number) **or growth** (negative number) in units: /day (per day).

(c) Heated Discharge:
The discharge will experience heat loss to the atmosphere in cases where the plume contacts the water surface. It is necessary to specify the discharge condition in terms of *excess temperature ("delta T") above ambient in units degC*, and the **surface heat exchange coefficient** in units W/m^2,degC. Values of the heat exchange coefficient depend on ambient water temperature and wind speed. The following listing provides a guideline for the selection.

Typically, the near-field behavior is quite insensitive to the choice of these values, but it may affect the prediction results at greater distances in the far-field.

The **discharge concentration (C0)** of the material of interest (pollutant, tracer, or temperature) is defined as the *excess concentration above any ambient background concentration* of that same material. The user can specify this quantity in any **units of concentration** (e.g. mg/l, ppm, %, °C). CORMIX predictions should be interpreted as computed excess concentrations in these same units.

SURFACE HEAT EXCHANGE COEFFICIENT (W/m^2,°C)
Values for a lightly heated, natural water surface
(local excess temperatures 0 to 3 °C)

Ambient Water Temp. (°C)	Wind Speed (m/s) 0	1	2	4	6	8
5	5	10	14	24	33	42
10	5	11	16	27	38	49
15	5	12	18	31	44	59
20	5	14	21	38	52	68
25	6	16	25	45	63	82
30	6	19	30	54	76	100

Ref: "Heat Disposal in the Water Environment", E.E. Adams, D.R.F. Harleman, G.H. Jirka, and K.D. Stolzenbach, Course Notes, R.M. Parsons Laboratory, Mass. Inst. of Techn., 1981.

If no pollutant data at all is available, it is most convenient to specify C0 = 100 %.

In case of an **ambient background concentration** it is important to treat all pollutant related data items in a consistent fashion. This includes the specification of any regulatory values as discussed in Section 4.8 below.

> _Example:_ suppose the actual discharge concentration for a particular pollutant is 100 mg/l, and values of CMC and CCC for the pollutant are 20 mg/l and 10 mg/l, respectively. If the background ambient concentration for the same pollutant is 4 mg/l, the data entry to CORMIX would be for the discharge concentration = 96 mg/l, for CMC = 16 mg/l, and for CCC = 6 mg/l, respectively. All concentration values listed in the diverse CORMIX output (see Chapter V) must then be interpreted accordingly, and the actual concentration values are computed by adding the background concentration value. E.g. if the CORMIX predicted value for one particular point happens to be 13.6 mg/l, then the total concentration value at that point would be 17.6 mg/l. Also, all program mixing zone messages would occur at correct regulatory concentrations because they are interpreted as excess plume concentrations above ambient.

4.8 Mixing Zone Data

The user must indicate: (a) whether EPA's toxic dilution zone (TDZ) definitions apply, (b) whether an ambient water quality standard exists, (c) whether a regulatory mixing zone (RMZ) definition exists, (d) the spatial region of interest (ROI) over which information is desired, and (e) number of locations (i.e. "grid intervals") in the ROI to display output details. Depending on the responses to the above, several additional data entries may be necessary as described in the following paragraphs.

When TDZ definitions apply, the user must also indicate the criterion maximum concentration (CMC) and criterion continuous concentration (CCC) which are intended to protect aquatic life from acute and chronic effects, respectively. CORMIX will check for compliance with: (a) the CMC standard at the edge of the TDZ and (b) the CMC standard at the edge of the RMZ, proving a RMZ was defined. See Subsection 2.2.2 for additional discussion.

When a RMZ definition exists, it can be specified by: (a) a distance from the discharge location, (b) the cross-sectional area occupied by the plume, or (c) the width of the effluent plume.

The ROI, which is a user defined region where mixing conditions are to be analyzed, is specified as the maximum analysis distance in the direction of mixed effluent flow. The level of detail for the output data within the ROI and thus, for the entire hydraulic simulation, is established by specifying the number of grid intervals that will be displayed in the output files. This parameter's allowable range is 3 to 50 and the chosen value does not affect the accuracy of the CORMIX prediction, only the amount of output detail. A low value should be specified for initial calculations to minimize printout lengths while a large value might be desirable for final predictions to give enough resolution for plotting of plume dimensions.

4.9 Units of Measure

CORMIX uses the metric system of measurement. When data values are provided to the user in English units, these must be converted to equivalent metric measures. The list at the beginning of this manual gives the five metric dimensions used by CORMIX in the left column, and on the right, their equivalents in some common English units.

Pollutant concentrations can be entered in any conventional measure such as mg/L, ppb, bacteria-count, etc.

Considering the potential accuracy of CORMIX predictions, 3 to 4 significant digits are sufficiently accurate for most input data values as suggested in the above conversion list. The only exceptions are the ambient and effluent density values. These may require 5 significant digits, especially when simulating the discharge to an ambient density-stratified receiving water body.

V CORMIX Output Features

CORMIX is a highly interactive system and conveys information to the user through qualitative descriptions and detailed quantitative numerical predictions. This output can be viewed on-screen in text mode or graphics mode, can be directed to a printer, and is stored in subdirectory CORMIX\SIM and CORMIX\SIM\CXn files. In this chapter the label n = 1, 2 or 3 designates the appropriate CORMIX subsystem.

5.1 Qualitative Output: Flow Descriptions

After completion of the input data entry sequences, the system proceeds through the program elements following the flow chart displayed in Figure 3.1. In addition to the routine operational messages provided during program execution, important qualitative information is displayed on-screen about the ongoing analysis of the given ambient/discharge case. The three general types of descriptive information provided are: (a) descriptive messages, (b) length scale computation results and (c) flow class descriptions. The paragraphs within this Section aid in the interpretation of that information.

The program elements PARAM and CLASS, in particular, provide essential information on the expected dynamic behavior of the discharge. By actively participating in the interactive process, the novice and intermediate user can derive a substantial educational benefit and a technical appreciation of the physical aspects of initial mixing processes. Although advanced users may find some of the presented material somewhat repetitive, they should still consult the length scale computation results.

5.1.1 Descriptive Messages

These messages provide both physical information and insight into the logic reasoning employed by CORMIX. Three example descriptive messages are:

```
"The effluent density (1004.5 kg/m^3) is greater than the surrounding
water density at the discharge level (997.2 kg/m^3).
Therefore, the effluent is negatively buoyant and will tend to sink
towards the bottom."

"STRONG BANK INTERACTION will occur for this perpendicular diffuser
type due to its proximity to the bank (shoreline). The shoreline will
act as a symmetry line for the diffuser flow field.
The diffuser length and total flow variables are doubled (or
approximately doubled, depending on the vicinity to the shoreline).
All of the following length scales are computed on that basis."

"The specified two layer ambient density stratification is dynamically
important. The discharge near field flow will be confined to the lower
layer by the ambient density stratification.
Furthermore, it may be trapped below the ambient density jump at the
pycnocline."
```

The preceding example output highlights several features of CORMIX's descriptive messages. These include: (a) conveying basic information about the involved mixing processes, (b) using a careful terminology (e.g. "..tend to sink.."), (c) describing key calculation assumptions, and (d) alerting the user to sensitive analysis conditions. In some instances, the provided information may be obvious to the user, while in others it may not, particularly for situations involving linear ambient stratification. The use of a careful terminology is necessary because messages are presented as the analysis proceeds and subsequent tests may alter, or amplify, initial results. For example, near-field instabilities, which are tested for late in the analysis, can prevent an otherwise sinking plume.

5.1.2 Length Scale Computations

The program element PARAM computes so-called **"length scales"** which represent important dynamic measures about the relative influence of certain hydrodynamic processes on effluent mixing. These calculated values are subsequently used in program element CLASS to identify the generic flow class upon which the hydraulic simulations will be based. This flow classification is accomplished through formal dynamic **length scale analysis**, which is a key aspect of the theoretical underpinnings for the CORMIX approach. The CORMIX documentation manuals (5,6,7) and related journal publications provide the theoretical background on length scale definitions and significance, their derivation from principles of dimensional analysis, and their use in the CORMIX flow classification approach.

Although flow classification is a formal process using criteria derived from theoretical studies and/or experimental data, a great deal can be deduced about the flow dynamics by comparing the calculated length scales to the actual physical measures of the ambient/discharge situation. Of greatest importance are comparison to such geometric measures as: the available water depth (HD), a pycnocline height (HINT) and the distance to the nearest bank (DISTB). The following discussion provides a brief explanation of the more important length scales and examples on how to make appropriate comparisons in a given application. Users are encouraged to make these comparisons.

a) Single port discharges: Some important length scales relating to submerged round buoyant jets (CORMIX1) are described in Table 5.1. All of these scales are defined from an interplay of the momentum and buoyancy flux quantities of the discharge with each other or with the current velocity and stratification gradient variables.

As an example, consider a vertically discharging buoyant jet into an unstratified ambient receiving water. When both calculated L_m and L_b values are substantially less than the local water depth (HD), this is an immediate indication to the user that the crossflow is very strong, leading to complete bending of the buoyant jet. If the reverse holds true, the crossflow may be so weak that its deflecting effect is negligible, and the buoyant jet will strongly interact (impinge) with the water surface. In the first instance, a situation as depicted in Figures 2.1b combined with Figure 2.1a will result, while in the second instance, a flow resembling Figures 2.2c or 2.2d may arise, depending on the relation of the two scales with each other.

As another example, consider a buoyant jet discharging into a linearly stratified ambient. If both L_m' and L_b' both larger than the pycnocline height (HINT) and even the water depth (HA), this would be an indication that the existing stratification is so weak that it will not lead to any trapping of the effluent plume within the available vertical space.

By making such comparisons, users will gradually get a good feel for the behavior of the buoyant jet, and other mixing processes within the space constraints of the ambient environment. Those interested in design can quickly gain an appreciation of the length scale measures and their sensitivity to design choices. However, there are limitations to these simplistic comparisons because the "length scales" are by no means precise measurements for the influence of the different processes. As their name implies they should be taken only as "scale" estimates. The actual CORMIX classification scheme uses formal criteria when comparing the length scale measures with the geometric constraints or each other.

b) Multiport diffusers: Some important length scales for multiport diffusers (CORMIX2) are described in Table 5.2.

To a large extent, these scales have a similar meaning for the behavior of the plane buoyant jet as the earlier ones discussed for the round buoyant jet (Table 5.1). However, they are calculated differently because the CORMIX2 system uses the "equivalent slot diffuser" concept to model the overall dynamics of the submerged multiport diffuser (Section 3.1). Except for the immediate close-up zone before the individual jets merge (Figure 2.1d) this concept is a dynamically valid and accurate representation of multiport diffuser flows (6).

Table 5.1
Length Scales for Single Port Submerged Discharges
(Used in CORMIX1 and CORMIX2)

Jet/plume transition length scale $L_M = M_o^{3/4} / J_o^{1/2}$

interpretation: For combined buoyant jet flow, the distance at which the transition from jet to plume behavior takes place in a stagnant uniform ambient.

Jet/crossflow length scale $L_m = M_o^{1/2} / u_a$

interpretation: In the presence of a crossflow, the distance of the transverse (i.e. across ambient flow) jet penetration beyond which the jet is strongly deflected (advected) by the cross flow. For a strictly co-flowing discharge ($\theta = 0$, $\sigma = 0$), the length of the region beyond which the flow is simply advected.

Plume/crossflow length scale $L_b = J_o / u_a^3$
interpretation: The vertically upward or downward flotation distance beyond which a plume becomes strongly advected by crossflow.

Jet/stratification length scale $L_m' = M_o^{1/4} / \epsilon^{1/4}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **jet** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Plume/stratification length scale $L_b' = J_o^{1/4} / \epsilon^{3/8}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **plume** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Notes: $M_o = U_oQ_o$, kinematic momentum flux
$J_o = g'_oQ_o$, kinematic buoyancy flux
$Q_o = U_oa_o$, source discharge volume flux
a_o = port area
u_a = ambient velocity
U_o = port discharge velocity
ϵ = ambient buoyancy gradient
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$

However, there are some exceptions and additional complexities to interpreting the two-dimensional slot length scales measures described in Table 5.2. In addition to the predominately two-dimensional flow behavior, some of the large scale dynamics of multiport diffusers may also be influenced by other scales depending on the overall diffuser flow pattern. A notable example is circulating motions induced in shallow receiving waters due to intermediate-field effects (Section 2.1.1). The immediate close-up zone before the individual jets merge is also not addressed by the two-dimensional length scales. Additional discussion of these and other peculiarities can be found elsewhere (6,18).

Table 5.2
Dynamic Length Scales for Multiport Diffuser (CORMIX2) in the Two-Dimensional "Slot" Discharge Representation

Slot jet/plume transition length scale $\ell_M = m_o / j_o^{2/3}$

interpretation: For combined buoyant jet flow, the distance at which the transition from jet to plume behavior takes place in a stagnant uniform ambient.

Slot jet/crossflow length scale $\ell_m = m_o / u_a^2$

interpretation: In the presence of a crossflow, the distance of the transverse (i.e. across ambient flow) jet penetration beyond which the jet is strongly deflected (advected) by the cross flow. For a strictly co-flowing discharge ($\theta = 0$, $\sigma = 0$), the length of the region beyond which the flow is simply advected.

Slot jet/stratification length scale $\ell_m' = m_o^{1/3} / \epsilon^{1/3}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **jet** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Slot plume/stratification length scale $\ell_b' = j_o^{1/3} / \epsilon^{1/2}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **plume** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Crossflow/stratification length scale $\ell_a = u_a / \epsilon^{1/2}$
interpretation: The vertically upward or downward floatation distance beyond which a plume becomes strongly advected by crossflow.

Notes: $m_o = U_o q_o$, kinematic momentum flux per unit length
$j_o = g'_o q_o$, kinematic buoyancy flux per unit length
$q_o = U_o n a_o / L_D$, source discharge volume flux
a_o = port area
u_a = ambient velocity
U_o = port discharge velocity
ϵ = ambient buoyancy gradient
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$
n = total number of nozzles
L_D = overall diffuser length

c) Buoyant surface jets: Some important length scales that describe the near-field dynamics of buoyant surface jets discharging into unstratified receiving waters (CORMIX3) are listed in Table 5.3. These scales are defined in a similar manner to the submerged discharged cases but due to the discharge location at the surface, they have different interpretations. For example, L_m is compared to the channel width (BS) instead of the local water depth as it was in submerged case examples; if it exceeds BS, the discharge will quickly interact with the opposing bank.

Table 5.3
Dynamic Length Scales for Buoyant Surface Jets (CORMIX3)
Discharging into Unstratified Receiving Water

Jet/plume transition length scale $L_M = M_o^{3/4} / J_o^{1/2}$

interpretation: For stagnant ambient conditions, the extent of the initial jet region before mixing changes over into an unsteady surface spreading motion.

Jet/crossflow length scale $L_m = M_o^{1/2} / u_a$

interpretation: The distance over which a discharging jet intrudes into the ambient cross-flow before it gets strongly deflected.

Plume/crossflow length scale $L_b = J_o / u_a^3$

interpretation: A measure of the tendency for upstream intrusion for a strongly buoyant discharge.

Notes: $M_o = U_oQ_o$, kinematic momentum flux
$J_o = g'_oU_o$, kinematic buoyancy flux
$Q_o = U_oa_o$, source discharge volume flux
a_o = channel cross-sectional area
u_a = ambient velocity
U_o = channel discharge velocity
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$

d) Tidal reversing flows: Additional length and time scales can be defined for unsteady flows in which the scale of influence of oscillating plume depends on the rate of velocity reversal change at slack tide (8,17). CORMIX will take the actual steady-state predictions and adjust their concentration values according to the time after reversal relative to the time scale T_u and also limit their areal applicability relative to L_u.

5.1.3 Description of Flow Classes

Program element CLASS, performs a rigorous classification of the given discharge/ambient situation into one of many **generic flow classes** with distinct hydrodynamic features. In a way, this amounts to identifying a general pictorial description of the expected flow configuration.

Table 5.5 lists and describes the broad categories of flow classes available in CORMIX. CORMIX1, 2 and 3, consider 35, 31 and 11 distinct flow classifications, respectively. Each flow class identification consists of an alphanumeric label corresponding to the flow category and a number (e.g. MU2). Text descriptions of the flow classes are available on-screen during the analysis and can printed from the files stored within sub-directory CORMIX\TEXT (Table 3.1). Pictorial illustrations of the flow classes can be found in Appendix A. As an example, Figure 5.1 shows the pictorial illustration and text description for flow class S1, a case of an effluent that becomes trapped in ambient stratification. It is strongly recommended that novice or intermediate users scrutinize these materials to gain a qualitative understanding of the effluent flow's behavior.

Table 5.4
Dynamic Length and Time Scales for Discharges into Unsteady Tidal Reversing Flows

Jet-to unsteady-crossflow length scale $L_u = \left(\dfrac{M_o}{|du_a/dt|} \right)^{1/3}$

interpretation: A measure of the distance of the forward propagation into the ambient flow of a discharge during the reversal episode.

Jet-to unsteady-crossflow time scale $T_u = \left(\dfrac{M_o}{|du_a/dt|^{1/4}} \right)^{1/6}$

interpretation: a measure of the duration over which an effluent may be considered as discharging into stagnant water while the velocity field is reversing.

Notes: $M_o = U_o Q_o$, kinematic momentum flux
$|du_a/dt|$ = time rate of reversal of ambient velocity (absolute value)

Table 5.5
Flow Class Categories and Descriptions

CORMIX1:	35 flow classes
Classes S:	Flows trapped in a layer within linear stratification.
Classes V,H:	Positively buoyant flows in a uniform density layer.
Classes NV,NH:	Negatively buoyant flows in uniform density layer.
Classes A:	Flows affected by dynamic bottom attachment.
CORMIX2 :	31 flow classes
Classes MS:	Flows trapped in a layer within linear ambient stratification.
Classes MU:	Positively buoyant flows in a uniform density layer.
Classes MNU:	Negatively buoyant flows in uniform density layer.
CORMIX3	9 flow classes
Classes FJ:	Free jet flows without near-field shoreline interaction.
Classes SA:	Shoreline-attached discharges in crossflow.

Classes WJ:	Wall jets/plumes from discharges parallel to shoreline.
Classes PL:	Upstream intruding plumes.

```
FLOW CLASS S1

This flow configuration is profoundly affected by the linear
ambient density stratification. The predominantly jet-like flow
gets trapped at some terminal (equilibrium) level. The trapping
is also affected by the reasonably strong ambient crossflow.
Following the trapping zone, the discharge flow forms an internal
layer that is further influenced by buoyant spreading and passive
diffusion.

The following flow zones exist:

1) Weakly deflected jet in crossflow: The flow is initially
dominated by the effluent momentum (jet-like) and is weakly
deflected by the ambient current.

2) Strongly deflected jet in crossflow: The jet has become strongly
deflected by the ambient current and is slowly rising toward the
trapping level.

3) Terminal layer approach: The bent-over submerged jet/plume
approaches the terminal level. Within a short distance the
concentration distribution becomes relatively uniform across the
plume width and thickness.

***   The zones listed above constitute the NEAR-FIELD REGION
      in which strong initial mixing takes place. ***

4) Buoyant spreading in internal layer: The discharge flow within
the internal layer spreads laterally while it is being advected by
the ambient current. The plume thickness may decrease during this
phase. The mixing rate is relatively small. The plume may interact
with a nearby bank or shoreline.

5) Passive ambient mixing: After some distance the background
turbulence in the ambient shear flow becomes the dominating mixing
mechanism. The passive plume is growing in depth and in width. The
plume may interact with the upper layer boundary, channel bottom
and/or banks.

***   Predictions will be terminated in zone 4 or 5 depending on
      the definitions of the REGULATORY MIXING ZONE or the REGION OF
      INTEREST. ***
```

Figure 5.1: Example of a Flow Class Description

5.2 Quantitative Output: Numerical Flow Predictions

After execution of the detailed flow prediction in program element HYDROn, the system provides two types of detailed numerical output on effluent plume trajectory and mixing and on compliance with regulations. A concise summary is available on-screen in the final system element SUM and a detailed numerical output file is also generated for inspecting and plotting the plume's behavior after the analysis.

5.2.1 Summary Output in SUM

The self-explanatory summary output which can be displayed on-screen includes: (a) the date and time of the analysis section, (b) a complete echo of the input data, (c) the calculated flux, length scale and non-dimensional parameter values, (d) the flow classification used for predicting plume trajectory and mixing, (e) the coordinate system used in the analysis, (f) a summary of the near-field region (NFR) conditions, (g) the far-field locations where the plume becomes essentially fully mixed (i.e. uniform concentration) in the horizontal and vertical directions, (h) a summary of the toxic dilution zone (TDZ) conditions, and (I) a summary of the regulatory mixing zone (RMZ) conditions. Although the raw data used to construct this summary output is permanently stored in file 'fn'.CXC within the output sub-directory CORMIX\SIM\CXn, a hard-copy printout should be requested during the analysis session because the raw data file is unformatted and does not contain the explanatory text that is available during program execution; 'fn' is the filename specified by the user during input data entry.

The **coordinate system conventions** pertain to the origin location and axis direction. In CORMIX1 analyses, the origin is located at the bottom of the receiving water just below the discharge port center and thus, at a depth HD below the water surface. In CORMIX2 analyses, the origin is located at the bottom of the receiving water, at the midpoint of the diffuser line and thus, at a depth HD below the water surface. In CORMIX3 analyses, the origin is located at the water surface where the discharge channel centerline and receiving water shoreline intersect. The x-axis lies in the horizontal plane and points downstream in the direction following the ambient flow; the y-axis lies in the horizontal plane and points to the left as seen by an observer looking downstream along the x-axis; and the z-axis points vertically upward. Note that when the ambient current direction varies (e.g. due to reversing tidal flows), the interpretation of simulation results becomes more involved since the x-axis and the y-axis will change depending on flow direction.

In addition to the numerical predictions of the plume size, location and chemical concentration, the summary of the near-field region (NFR) conditions describes other relevant plume features such as bottom attachment, bank interaction and the degree of upstream intrusion. This information is useful for both engineering design and for determining whether important resource areas may be exposed to undesirable chemical concentrations.

In case of a toxic discharge, the summary toxic dilution zone (TDZ) conditions will indicate the location along the plume where the local concentration begins to fall below the specified CMC. CORMIX automatically checks compliance with the three geometric restrictions listed for mixing zones associated with toxics discharges under alternative 3 (see Subsection 2.3.3) and the results of these comparisons are displayed. The user can evaluate the fourth alternative by referring to travel times given at the end of each simulation module in the related output files.

When regulatory mixing zone (RMZ) criteria have been specified during input data entry, the geometric, dilution and concentration conditions at the edge of the specified or proposed RMZ are compared to these criteria and/or to the applicable CCC concentration following the practices discussed in Subsection 2.2.4. The results of these comparisons are displayed.

5.2.2 Detailed Prediction Output File*fn*'.CXn

The file 'fn'.CXn stored within sub-directory CORMIX\SIM contains the same kinds of information available in the summary output plus the detailed numerical predictions on plume geometry and mixing produced during the hydraulic simulation. Data in that file forms the basis for further analysis, inspection, evaluation, and plotting of the plume shape and trajectory. The graphics package also uses the same data to plot on-screen, and print if desired, the plume properties as explained in Section 5.2.3.

During program execution, the user has several opportunities to display on-screen or print out this file. It can also be printed at a later date by using the DOS PRINT command or any word processor. CORMIX will not erase any of the files with .CXn (or .CXC) extension that get stored in the CORMIX\SIM sub-directory. Consequently, periodic directory maintenance is recommended to remove old and superfluous files. This is best accomplished with a built-in file manager (see Main Menu) that deletes the specified files from the hard disk, but also erases their entry from the record keeping file CORMIX\SIM\CXn\summary.

The 'fn'.CXn file is a FORTRAN output file generated by the HYDROn prediction program. As is typical of many FORTRAN outputs, its display features are terse with tight format control and data items labeled in symbolic form only (e.g. "Q0" for discharge flow rate). Complete output file examples can be inspected in Appendices B, C and D.

All three CORMIXn subsystems produce a 'fn'.CXn output file with common appearance and features as described in the following paragraphs.

a) Lead-in information: The output starts (and ends) with a "111...111", "222...222", or "333...333" banner line to accentuate which subsystem has been used. The date and time of the analysis session and all important input data are the next items in the file. These are subsequently followed by the calculated length scale values, non-dimensional numbers of interest to the specialist, the flow class identification, and the coordinate system is displayed.

b) Prediction results for each flow "module": As was mentioned previously in Subsection 3.6, the CORMIX prediction methodology utilizes a number of **simulation modules** that are executed sequentially and that correspond to the different flow processes and associated spatial regions which occur within a given flow class. The 'fn".CXn output reflects that sequence and is a arranged in output blocks for each module.

Each simulation module has a "MODnxx" label where "n" is 1, 2, or 3 corresponding to CORMIXn, and "xx" is a two-digit identification number. The two general types of modules are continuous flow and control volume.

The **continuous flow module** type describes the continuous evolution of a flow region along a trajectory. Depending on the number of grid intervals specified by the user, information on plume geometry, flow, and mixing information along the plume trajectory may be available for a few or many water body locations.

Figure 5.2 provides examples of typical output from continuous flow modules. The annotations along the right margin illustrate important features of the output format. Figure 5.2a was taken from a CORMIX1 simulation output file and shows an example of a submerged jet region module (MOD110, equivalent to CORJET). The output contains labeling information on the module, and explanatory notes on profile definitions. It also gives a numerical list on the predictions, first repeating the final values from the preceding flow module and then one line for each user-specified grid interval. This information gives the x-y-z position of the jet/plume centerline, the dilution (S) and concentration (C) at the centerline, and the jet width (B).

Dilution (S) is defined as the ratio of the initial concentration (at the discharge port) to the concentration at a given location, irrespective of any decay or growth effects if specified for a non-conservative pollutant. However, **concentration** (C) will include any first-order effects for non-conservative pollutants. Dilution (S) given by CORMIX for submerged jet or plume regions is the minimum centerline dilution for the jet/plume. The control volume and buoyant spreading modules give bulk dilutions, which are equivalent to flux-averaged dilutions for these regions. If a flux-averaged dilution S_f is desired for submerged jet or plume regions, the ratio of flux-average to minimum centerline dilution $S_f/S = 1.7$ and 1.3, for single-port round and multiport plane discharges, respectively.

```
--------------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
 Jet/plume transition motion in weak crossflow.
  Zone of flow establishment:          THETAE=      0.00  SIGMAE=    277.06
  LE    =       3.39  XE    =       0.21  YE    =     -3.38  ZE    =      1.00
 Profile definitions:
   B = Gaussian 1/e (37%) half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)
        X         Y        Z         S        C          B
      0.00      0.00     1.00      1.0 0.100E+03   0.76
      0.21     -3.38     1.00      1.0 0.100E+03   0.76
      0.90     -7.41     4.11      1.8 0.562E+02   1.13
      1.55     -9.36     9.07      3.3 0.300E+02   1.59
      2.23    -10.55    14.27      5.4 0.186E+02   2.10
      2.95    -11.39    19.56      7.9 0.127E+02   2.63
      3.72    -12.02    24.85     10.8 0.928E+01   3.16
 Cumulative travel time =           18. sec
END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
--------------------------------------------------------------------------------
```

a) Submerged buoyant jet module

```
--------------------------------------------------------------------------------     BEGIN MOD341:
BUOYANT AMBIENT SPREADING                                                Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally from bank/shoreline
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
  Plume Stage 1 (not bank attached):
       X         Y        Z         S        C         BV        BH
      1.93     -.82     0.00      8.4  .884E+00     .03       .58
      2.07     -.82     0.00      8.5  .869E+00     .03       .62
      2.20     -.82     0.00      8.6  .856E+00     .03       .65
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .850E+00 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      2.34     -.82     0.00      8.8  .844E+00     .03       .68
      2.48     -.82     0.00      8.9  .833E+00     .03       .71
      2.62     -.82     0.00      9.0  .822E+00     .03       .74
      2.76     -.82     0.00      9.1  .811E+00     .03       .77
      2.89     -.82     0.00      9.2  .801E+00     .03       .80
      2.96     -.82     0.00      9.3  .796E+00     .03       .82
 Cumulative travel time =           95. sec
-------------------------------------------------------------------------------     Plume is ATTACHED
to LEFT  bank/shore.
   Plume width is now determined from LEFT  bank/shore.
 Plume Stage 2 (bank attached):
       X         Y        Z         S        C         BV        BH
      2.96      .00     0.00      9.3  .796E+00     .03       .82
     16.05      .00     0.00     31.3  .237E+00     .03      2.59
     29.13      .00     0.00     96.8  .764E-01     .06      3.77
     42.22      .00     0.00    220.7  .335E-01     .10      4.76
     55.31      .00     0.00    411.4  .180E-01     .16      5.64
     68.39      .00     0.00    675.3  .110E-01     .23      6.45
     81.48      .00     0.00   1017.8  .727E-02     .31      7.20
     94.56      .00     0.00   1443.5  .513E-02     .40      7.91
    101.11      .00     0.00   1688.9  .438E-02     .45      8.26
 Cumulative travel time =         3367. sec
 END OF MOD341: BUOYANT AMBIENT SPREADING
--------------------------------------------------------------------------------
```

b) Far-field flow module (example of buoyant spreading with bank contact)

Figure 5.2: Examples of continuous flow modules within CORMIX

The **cumulative travel time** (T) is given at the end of each simulation module. The travel time can be used to assess the applicability of the steady-state predictions given by CORMIX to time scales appropriate for the particular application.

Another example of a continuous flow module output is shown in Figure 5.2b. It was abstracted from a CORMIX simulation output file and shows predictions for the far-field process of buoyant ambient spreading (Figure 2.6). Although it is terse, the output file values and commentary generally provide a complete picture of flow conditions. In this example output (Figure 5.2b), evidence of this completeness includes: (a) the prediction output is separated in two stages corresponding to before and after bank interaction, respectively; due to the typical oblong cross-section of the plume in this stage, width dimensions for the vertical and lateral extent are given and defined; the coordinates for the upper and lower boundaries of the plume are listed as a convenience for plotting; and the system searches for criteria that apply to mixing zone regulations and when a criterion is satisfied, a remark gets inserted in the output list at the appropriate spatial position. (Note: The length dimensions in Figure 5.2b are small as they relate to a laboratory simulation.)

Some mixing flow processes are so complicated that no mechanistically-based mathematical description of them is presently available in state-of-the-art science. Those processes are best analyzed with **control volume modules** as shown in Figure 5.3.

In the control volume modeling approach, the outflow values for a region are computed as a function of the inflow values and are based on conservation principles.

An output example for control volumes modules is illustrated in Figure 5.3. It is taken from a CORMIX1 simulation output file and gives predictions for a flow case corresponding to an unstable near-field (Figure 2.2c). Note that a separate listing of inflow variables and outflow variables is given with appropriate explanations. The tabular listing of plume shape is based on an interpolation routine using a generic plume shape for these upstream intruding motions, rather than a detailed computation.

c) Numerous other supplementary messages on plume behavior (e.g. bottom attachment, bank contact, etc.) and on possible model restrictions (e.g. ambient dilution limitations in a flow-restricted river) are contained in the output as warranted; Figures 5.2 and 5.3 provide but a few examples of these user aids.

5.3 Graphical Output: Display and Plotting of Plume Features Using CMXGRAPH

5.3.1 Access to CMXGRAPH

CMXGRAPH is a specially developed graphics package, written in C++, for the display and plotting of CORMIX (and also CORJET, see Section 6.2) predicted effluent plumes. It uses the prediction files 'fn'.CXn that are stored in the directory CORMIX\SIM, and plots plume features based on the numerical and narrative information contained in these files.

The graphics system can be accessed in different ways:

(1) Use within CORMIX: Different access modes exist here.

(1a) The user can display the plume graphics immediately after the actual prediction and *before the file information is stored.* This is useful for an initial inspection and evaluation of results.
(1b) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.
(1c) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

(2) Use outside CORMIX:
The graphics system can be invoked directly by typing:

cmxgraph (or simply: cg) *filename*
where *filename* (including path and extension) is any prediction file generated by CORMIX or by CORJET.

```
---------------------------------------------------------------------------
BEGIN MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING

  Vertical angle of layer/boundary impingement    =      79.65 deg
  Horizontal angle of layer/boundary impingement  =     324.93 deg


 UPSTREAM INTRUSION PROPERTIES:
        Upstream intrusion length                   =     328.95 m
        X-position of upstream stagnation point =    -325.23 m
        Thickness in intrusion region               =       0.55 m
        Half-width at downstream end                =     470.97 m
        Thickness at downstream end                 =       0.70 m

 In this case, the upstream INTRUSION IS VERY LARGE, exceeding 10 times
   the local water depth.

 This may be caused by a very small ambient velocity, perhaps in
   combination with large discharge buoyancy.

  Control volume inflow:

      X         Y         Z         S       C          B
    3.72    -12.02    24.85      10.8 0.928E+01    3.16

 Profile definitions:

   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

      X         Y         Z         S       C          BV        BH        ZU        ZL
  -325.23    -12.02    28.00    9999.9 0.000E+00    0.00      0.00     28.00     28.00
  -313.94    -12.02    28.00      46.5 0.215E+01    0.13     66.61     28.00     27.87
  -258.63    -12.02    28.00      19.3 0.519E+01    0.31    161.78     28.00     27.69
  -203.31    -12.02    28.00      14.5 0.688E+01    0.40    218.89     28.00     27.60
  -148.00    -12.02    28.00      12.5 0.802E+01    0.47    263.91     28.00     27.53
   -92.68    -12.02    28.00      11.4 0.878E+01    0.52    302.30     28.00     27.48
   -37.37    -12.02    28.00      10.9 0.919E+01    0.54    336.34     28.00     27.46
    17.95    -12.02    28.00      11.0 0.913E+01    0.55    367.24     28.00     27.45
    73.26    -12.02    28.00      14.4 0.694E+01    0.59    395.73     28.00     27.41
   128.58    -12.02    28.00      19.1 0.522E+01    0.65    422.30     28.00     27.35
   183.89    -12.02    28.00      22.0 0.455E+01    0.68    447.30     28.00     27.32
   239.21    -12.02    28.00      23.2 0.431E+01    0.70    470.97     28.00     27.30
 Cumulative travel time =          3037. sec

END OF MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING
---------------------------------------------------------------------------
```

Figure 5.3: Example of control volume flow module

As mentioned, numerous flow features (as evidenced by the different flow classes) can occur. It is difficult to develop a robust graphics package that operates safely for all of these possibilities. The CMXGRAPH system has been widely tested, but occasional crashes can occur for rare flow module combinations and then only for certain plot types. Should a crash occur and the direct access mode (1a), listed above, has been used then the current file information will be lost. In those cases, it is safer to *first save the current session file data* and then exercise the graphics system.

5.3.2 Use of CMXGRAPH

The graphics system has a self-explanatory screen interface as shown in Figure 5.4. The menu is controlled by the **keyboard** alone by typing the letters that appear in capital on the menu buttons, or by user the four cursor keys when in zoom mode.

The **GRAPHICS MENU COMMANDS** are as follows:

Help — an advice section is available listing the same information as given here

Quit — exits the graphics system

There exist FIVE PLOT TYPES:

Plan — generates a plan view of plume (x-y), as seen from above *(entry option)*

Side — generates a side view of plume (x-z), as seen by an observer looking from the bank/shore

Traj — generates a side view along trajectory of plume. The view is stretched out along the actually curving centerline trajectory.

c-**X** — generates a plot of concentration on the plume centerline plotted against downstream distance x

c-**D** — generates a plot of concentration on the plume centerline plotted against distance along the plume trajectory

The user can CONTROL the plume VIEW:

Near — displays the near-field region only ; useful for close-up details *(entry option)*

Full — displays the complete near- and far-field regions (i.e. the entire prediction results)

SHOW/HIDE FEATURES can be exercised to display additional information:

Labels — puts identifier labels (site/case information) on top of plot *(entry option)*

Wqual — displays information on regulatory mixing regulations (TDZ, RMZ, ...) on the plot; this is displayed by dotted lines where particular regulations are encountered.

Module shows boundaries of prediction modules

ZOOM/SCALE CONTROL allows control of plot details:

Zoom allows the user to enlarge any RECTANGULAR SECTION of the current plot; this is accomplished by:
-- Use CURSOR Control keys to move cursor (up,down,left,right)

-- Cursor SPEED can be modified by typing any number: 1(slowest),2,.. to 0(fastest)
-- Press RETURN when first corner of desired rectangle has been reached
-- Move cursor to find opposite corner and press RETURN to fix opposite corner

s**K**ale allows the user to FIX SCALE distortion of current plot. The current scale is displayed in a window on the menu bottom (see Figure 5.4).
-- Type in desired distortion at the prompt: All subsequent versions of the plot (including zooms will be fixed at this scale distortion.
-- Use the sKale button again, to release the scale distortion.

Bkup back-up to earlier zoomed/scaled versions of current plot

Esc exit from zoom/scale mode (also Quit or repeated Bkup can be used to exit)

Several PRINT OPTIONS are available:

pf**I**le writes the current plot to a POSTSCRIPT FILE for later printing. The file can be edited and/or printed later using any compatible software (including public domain software, such as Ghostscript).

-- Each print file is stored as \"*filename*.Pvn\" where:

filename = CORMIX or CORJET assigned filename,
Pvn = file extension indicating a Postscript file,
v = P, S, T, X or D, for one of the five view types,
n = 0 to 9, increasing file number.

-- If the total file number for a particular view type exceeds the maximum of ten (10), the first file in the series will be erased and replaced by the new file.

ps**C**rn allows a PRINT SCREEN action of the current plot

-- The plot is first recreated without the menu interface and plot border.

-- Then use the Shift-PrintScreen buttons, to print the plot on-line.
Important: The PRINTER must have been initialized for GRAPHICS MODE with the DOS command: \"graphics [type] /r\" where: [type] = type of printer (e.g.: color4, laserjetii).

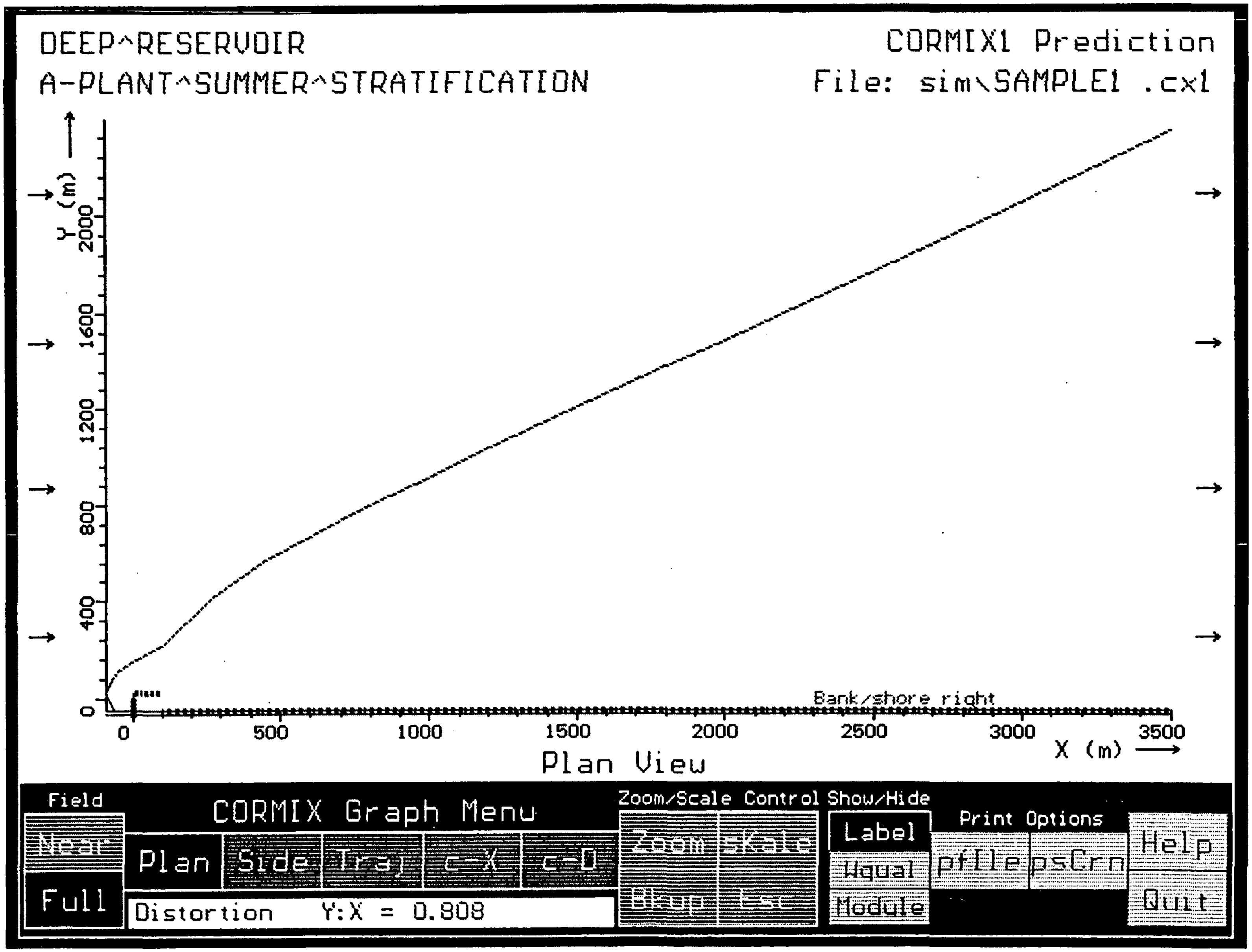


Figure 5.4 CMXGRAPH interface with menu options including example plot

The case study materials in the Appendices show some of the possibilities that can be exercised in the graphics display the plume features described in the *fn*.CXn output files. As shown above, the plume is characterized by its centerline trajectory, dilution, and width values. For understanding added detail in the plume cross-section, it is important to keep in mind the different concentration distributions and meanings of "plume width". These are explained in the supplemental statements at the beginning of each flow module (see Figures 5.2 and 5.3). Also, Figure 5.5 may be useful for further illustration. It gives the cross-sectional distribution of concentration for many of the commonly occurring plume cross-sections in the various regions predicted by the CORMIXn subsystems.

In some instances, users may desire to plot concentration isolines for the predicted plume shapes. The information contained in the HYDROn output file for each module and the definitions shown in Figure 5.5 are sufficient to construct such plots. In particular, in submerged plume or passive mixing regions having a Gaussian distribution, the following formula can be used

$$c(n) = c_c e^{-(\frac{n}{b})^2}$$

where c(n) is the lateral concentration, n is the coordinate position measured tranversely away from the centerline, c_c is the centerline concentration, e is the natural logarithm base, and b is the local plume half-width. However, this equation can not be used to plot concentration isolines in the control volume or buoyant spreading regions because they are defined with a top-hat or uniform concentration profile and not a Gaussian distribution.

By and large, all CORMIXn predictions are continuous from module to module satisfying the conservation of mass, momentum and energy principles. Occasionally, some *mismatches in plume width* can occur as a consequence of enforcing these principles. Most of these will be barely noticeable with the usual plotting resolution and they can usually be safely ignored. Some of the mismatches or discontinuities can be kept to a minimum by *specifying a large number for the grid intervals* (see Section 4.9) to increase the resolution of the CORMIX prediction. This is especially useful for the final simulations on a particular design case.

In addition, when bottom attachment or bank interaction occurs, the plume trajectory is assumed to (and simulation predictions do) shift suddenly to the boundary. In actuality, that shift would be much more gradual and this should be considered when interpreting the results of the CMXGRAPH plots or, alternatively, when plotting plume features by hand.

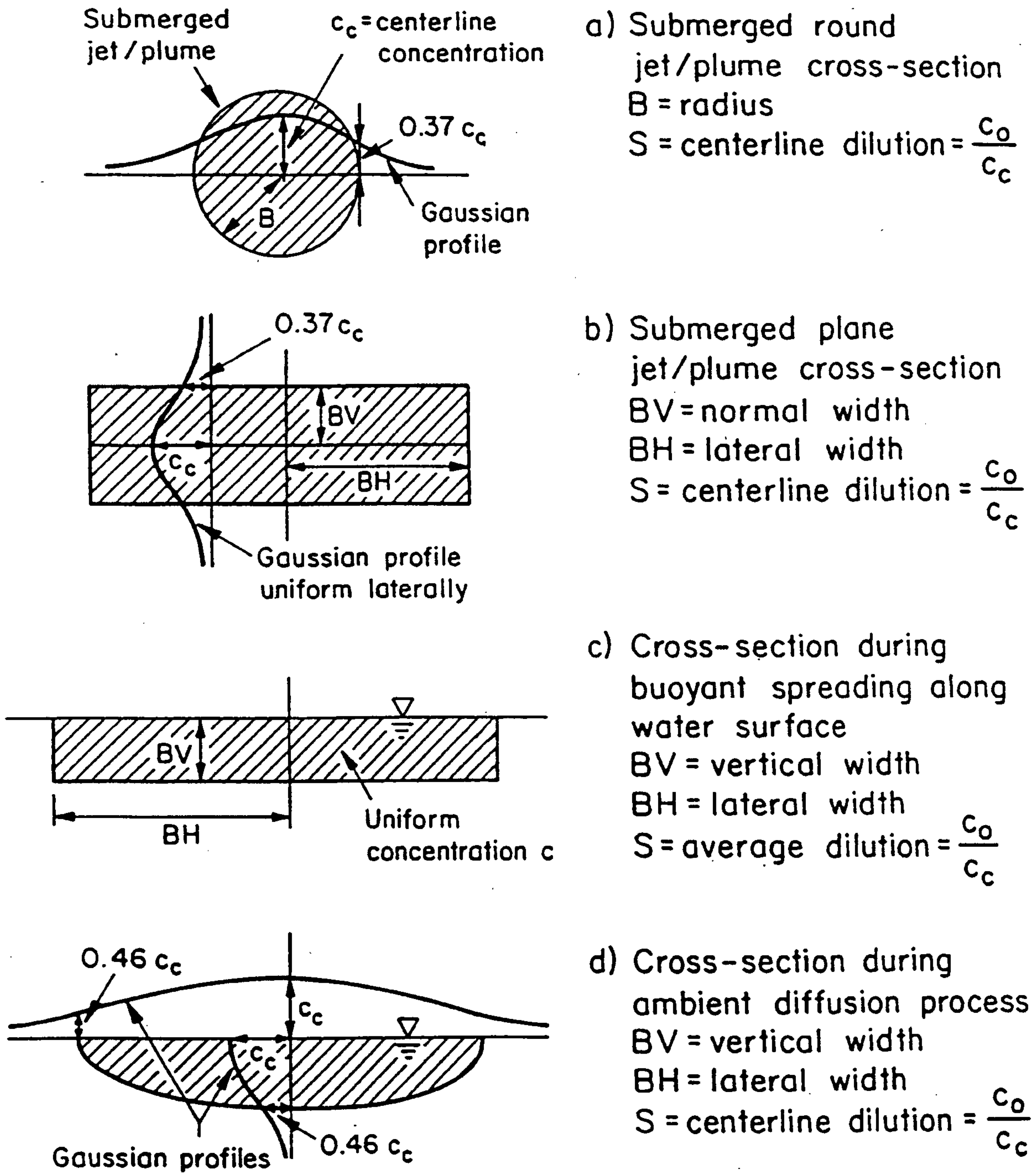


Figure 5.5: Cross-sectional distributions of CORMIX predicted jet/plume sections

VI Post-Processor Models CORJET and FFLOCATR: Input and Output Features

The CORMIX system contains three post-processor options which be accessed directly from within the system or independently outside of CORMIX. In either case, the post-processor options provide additional enhancements to CORMIX in terms of plume display, and more detailed computation of near- and far-field plume features.

The first of the options, the graphics package CMXGRAPH, has already been described in Section 5.3. The second option is CORJET, the Cornell Buoyant Jet Integral Model, for the detailed analysis of the near-field behavior of buoyant jets. FFLOCATR, the Far-Field Plume Locator, for the far-field delineation of discharge plumes in non-uniform river or estuary environments is the third option. The latter two are described in this chapter.

6.1 CORJET: The Cornell Buoyant Jet Integral Model

6.1.1 General Features

CORJET is a Fortran model that solves the three-dimensional jet integral equations for submerged buoyant jets --either **a single round jet** or **interacting multiple jets in a multiport diffuser**-- in a highly arbitrary ambient environment. The ambient/discharge conditions include an arbitrary discharge direction, positive, neutral or negative discharge buoyancy, an arbitrary stable density distribution, and a non-uniform ambient velocity distribution with magnitude and direction as a function of vertical position.

Figure 6.1 displays these general characteristics for the case of a single port. In case of the multiport diffuser all the discharge port/nozzles point in the same direction (unidirectional or staged design) and the diffuser line can have an arbitrary alignment angle relative to the ambient current (for definitions see Section 4.5.1).

The detailed theoretical basis for CORJET can be found in the documentation report (8) on recent CORMIX system enhancements. CORJET is a type of a jet integral model whose original development in a two-dimensional framework and for a round jet only was first reported in the peer-reviewed literature by Jirka and Fong (25). Detailed verification studies with various experimental data sources have been reported (8,26).

In jet integral models the hydrodynamic equations governing the conservation of mass and momentum, and of other quantities as pollutant mass, density deficit, temperature and/or salinity, are solved step-wise along the general curved jet trajectory. The solution yields values of the trajectory position itself and of the centerline concentrations of these quantities, while the actual cross-sectional distribution is fixed a priori (mostly as a Gaussian distribution) in these models. Literally several dozen such model developments have been reported in the literature over the last thirty years or so of research on these mixing phenomena. Most of these developments differ (I) in the degree of simplifying assumptions on the ambient/discharge characteristics (e.g. two-dimensional trajectories or uniform ambient conditions only), and (ii) in the type of closure that is made to specify the turbulent growth and entrainment behavior in these jets under a variety of forcing conditions. Thus, some of these models can be demonstrated to be unduly limited for practical applications, and others to be clearly invalid in certain limiting regimes of plume behavior.

Whenever a jet integral model is reasonably general in its formulation and has been validated through experimental data comparison under a number of conditions it can be considered a useful prediction tool for near-field plume analysis. For practical purposes, all the models that meet the above conditions, in fact, differ little in their prediction results. The deviation among model results is usually less than the scatter in experimental data that is used for their verification. This holds true also for CORJET as well as another jet integral model,

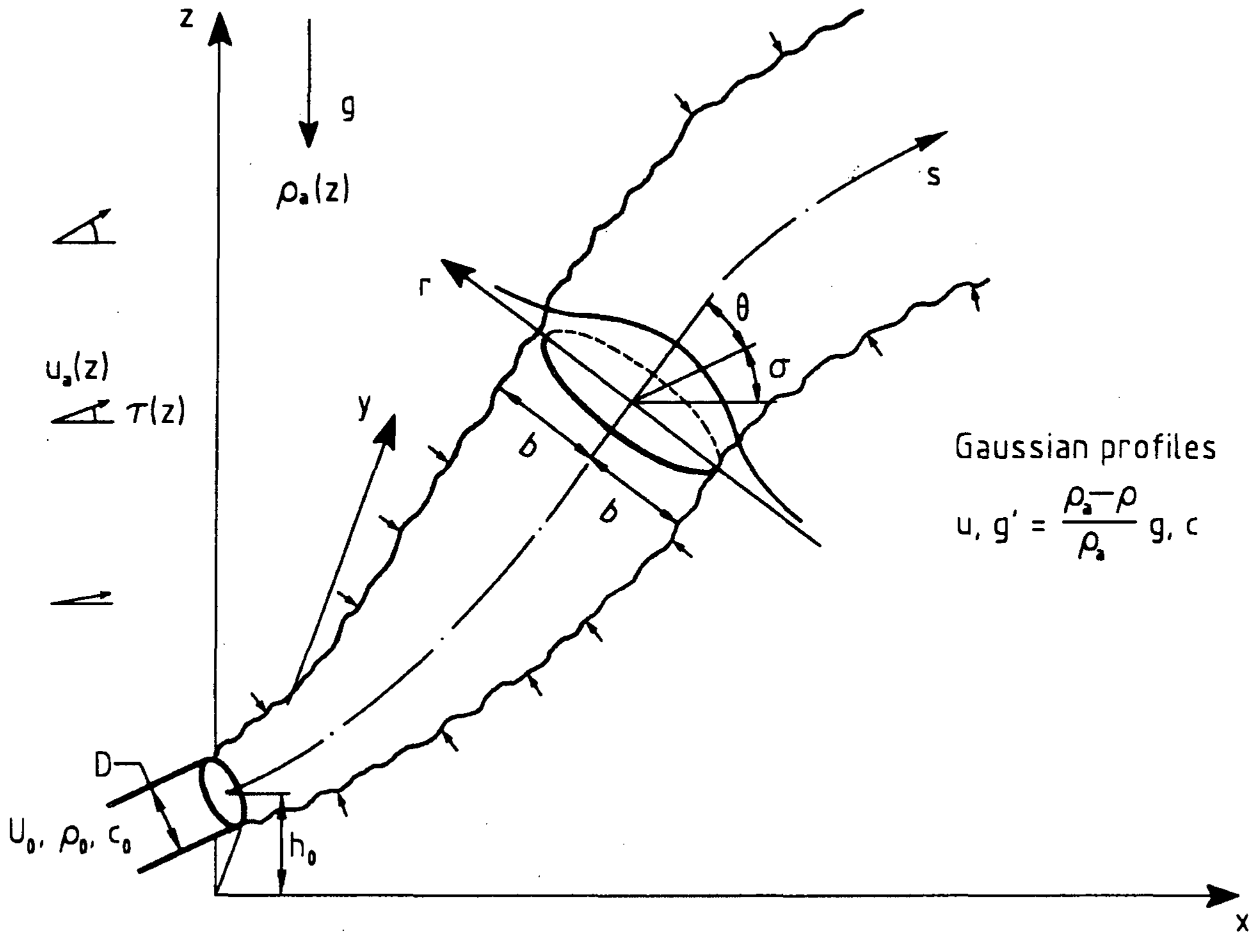


Figure 6.1: General three-dimensional trajectory of submerged buoyant jet in ambient flow with arbitrary density and velocity distribution: Case of a single round jet

(27), that has current USEPA support and distribution.

Both CORJET and PLUMES, although they differ in their internal formulation and closure assumptions, have a wide generality in discharge/ambient conditions and a reasonable verification base for a variety of conditions. They can deal with three-dimensional trajectories, with positive, neutral or negative discharge buoyancy, with conditions of reversible buoyancy (so-called nascent conditions in freshwater systems due to the density maximum at 4°C, requiring use of the full non-linear equation of state), with first-order pollutant decay, with variable stable ambient density, and with sheared non-uniform ambient currents, and with the merging of multiple port diffuser plumes. Three specialized features that the PLUMES model cannot deal with are a variable current direction at different levels, arbitrary diffuser alignments (with the extreme of a fully parallel alignment, $\gamma = 0^\circ$ in Figure 4.6), and applications to atmospheric plumes (using the concept of potential temperature and density).

Jet integral models, such as CORJET and

PLUMES, appear as useful and efficient tools for the rapid analysis of the near-field mixing of aqueous discharges. They require fairly little input data and are numerically efficient. However, their inherent limitations must be kept in mind.

All **jet integral models**, including CORJET, **assume an infinite receiving water body**, without any boundary effects due to limiting dimensions vertically (surface, bottom, or pycnocline) or laterally (banks or shore). Thus, they do not deal with such hydrodynamic effects as jet attachment and near-field instabilities that are so prevalent in many aqueous discharge plumes as emphasized in Section 2.1.1. Furthermore, they are **near-field models only** and do not give predictions on what happens to the entire mixing zone that may often cover larger distances (see Section 2.2.5).

In summary, jet integral models **if used alone** and by an inexperienced analyst are **not a safe methodology for mixing zone analysis**. They become safe only when used in conjunction with a more comprehensive analysis using the full CORMIX system. Therefore, in case of engineering design applications, **CORJET should be employed after prior use of the expert system CORMIX has indicated that the buoyant jet will not experience any instabilities due to shallow water or due to attachment to boundaries.**

In fact, the CORMIX system has built in several safeguards and warning statements to the user as explained below. When used in that context CORJET becomes a highly useful addition to the CORMIX system that can provide considerable additional detail and sensitivity analysis in the immediate near-field of the discharge plume.

6.1.2 Access to CORJET

CORJET, like the other post-processor options such as the graphics system (Section 5.3.1), can be accessed in different ways:

(1) Use within CORMIX:

(1a) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.

(1b) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

In either case, once the CORJET option is chosen the user must first specify whether a CORMIX1 or 2 simulation should be analyzed for the near-field with CORJET. Then the CORMIX1 or 2 filename in the CORMIX\SIM directory must be specified. CORJET will run automatically using the input data of the given CORMIX data file.

(2) Use outside CORMIX:

CORJET can be invoked directly by typing:

corjet (or simply: cj) *filename*

where *filename* (including path and extension) is any specially prepared input data file (see following section). Alternatively if one types:

corjet (or simply: cj)

the model will prompt the user for the input data filename.

6.1.3 CORJET Input Data File

This section for data preparation applies only if CORJET is run independently from the CORMIX system as discussed above. The **checklist** given on the following page is useful for data assembly prior to input data entry.

In this case, the Fortran model CORJET reads input data file with *filename* that is user-specified with arbitrary name, extension and directory. For user convenience it is recommended that all such files be kept in the special directory CORMIX\POST\CJ.

The input data file is a Fortran-readable file that is read in open format, that is all pertinent data values are arranged on a line and separated by one or more open spaces. The file consists of five data blocks, each of which must be lead in by two dummy lines that are not read. Table 6.1 gives an example of a data file in which the dummy lines are indicated by the # sign.

Table 6.1
Example of an input data file for CORJET

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case2: SINGLE PORT, STRATIFIED, VARIABLE CURRENT
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (½):   Density option (½):   Ambient levels (1-10):
1             1                     3
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA    TA     SA     RHOA   UA     TAUA
1      0.    12.    30.           0.5    0.
2      5.    15.    29.5          0.8    0.
3      15.   20.    28.           1.2    0.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0    H0     U0     THETA0 SIGMA0 C0     KD     T0     S0     RHO0   LD     ALIGN
1      0.5   0.     3.0    45.    45.    100.   0.     30.    0.            0.     0.
#Program control:
#ZMAX  ZMIN  DISMAX NPRINT
30.    0.    200.   10
```

The **required input data values** (all in SI units) are discussed in the following. The definition of these values is entirely consistent with those for CORMIX (in particular, see Section 4.4 and 4.5 for discharge conditions).

<u>Block 1: Identifier</u>
LABEL: Any descriptive label/text (should not exceed 50 characters, so that it does not get truncated on the graphics plots)

<u>Block 2: Fluid and density specification</u>
IFLUID: 1 (water) or 2 (air, for atmospheric applications)
IDENOP: 1: in case of water: Density will be calculated from specified temperature and/or salinity
In case of air: Potential density will be calculated from potential temperature assuming dry adiabatic conditions
2: Density values will be specified directly
LEVAMB: Number of levels for which ambient conditions are given (1 to 10)

<u>Block 3: Ambient Conditions</u> (specify LEVAMB lines)
LEV: Level number (increasing from 1 to LEVAMB)
ZA: Specify vertical level (z-coordinate) (m)
TA : if IFLUID=1(water): Temperature at ZA (degC) *(omit if IDENOP=2)*
if IFLUID=2(air): Potential temperature at ZA (degC) *(omit if IDENOP=2)*
SALA: Salinity at ZA (ppt) *(omit if IDENOP=2 or if IFLUID=2)*
RHOA: if IFLUID=1: Density at ZA (kg/m^3) *(omit if IDENOP=1)*
if IFLUID=2: Potential density at ZA (kg/m^3) *(omit if IDENOP=1)*
UA: Ambient velocity (speed) at ZA (m/s)
TAUA: Angle of ambient velocity vector measured CCW from x-axis (deg) (set = 0. unless velocity distribution in vertical is skewed, i.e. spiral-type)

<u>Block 4: Discharge Conditions</u>
NOPEN: 1: if SINGLE PORT DISCHARGE (i.e. 1 opening)
>= 3: number of openings (ports) for MULTIPORT DIFFUSER
D0: Port diameter (m) (should include contraction effects if any)
H0: Port center height above x-y plane (m)
U0: Jet exit velocity (m/s)
THETA0: Vertical angle of discharge (deg)

CHECKLIST FOR DATA PREPARATION

CORJET -- CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.10

DOS File Name:

Date:
Prepared by:

Label:

Fluid/Density:

Fluid: 1 (water) 2 (air)

Density specificaton: 1 (via temp./sal.) 2 (direct)

Number of ambient levels: (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)	Velocity (m/s)	Angle of velocity (deg)

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m^3)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)

Program Control:

Max. vertical distance (m):

Min. vertical distance (m):

Max. distance along trajectory (m):

Print intervals: (best 5 to 10)

SIGMA0: Horizontal angle of discharge axis measured CCW from x-axis (deg)
Examples: 0. = co-flow, 90. or 270. = cross-flow, 180. = counterflow
C0: Discharge concentration (any units that need not be specified)
KD: Coefficient of substance decay [negative value if growth] (/s)
T0: Discharge temperature (degC) *(omit if IDENOP=2)*
S0: Discharge salinity (ppt) *(omit if IDENOP=2 OR IF IFLUID=2)*
RHO0: Discharge density (kg/m^3) *(omit if IDENOP=1)*
LD: Diffuser length (m) (set = 0. [non-blank] if NOPEN=1)
ALIGN: Diffuser alignment angle (deg) measured CCW from x-axis (set = 0. if NOPEN=1)
Examples: 0. = parallel diffuser, 90. = perpendicular diffuser

Block 4: Program Control
ZMAX: Maximum vertical coordinate of interest (m)
ZMIN: Minimum vertical coordinate of interest (m)
ZMAX and ZMIN are cutoffs for + and - buoyancy, respectively!
DISMAX: Maximum distance of interest along trajectory (m)
NPRINT: Print intervals (any positive number less than 100; recommended value 5 to 10; does not affect accuracy of computation!)

Note on density specification: It is important to note the mutual exclusivity for the indirect or direct density specification as listed above. Omit the values (i.e. leave blank spaces) depending on the value of the IDENOP parameter. This can be seen in the preceding example data file. Up to 10 ambient levels can be specified for density and velocity distribution. This is sufficient to replicate complicated observed ambient profiles. CORJET performs internal **consistency checks** to test whether the specified density distribution is statically stable.

The **coordinate system** in CORJET can, in principle be taken as consistent with the CORMIX1 and 2 conventions (Section 5.2.1), i.e. the origin at the bottom of the receiving water body. (In fact, this convention is exercised whenever CORJET is run from within CORMIX.) However, since CORJET does not recognize the dynamic effect of the presence of the actual bottom boundary it is often convenient to set the origin at the center of the discharge port. In that case the port height H0 must be entered as 0.0. x points horizontally in the downstream direction, y laterally across in the horizontal plane, and z vertically upward. In the rare case when the ambient velocity distribution is skewed in the vertical, the definition of the x direction is best made by the direction of the ambient velocity **at** the level of origin (then TAUA is 0.0 at that level!), but any other convention is possible, too, and can be implemented by the choice of the TAUA value at the level of origin.

The CORMIX system contains upon its installation several **CORJET case studies** (see also Appendix E) that are installed as CORMIX\POST\CJ\case*.inp. It is recommended to copy one or more of these files and use the copy for constructing any future input data file.

6.1.4 CORJET Output Features

Regardless of the access mode (within or outside of CORMIX) CORJET has two output mechanisms, a numerical output file and a graphical display by means of CMXGRAPH.

(a) CORJET Output File:

(a.1) Use within CORMIX:

The output file gets stored as CORMIX\POST\CJ*fn*.CJX where *fn* is the CORMIX1 or 2 filename that has been specified during the data entry. This file can be viewed on-screen or printed within CORMIX.

A typical CORJET output file generated in this access mode is shown in Table 6.2 below corresponding to the input example presented above. The header information starts with the banner 'JJJ' and then echoes all the pertinent data that had been supplied to CORMIX and had been picked up for the CORJET simulation. The underlying CORMIX1 or 2 **flow class** is listed. If one of the **unstable or bottom-attaching** flow classes is encountered in this access mode, then **CORJET will not provide any predictions** since a pure jet integral model would not be **applicable**.

The tabular listing (see Table 6.2) gives the plume values along the trajectory. CORJET will cut off at a vertical level ZMAX that is equal to the water depth at discharge or ZMIN = 0.0 (for negatively buoyant cases) equal to the water body bottom. In neither case does it compute the actual boundary approach or impingement processes (as does the more complete CORMIX model in which some CORJET elements are, in fact, integrated, starting with Version 3.0). The interpretation of data values in this tabular listing is consistent with that for CORMIX1 or 2 (see Section 5.2.2).

Table 6.2
Example of CORJET output file when accessed within CORMIX

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.0, March 1995
---------------------------------------------------------------------------
FILE NAME:                cormix\post\cj\SAMPLE1.CJX
 Label/identifier:        A-PLANT^SUMMER^STRATIFICATION
 Time of CORJET run:       4/12/96--18:40:19
NEAR-FIELD DATA values for earlier CORMIX1  prediction (metric):
 Site name/label:         DEEP^RESERVOIR
 Design case:             A-PLANT^SUMMER^STRATIFICATION
 FILE NAME:               cormix\sim\SAMPLE1 .CX1
 Time of CORMIX run:      06/24/95--22:29:54
 HD     =     30.50  UA     =         .01  CUNITS= PPM
 STRCND=   C         density stratified environment
 RHOAS =     996.21  RHOAB =      999.61  HINT  =      15.50  DRHOJ =      2.181
 FLOCLS=   S3
Corresponding CORJET ambient conditions:
   LEV      ZA     RHOA       UA     TAUA
    1       .00   999.61      .01      .00
    2     14.75   998.39      .01      .00
    3     16.25   996.21      .01      .00
    4     30.50   996.21      .01      .00
  Pycnocline thickness has been set to 1/10 of upper layer thickness.
Discharge conditions (metric):  SINGLE PORT
   D0       H0        U0    THETA0 SIGMA0    C0        KD       RHO0
   .254      .60      3.02  10.00   90.00 .35E+04  .00E+00   998.21
Program control:
   ZMAX     ZMIN    DISMAX   NPRINT
   30.50     .00 1525.00        10
Flux variables (based on ambient at discharge level):
 Q0     = .153E+00  M0     = .462E+00  J0     = .203E-02  GP0    = .133E-01
Length scales (m) and parameters:
 LQ     =       .23  LM     =      12.44  Lm     =      45.31  Lb     =     601.53
 Lmp    =      4.88  Lbp    =       3.06
 FR0    =     52.01  R      =     201.31
---------------------------------------------------------------------------
CORJET PREDICTION:                Stepsize =    .2251  Printout every  10 steps
 Single jet/plume:
    X       Y       Z      Sc        Cc       B  |  DIST   Save    Gpc     Flc
    .00     .00     .60    1.0  .350E+04    .13|     .00   1.0  .13E-01 52.01
    .01    1.23     .82    1.0  .350E+04    .13|    1.25   1.4  .16E-01 95.03
    .04    3.45    1.22    2.5  .142E+04    .37|    3.50   4.2  .50E-02 33.42
    .11    5.65    1.65    4.1  .852E+03    .62|    5.75   7.0  .25E-02 21.98
    .22    7.85    2.13    5.8  .607E+03    .87|    8.00   9.8  .12E-02 19.01
    .35   10.04    2.65    7.4  .471E+03   1.12|   10.25  12.6  .32E-03 25.46
    .44   11.13    2.92    8.3  .423E+03   1.25|   11.38  14.0 -.59E-04 50.81
 Level of buoyancy reversal in stratified ambient.
    .53   12.22    3.19    9.1  .384E+03   1.37|   12.50  15.4 -.40E-03 16.80
    .74   14.40    3.68   10.8  .325E+03   1.63|   14.76  18.2 -.97E-03  8.35
    .99   16.61    4.06   12.4  .282E+03   1.88|   17.01  21.0 -.13E-02  5.70
   1.28   18.83    4.20   14.1  .248E+03   2.14|   19.26  23.8 -.13E-02  4.61
   1.31   19.05    4.20   14.3  .245E+03   2.17|   19.48  24.1 -.13E-02  4.56
 Maximum jet height has been reached.
   1.62   21.05    4.05   15.9  .220E+03   2.40|   21.51  26.8 -.99E-03  4.54
   1.99   23.23    3.63   17.8  .196E+03   2.66|   23.76  30.0 -.34E-03  6.68
   2.19   24.31    3.37   18.8  .187E+03   2.80|   24.89  31.6  .27E-04 22.15
 Terminal level in stratified ambient has been reached.      PROGRAM STOPS!
---------------------------------------------------------------------------
END OF CORJET PREDICTION:          Total number of integration steps =    106
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

The main usefulness of CORJET when run in this mode lies in the short and separate display of the near-field buoyant jet only. In some cases, the pertinent regulatory constraints may be limited to that region.

(a.2) Use outside of CORMIX:

The output file gets stored as *filename*.OUT in the same directory for which the user had specified the input file (see Section 6.1.2(2)). This file can be viewed on-screen or printed using any text processor.

The CORJET output file corresponding to the input data file of Table 6.1 is listed in Table 6.3. The lead-in data provide an echo of the input data and then lists the calculated length scale and non-dimensional numbers controlling the mixing process.

Table 6.3
Example of CORJET output file

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL           Version 4.0, March 1995
----------------------------------------------------------------------------
FILE NAME:                 post\cj\case2.OUT
 Label/identifier:         Case2: SINGLE PORT, STRATIFIED, VARIABLE CURRENT
 Time of CORJET run:        4/10/96--19:28: 6

Ambient conditions:        No. of levels: 3   Fluid: Water   Density option: 1
   LEV      ZA        TA       SA    RHOA      UA    TAUA
    1        .00     12.00    30.00 1022.71     .50      .00
    2       5.00     15.00    29.50 1021.74     .80      .00
    3      15.00     20.00    28.00 1019.43    1.20      .00
Discharge conditions (metric):  SINGLE PORT
   D0      H0        U0    THETA0 SIGMA0     C0       KD       T0      S0      RHO0
   .500     .00      3.00   45.00  45.00 .10E+03 .00E+0    30.0      .0   995.65
Program control:
   ZMAX     ZMIN   DISMAX  NPRINT
  30.00      .00  200.00      10
Flux variables (based on ambient at discharge level):
 Q0    =  .589E+00  M0    =  .177E+01  J0    =  .153E+00  GP0   =  .259E+00
 QT0   =  .106E+02  QS0   = -.177E+02
Length scales (m) and parameters:
 LQ    =       .44  LM    =      3.92  Lm    =      2.66  Lb    =      1.22
 Lmp   =      5.61  Lbp   =      6.71
 FR0   =      8.33  R     =      6.00
Zone of flow establishment (m):
 LE    =      1.30  XE    =       .75  YE    =       .62  ZE    =       .86
 THETAE=     38.34  SIGMAE=     34.00  GAMMAE=     49.43
----------------------------------------------------------------------------
CORJET PREDICTION:               Stepsize =    .2659  Printout every  10 steps
 Single jet/plume:
    X        Y       Z       Sc       Cc       B  |  DIST   Save     Gpc   dTc dSALc
    .00      .00     .00    1.0  .100E+03    .25|     .00    1.0  .26E+00 18.0-30.0
    .75      .62     .86    1.0  .100E+03    .25|    1.30    1.4  .27E+00 20.8-34.7
   2.81     1.50    2.27    3.0  .334E+02    .64|    3.96    4.6  .83E-01  5.2 -9.9
   5.22     1.96    3.28    5.7  .176E+02    .94|    6.62    8.3  .42E-01  2.1 -5.1
   7.74     2.22    4.07    8.4  .118E+02   1.16|    9.27   12.1  .26E-01   .8 -3.3
  10.31     2.40    4.74   11.2  .890E+01   1.34|   11.93   15.8  .18E-01   .1 -2.4
  12.90     2.52    5.32   14.0  .716E+01   1.49|   14.59   19.5  .13E-01  -.3 -1.9
  15.51     2.61    5.84   16.6  .601E+01   1.62|   17.25   23.2  .96E-02  -.6 -1.5
  18.12     2.68    6.31   19.2  .520E+01   1.74|   19.91   26.7  .70E-02  -.8 -1.2
  20.75     2.73    6.74   21.7  .460E+01   1.84|   22.57   30.0  .50E-02 -1.0 -1.0
  23.38     2.78    7.13   24.1  .414E+01   1.93|   25.23   33.3  .34E-02 -1.1  -.8
  26.01     2.82    7.48   26.4  .379E+01   2.01|   27.89   36.3  .21E-02 -1.3  -.6
  28.65     2.85    7.80   28.5  .351E+01   2.08|   30.54   39.1  .10E-02 -1.4  -.5
  31.29     2.88    8.09   30.4  .329E+01   2.14|   33.20   41.6  .15E-03 -1.5  -.4
  31.82     2.89    8.14   30.8  .325E+01   2.15|   33.73   42.1 -.13E-04 -1.5  -.4
 Terminal level in stratified ambient has been reached.      PROGRAM STOPS!
----------------------------------------------------------------------------
END OF CORJET PREDICTION:          Total number of integration steps =    123
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

The actual tabular listing of the numerical output is divided in two halves by a vertical line. The left half lists data exactly in the same fashion as a CORMIX1 or 2 prediction file (see Section 5.2.2). The right half gives additional detailed information on the following variables:

DIST:	distance (m) along the jet trajectory
Save:	average (bulk) dilution, defined on the basis of total volume flux within the jet relative to the initial volume flux (discharge)
Gpc:	centerline buoyant acceleration (m/s^2)
dTc:	centerline temperature difference relative to local ambient temperature (°C) *(if IDENOP = 1)*
dSALc:	centerline salinity difference relative to local ambient salinity (ppt) *(if IDENOP = 1)*
Flc:	local densimetric Froude number *(if IDENOP = 2)*

In this mode CORJET becomes an important engineering tool for **design sensitivity analysis** --and also for research purposes-- to evaluate the behavior of the near-field processes to some of the ambient/discharge details, some of which had to be simplified (schematized) within the CORMIX approach. The user can learn to understand through repeated use of CORJET that plume mixing can indeed often be represented by simple linear, or even uniform, approximations to the ambient density structure.

Again, it is emphasized that CORJET when used alone is not a safe prediction methodology because of the limiting assumption of infinite receiving water. For that reason an alert is printed at the end of each CORJET output file:

```
Note: CORJET has been used outside the
      CORMIX system, assuming unlimited
      receiving water.
      Carefully examine all results for
      possible boundary effects due to
      surface, bottom, or lateral
      boundaries.
```

Previous application of CORMIX assures a careful examination of the interaction of the discharge with boundaries has been accomplished.

(b) Graphics display and plotting of CORJET results:

The graphical display and plotting of the CORJET prediction results by means of CMXGRAPH is similar to that of CORMIX results as described in Section 5.3.

The graphics package can be invoked in either access mode (within or outside of CORMIX) immediately after the computation or independently on any existing CORJET output file that has been computed earlier. Thus, **CMXGRAPH has been configured to deal with both CORMIX prediction files and CORJET output files.**

6.2 FFLOCATR: The Far-Field Plume Locator

6.2.1 General Features

Although the main emphasis of CORMIX is on the near-field mixing behavior of discharges it can also be used for providing plume predictions at larger distances in the far-field provided the flow is not highly irregular with pronounced recirculating zones and eddies in the ambient flow.

The CORMIX predicted far-field always applies to a rectangular schematized cross-section with a straight uniform channel (see Sections 4.3.1 and 4.3.2). The FFLOCATR is a simple method for interpreting the schematized CORMIX far-field plumes within the actual flow patterns in natural rivers and estuaries. This procedure, based on the cumulative discharge method, is illustrated in Figure 6.2.

The **cumulative discharge method**, first proposed by Yotsukura and Sayre (28; see also 19,20), is a convenient approach of dealing with lateral mixing in natural irregular (but not highly irregular with recirculating zones!) channels. In such channel geometry the passive far-field plume that is vertically mixed, or approaches vertical mixing, will be positioned around the "streamline", or more precisely the "cumulative discharge line", that passes through the plume

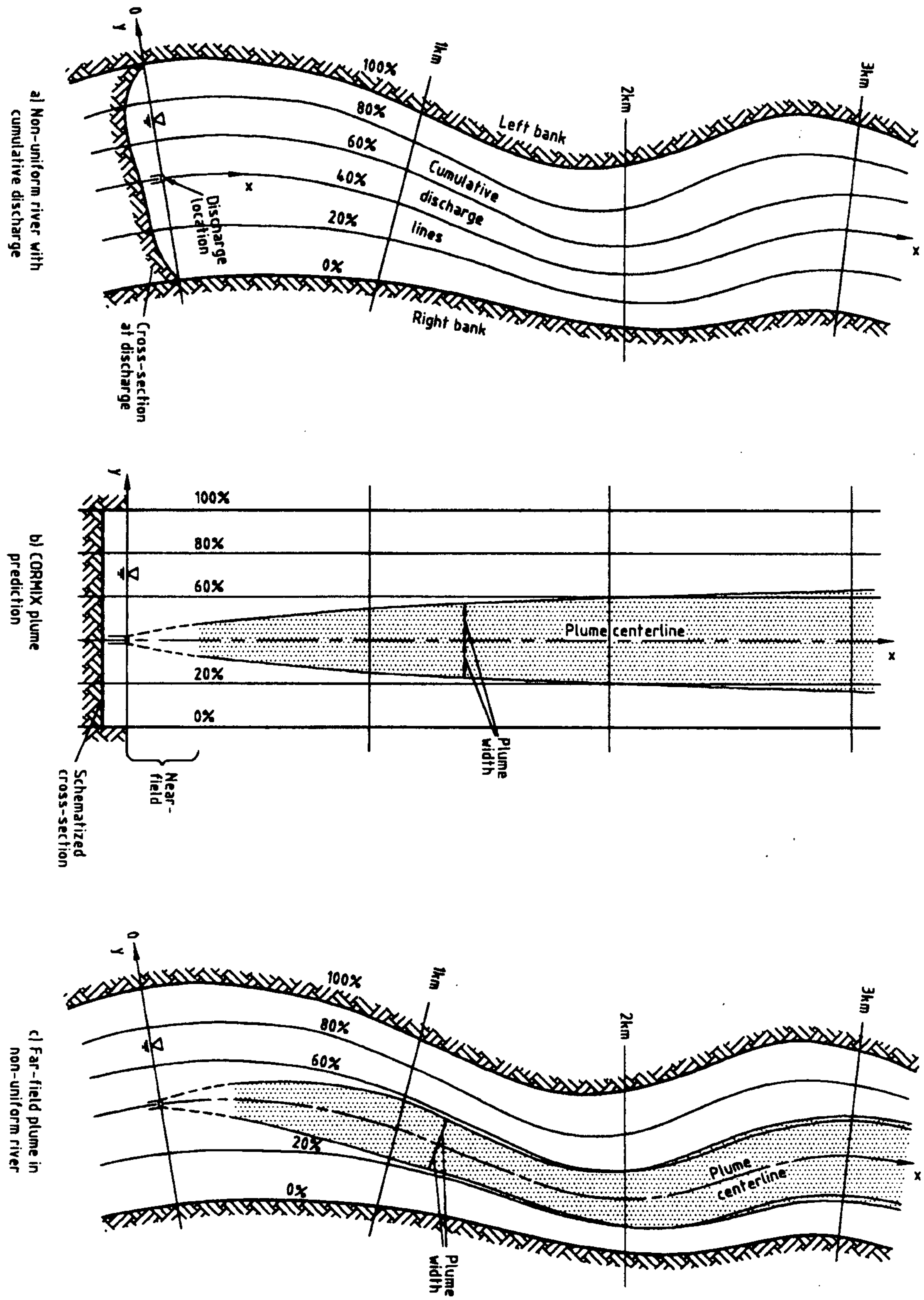


Figure 6.2: Illustration of the cumulative discharge method for translating the CORMIX predicted far field plume to the actual flow characteristics in winding irregular rivers or estuaries

center when it enters the far-field. Lateral spreading around this line occurs by lateral turbulent diffusion and can be enhanced buoyancy induced processes.

Looking downstream at a particular cross-section (see Figure 6.2a) the cumulative discharge $q(y)$ is defined as

$$q(y') = \int_0^{y'} \overline{u_a}(y')\, H(y')\, dy'$$

in which y' is the lateral coordinate pointing from the right bank to the left across the flow (y' differs from y as defined in CORMIX whose origin is at the discharge location), H is the local depth, and $\overline{u_a}$ is the depth-averaged local velocity. When the above equation is integrated across the full channel width B_s then the total discharge will result $Q_a = q(B_s)$. Hence, if the local values $q(y')$ are divided by Q_a the results can be presented in normalized form as the cumulative discharge lines ranging from 0% at the right bank to 100% at the left bank. The full distribution of such cumulative discharge lines in a river or estuary gives an appearance of the overall flow pattern that is important for pollutant transport. Closely spaced discharge lines are mostly indicative of areas of large depth and higher velocities as they occur in the outside portion of river bends or meanders (as sketched in Figure 6.2a).

In the CORMIX schematization of ambient flow characteristics and channel cross-section it is, in fact, useful to keep in mind the cumulative transport aspects of the ambient flow as remarked in Section 4.3.1 and 4.3.2. Thus, the uniform CORMIX flow field with the constant depth laterally is indeed conforming to a cumulative discharge distribution with equally spaced discharge lines, as indicated in Figure 6.2b. It is then conceptually straightforward to translate the CORMIX plume prediction back to the actual flow distribution by calculating and plotting the plume boundaries within the given cumulative discharge lines as shown in Figure 6.3c. The actual plume pattern may then show some surprising features such as strong "shifting back and forth" between opposing banks and an apparent "thinning' of the plume width. These realistic plume features are simply dictated by the non-uniform flow field.

Further technical details on the FFLOCATR model can be found in the report on CORMIX enhancements (8).

6.2.2 <u>Access to FFLOCATR</u>

FFLOCATR can also be accessed in different ways:

(1) Use within CORMIX:

(1a) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.

(1b) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

In either case, once the FFLOCATR option is chosen the user must first specify whether a CORMIX1, 2 or 3 simulation should be interpreted for the far-field with FFLOCATR. Then the CORMIX filename in the CORMIX\SIM directory must be specified. Finally, the user must specify the name of the <u>cumulative discharge input data file</u>, or if that does not yet exist, the user can first create such file by entering data on the cumulative discharge distribution at several cross-sections.

(2) Use outside CORMIX:

FFLOCATR can be invoked directly by typing the command line with three arguments:

fflocatr CORMIXn *fn* POST\FF*cumdata*.FFI

(alternatively, ffl can be typed instead of fflocatr) where CORMIXn, n = 1, 2 or 3, specifies which earlier CORMIX simulation should be analyzed for the far-field, *fn* (<u>without</u> path and extension) is the name of the CORMIX prediction file in the CORMIX\SIM directory, and *cumdata* (with directory designation POST\FF and fixed extension FFI) is the cumulative discharge input data file (see following section) existing in directory CORMIX\POST\FF.

Alternatively if one types:

fflocatr (or simply: ffl)

without the three arguments, the model will prompt the user for the file information.

6.2.3 <u>FFLOCATR Cumulative Discharge Input Data File</u>

In general, it is more convenient to construct the *cumdata*.FFI file outside of CORMIX and store it in the CORMIX\POST\FF directory. This option is described first.

(a) Input Data File Prepared Outside of CORMIX:

FFLOCATR is a Fortran program and reads the *cumdata*.FFI file in open format. An example is shown in Table 6.4 (corresponding to the test case discussed in <u>Appendix B</u>).

Table 6.4
Example of a cumulative discharge input data file for FFLOCATR

```
SHALLOW RIVER CUMULATIVE DISCHARGE           (applies to Sample2)
Number of Cross-sections (XS):
3
XS 'Label-'  Dist.  10%    20%    30%    40%    50%    60%    70%    80%    90%   100%
<> <------> <----> <---> <---> <---> <---> <---> <---> <---> <---> <---> <--->
1  'STA1'    30.5   6.1    12.2   15.9   20.7   27.5   33.6   58.0   76.3   82.4   88.5
2  'STA2'    152.5  9.2    16.8   21.4   24.4   27.5   33.6   36.6   39.7   54.9   79.3
3  'STA3'    305.   18.3   33.6   39.3   45.8   48.8   51.9   54.0   56.4   61.0   67.1
```

The **required input data values** (SI units) are:

<u>Line 1:</u> Any descriptive label.
<u>Line 2:</u> <dummy line; not read>
<u>Line 3:</u> NUMXS = Number of cross-sections (1 to 10) for which discharge data values will be entered
<u>Line 4:</u> <dummy line useful for formatting subsequent data; not read>
<u>Line 5:</u> <dummy line useful for formatting subsequent data; not read>
<u>Lines 6ff:</u> NUMXS lines must be entered, each containing the following data:

- XS = number of cross-section, numbered sequentially beginning with 1
- STALAB = arbitrary label for cross-section, bracketed by apostrophes ' with maximum total length of 10 characters (e.g. 'RM595' standing for river mile 595)
- YCD = 10 values, representing the position of the cumulative discharge line (m) measured from the right bank, beginning with the 10% line, incrementing by 10%, and ending with the 100% line. The 100% line is also equal to the channel width at that cross-section.

Consistency checks are performed on each data file to make sure that the entered values YCD are monotonically increasing. Essentially two methods can be used for obtaining the values for the cumulative discharge positions YCD in specific cases:

1) On the basis of detailed **stream-gaging surveys**, for example using the standard methods employed by the U.S. Geological Survey. This is the preferable approach for small to medium streams or rivers.

2) Using the results of detailed **numerical models** for the flow distribution in open channel flow. This is preferable for larger rivers or estuaries.

The primary application for FFLOCATR is for **bounded channels** such as streams, rivers or estuaries. The model will not execute when it encounters a CORMIX file for a design case involving an unbounded ambient flow.

Nevertheless, it may sometimes be useful to provide a detailed far-field plume delineation also for **unbounded flow situations**, such as coastal areas or lakes. This can be done when detailed hydrographic data or numerical model predictions describing the flow distribution in the near-shore where the plume may be located are available. A CORMIX simulation can then be re-run specifying a "bounded channel" with a width equal to some arbitrary bounding offshore streamline. The YCD data can then be specified relative to the value of that chosen streamline. FFLOCATR will thus predict the far-field plume location in the irregular coastal zone (assuming recirculating eddies do not exist in the flow).

(b) Input Data File Prepared Within CORMIX:

The user can generate the data file with exactly the same data structure as discussed above also within CORMIX. The system will prompt the user for the individual data items (up to 10 cross-sections can be entered) and then for a *cumdata* filename. The file will then be stored automatically in directory CORMIX\POST\FF with extension FFI.

6.2.4 FFLOCATR Output Features

FFLOCATR generates an output file CORMIX\POST\FF*fn*.FFX indicating that the far-field plume prediction for the CORMIX design case *fn* has been interpreted under the actual far-field flow distribution. This file can be inspected on-screen when in CORMIX or externally with any text processor, and can be printed out. No graphics plotting option exists for this file.

As an example, Table 6.5 on the next page shows the output file that combines the cumulative discharge input data of Table 6.4 with the CORMIX2 plume predictions that are part of Appendix B. The output file preceded by the banner 'FFF' consists of three parts. The first part lists some of the underlying CORMIX data including file information. The second part echoes the complete cumulative discharge input data file.

The actual results of the FFLOCATR translation routine are given in the third part. For each of the specified cross-sections (stations) the output file lists the station label, the downstream distance, and the position of plume center, left edge and right edge, respectively, each measured from the right bank, and the local centerline dilution and concentration. Data of this kind can then readily be used to prepare plots of far-field plumes superimposed on maps of the actual flow field. This last step has been illustrated in Figure 6.2c.

It should be understood that the plume centerline in the far-field does not necessarily coincide with the cumulative discharge line that passes through the offshore discharge location (as has been illustrated in Figure 6.2 where a co-flowing discharge had been assumed). The plume centerline can shift because of near-field processes, as in case of a cross-flowing discharge, or if bank interaction occurs in the far-field, causing the centerline to shift to one bank/shore.

Table 6.5
Example of FFLOCATR output file

```
FFLOCATR RESULTS FILE:
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
FFLOCATR:  FAR-FIELD PLUME LOCATOR                     Version 1.0, March 1994
-----------------------------------------------------------------------------
Output FILE NAME:        POST\FF\SAMPLE2.FFX
 Time of FFLOCATR run:   1995/ 6/ 2-- 8:54:38

-----------------------------------------------------------------------------
FAR-FIELD DATA values from earlier CORMIX2 prediction:
 FILE NAME:              SIM\SAMPLE2.cx2
 Site name/label:        B-PLANT^SHALLOW-RIVER
 Design case:            LOW-FLOW^7Q10
 Time of CORMIX2 run:    09/20/94--15:24:11

Channel characteristics (metric):
 BS    =     50.00  HA    =       .30  UA    =       .54
 BANK  =  right     DISTB =     20.00
 STRCND=  U         uniform density environment

Pollutant data:
 C0    =    100.00  CUNITS=   PERCENT

-----------------------------------------------------------------------------
CUMULATIVE DISCHARGE DATA (m):
 FILE NAME:              POST\FF\SH-RIVER.ffi
 Data label:             SHALLOW RIVER CUMULATIVE DISCHARGE
 Number of XS:           3
XS'Label-'  Dist.  10%   20%   30%   40%   50%   60%   70%   80%   90%  100%
1 'STA1  '   30.5  6.10 12.20 15.90 20.70 27.50 33.60 58.00 76.30 82.40 88.00
2 'STA2  '  152.5  9.20 16.80 21.40 24.40 27.50 33.60 36.60 39.70 54.90 79.00
3 'STA3  '  305.0 18.30 33.60 39.30 45.80 48.80 51.90 54.00 56.40 61.00 67.00

-----------------------------------------------------------------------------
FAR-FIELD PLUME PROPERTIES (m):
 XS  'Label-' Distance      Left     Plume      Right    Dilution     Conc.
  #          downstream     edge   centerline   edge
  1  'STA1  '    30.50     27.50     20.70     13.28       30.1     .332E+01
  2  'STA2  '   152.50     27.50     24.40     17.80       31.4     .318E+01
  3  'STA3  '   305.00     48.80     45.80     34.32       33.0     .303E+01
-----------------------------------------------------------------------------
END OF FFLOCATR:  FAR-FIELD PLUME LOCATOR
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
```

VII Closure

7.1 Synopsis

The Cornell Mixing Zone Expert System (CORMIX) is a series of software subsystems for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone including compliance with regulatory constraints. The system also predicts the behavior of the discharge plume at larger distances in the far-field.

The highly user-interactive CORMIX system is implemented on IBM-PC compatible microcomputers and consists of three subsystems. These are: CORMIX1 for submerged single port discharges, CORMIX2 for submerged multiport diffuser discharges and CORMIX3 for buoyant surface discharges. The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for the application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, two post-processing models are linked to the CORMIX system, but can also be used independently. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, and FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments.

This user's manual gives a comprehensive and uniform description of all three CORMIX subsystems; it provides advice for assembly and preparation of required input data; it delineates ranges of applicability of the three subsystems; it provides instruction for the interpretation and graphical display of system output; and it illustrates practical system application through several case studies.

7.2 System and Documentation Availability

The CORMIX system programs can be obtained from:

U.S. EPA - Center for Environmental
Assessment Modeling (CEAM)
Environmental Research Laboratory
960 College Station Road
Athens, GA 30605-2700 USA
Tel. 706-546-3549 (or FTS 250-3590)
Fax:706-546-3402
E-mail: ceam@athens.ath.epa.gov

As of the release of this manual (late 1996) the following versions of CORMIX are available: CORMIX Version2.1 (1993, without graphics and post-processor features) and Version3.1 (August 1996, as described in this report). The models can be obtained by mail or over the electronic bulletin board operated by CEAM. Information on program installation and computer configuration are also provided by CEAM. The ftp address is:

ftp://ftp.epa.gov/epa_ceam/wwwhtml/ceamhome.htm

The distribution versions of CORMIX contain only the executable code of the FORTRAN programs HYDROn; they do not include the source code. The source code can be requested separately by writing to CEAM at U.S. EPA-ERL and giving the reason for code inspection and possible manipulation. The full code, while made up of simple individual modules, is complex with multiple interdependencies; only experienced research personnel should attempt this work when engaged in comparison of model predictions to new field or laboratory data.

The technical documentation reports(5,6,7,8) are available as U.S. EPA and NITS publications, and have also been issued as technical reports of the DeFrees Hydraulics Laboratory.

7.3 User Support

Technical and scientific support for CORMIX under contract from the USEPA is provided by:

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email: doneker@ese.ogi.edu

This includes assistance on problems of system installation and execution, and advice on the specification of input data as well as interpretation of CORMIX output.

Any high-quality field or laboratory data on effluent mixing processes is a valuable asset for any future development or updates on CORMIX. Transmittal of such data to the following address will be greatly appreciated:

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PO Box 6380
D-76128 Karlsruhe, GERMANY
Tel. (49) 721/608-2200, Fax. (49) 721/66-16-86

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(25) Jirka, G.H. and Fong, H.L.M., "Vortex Dynamics and Bifurcation of Buoyant Jets in Crossflow", J. Engineering Mechanics Division, ASCE, Vol.107, pp. 479-499, 1981.

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(28) Yotsukura, N. and W.W. Sayre, "Transverse mixing in natural channels", Water Resources Research, Vol.12, 695-704, 1976.

Appendix A

Flow Classification Diagrams for the Three CORMIX Subsystems

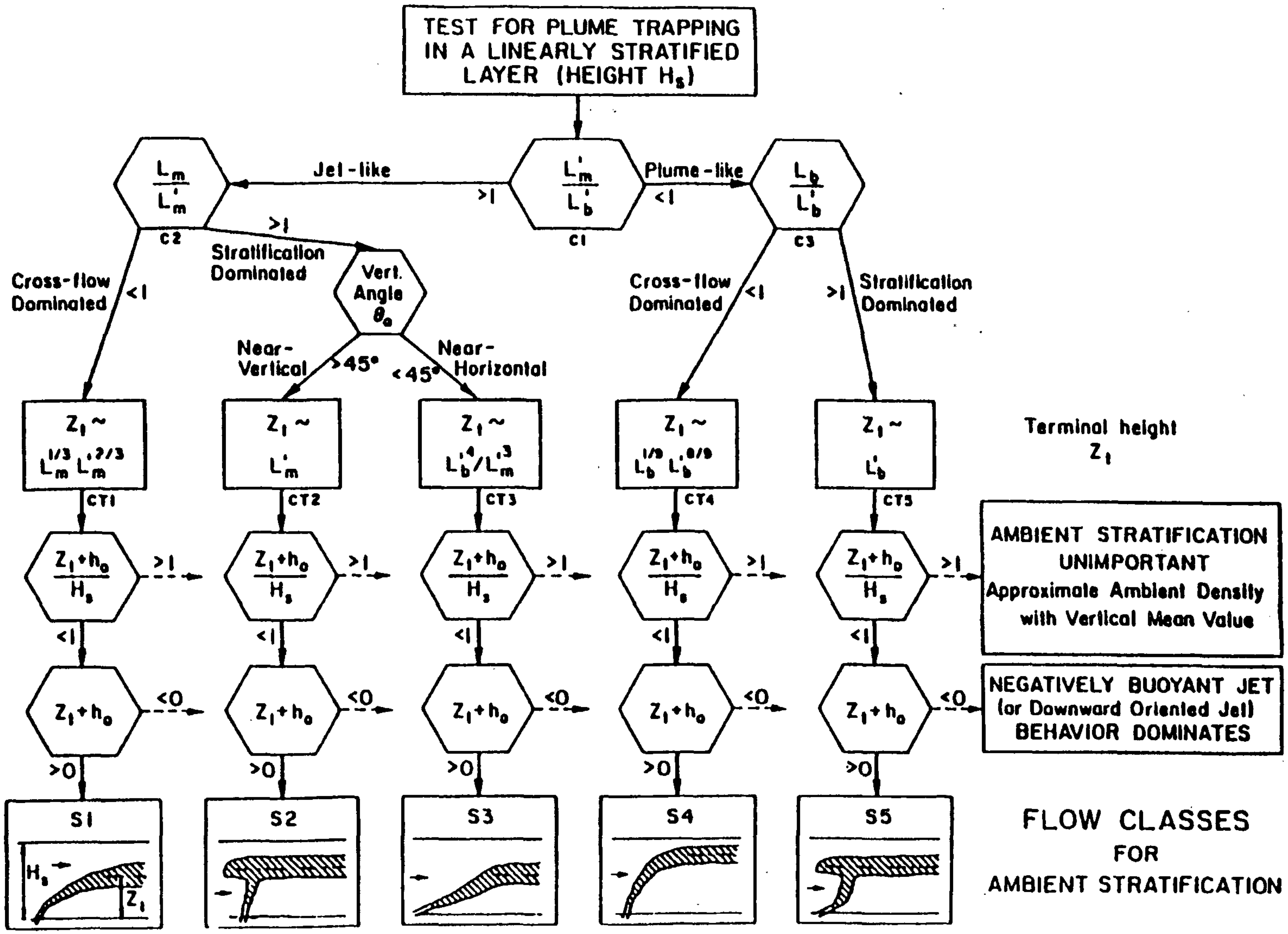


Figure A.1: CORMIX1 Classification: Assessment of ambient density stratification and different flow classes for internally trapped

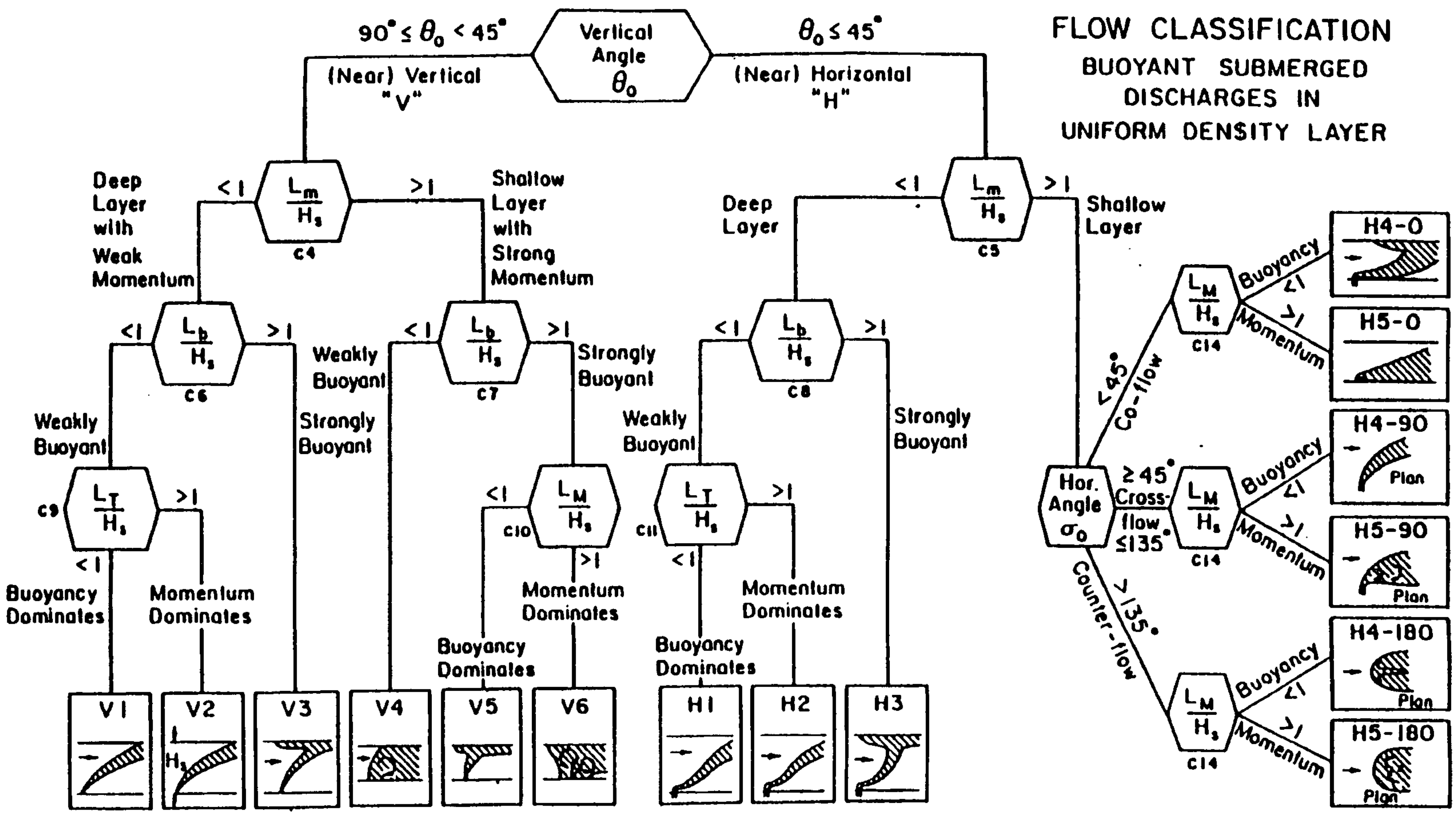


Figure A.2: CORMIX1 Classification: Behavior of positively buoyant discharges in uniform ambient layer flow

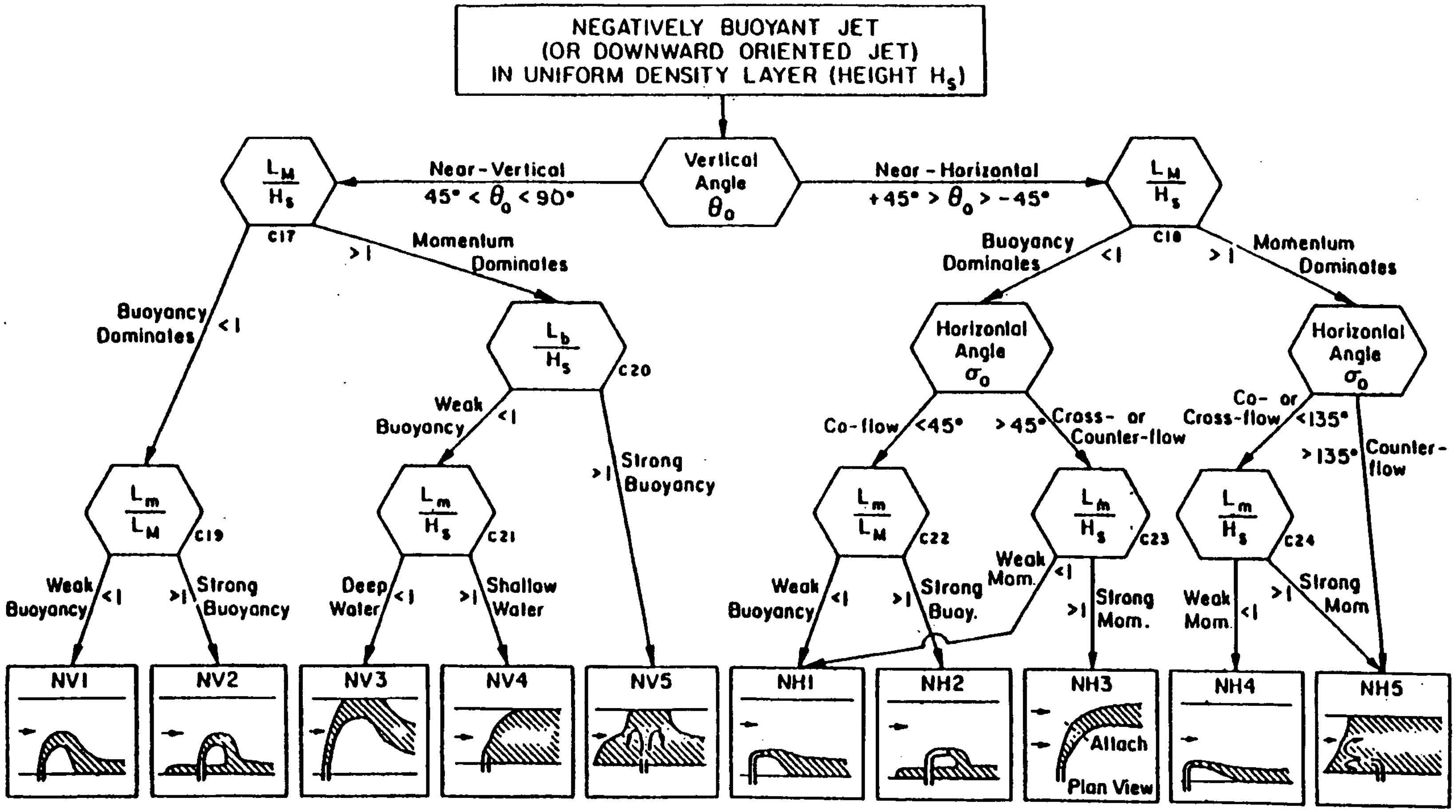


Figure A.3: CORMIX1 Classification: Behavior of negatively buoyant discharges in uniform layer flow (Flow Classes NV and NH)

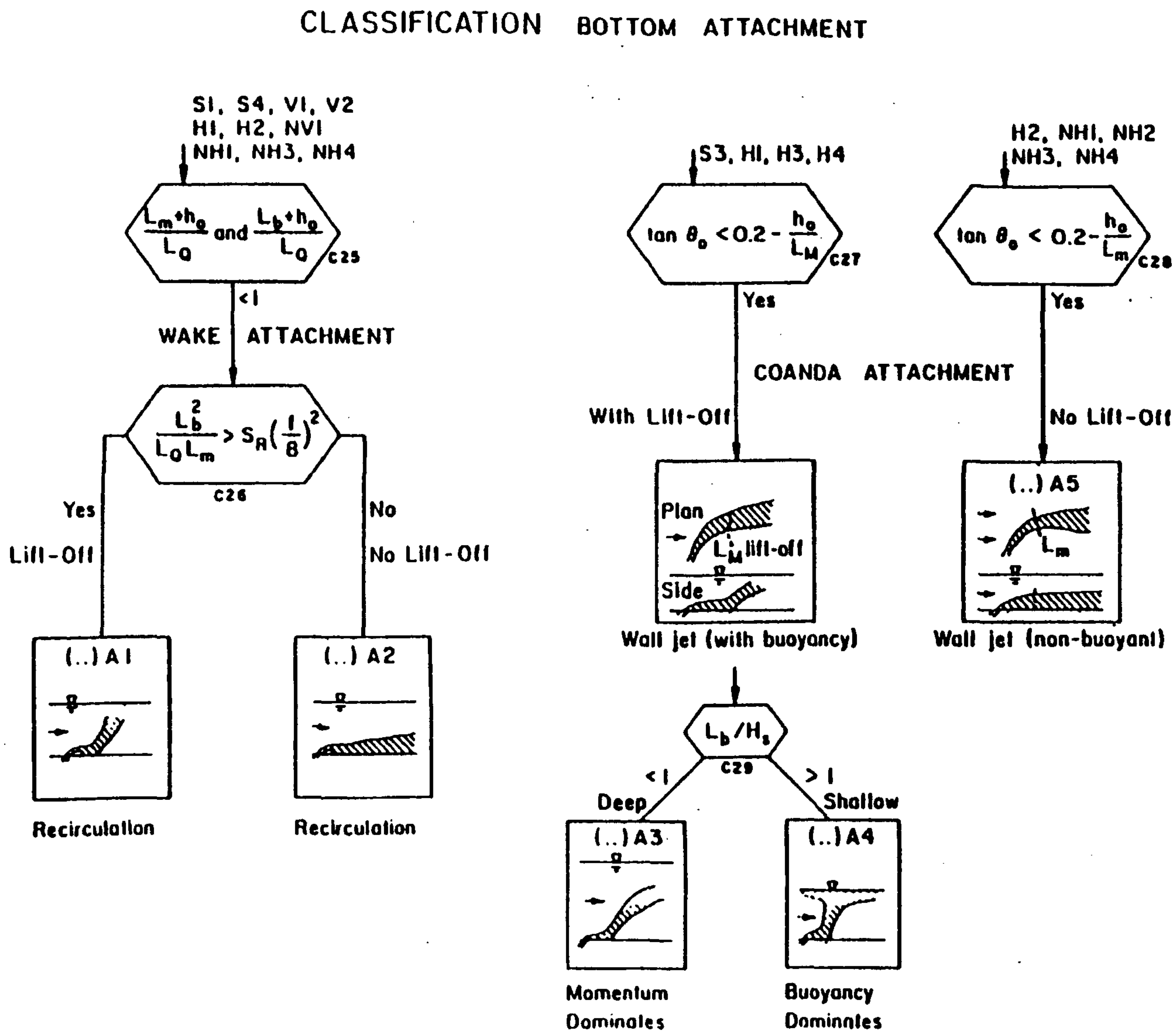


Figure A.4: CORMIX1 Classification: Dynamic bottom attachment of discharge due to wake or Coanda attachment

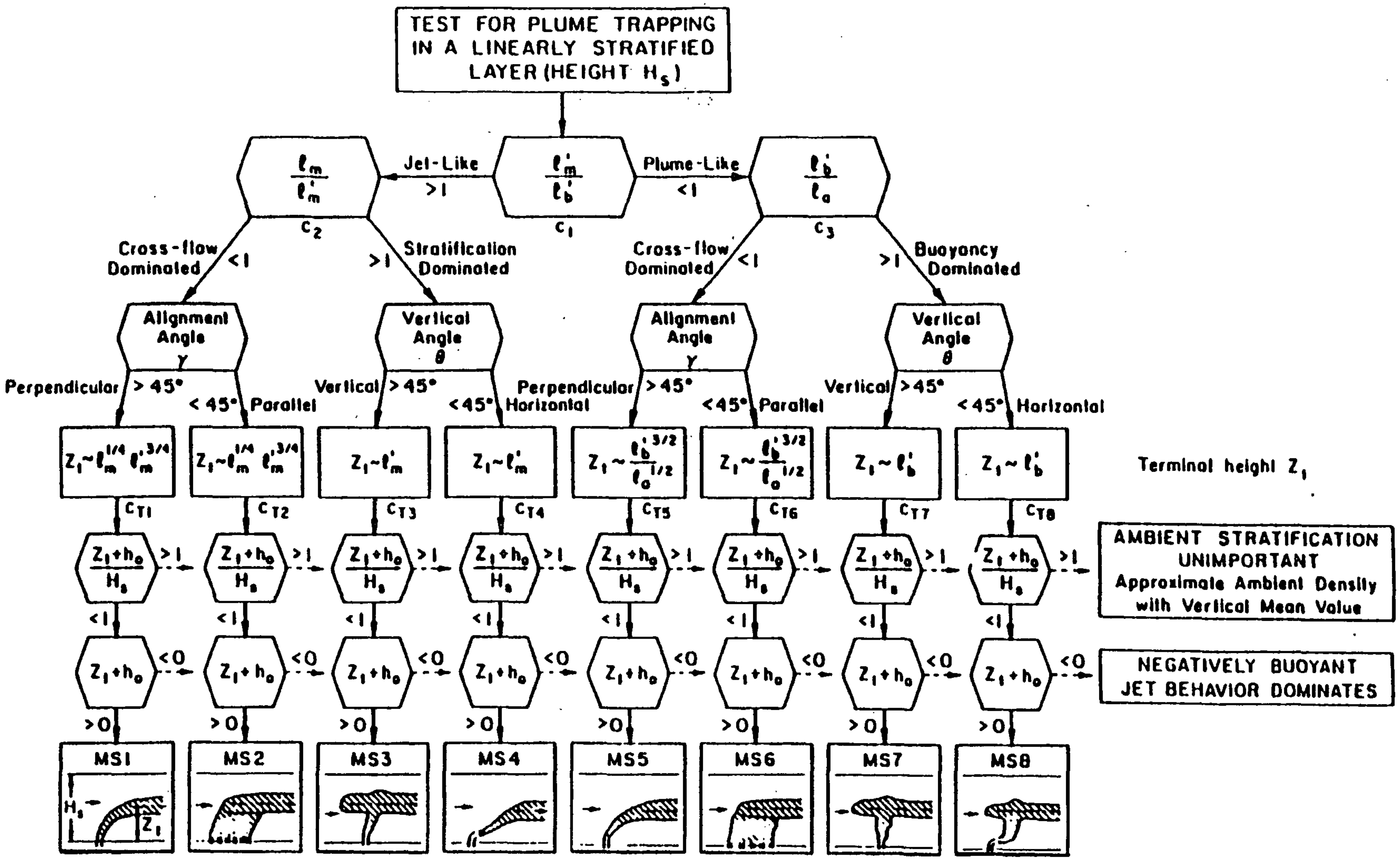


Figure A.5: CORMIX2 Classification: Assessment of ambient density stratification and different flow classes for internally trapped

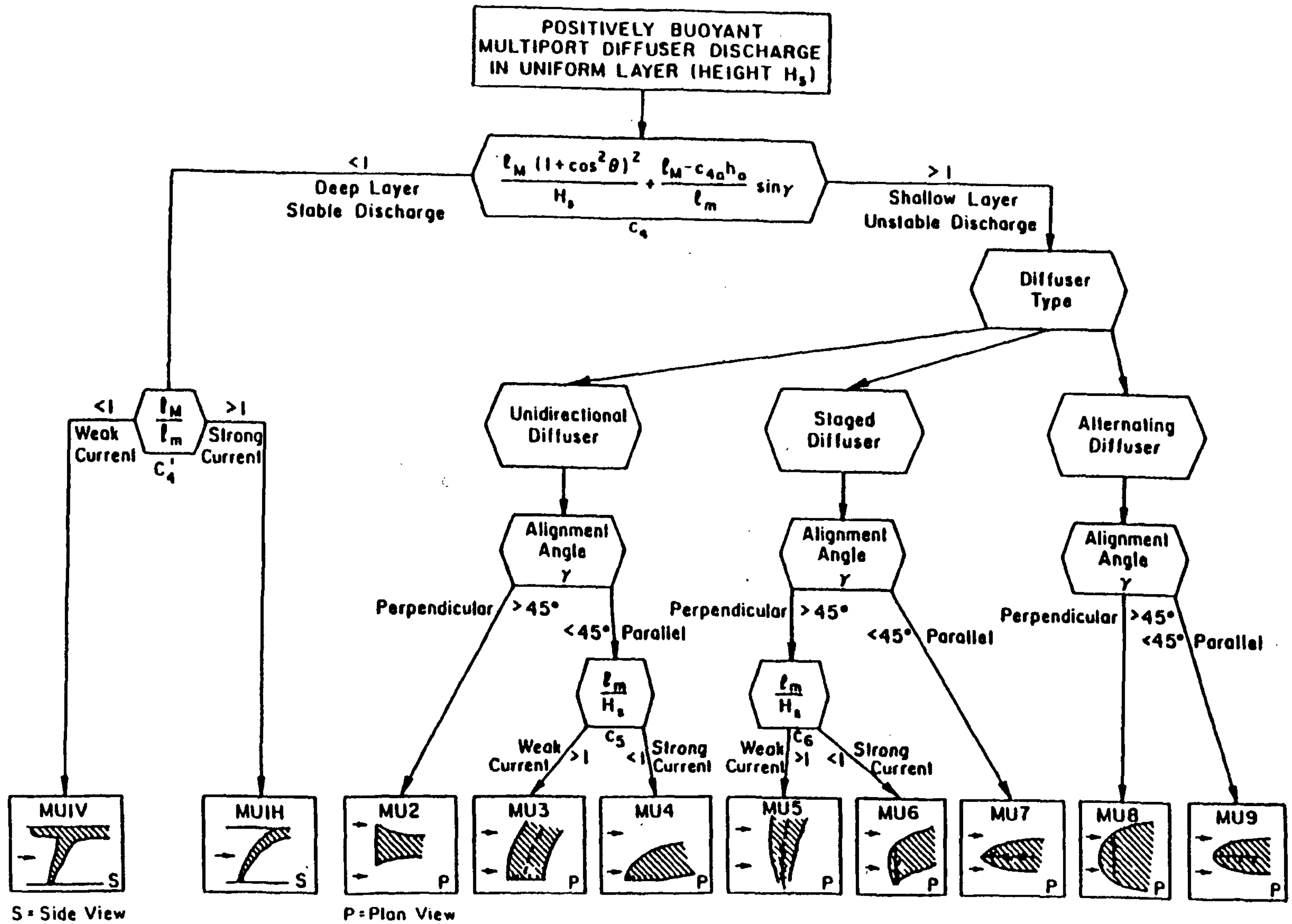


Figure A.6: CORMIX2 Classification: Behavior of positively buoyant multiport diffuser discharges in uniform ambient layer flow

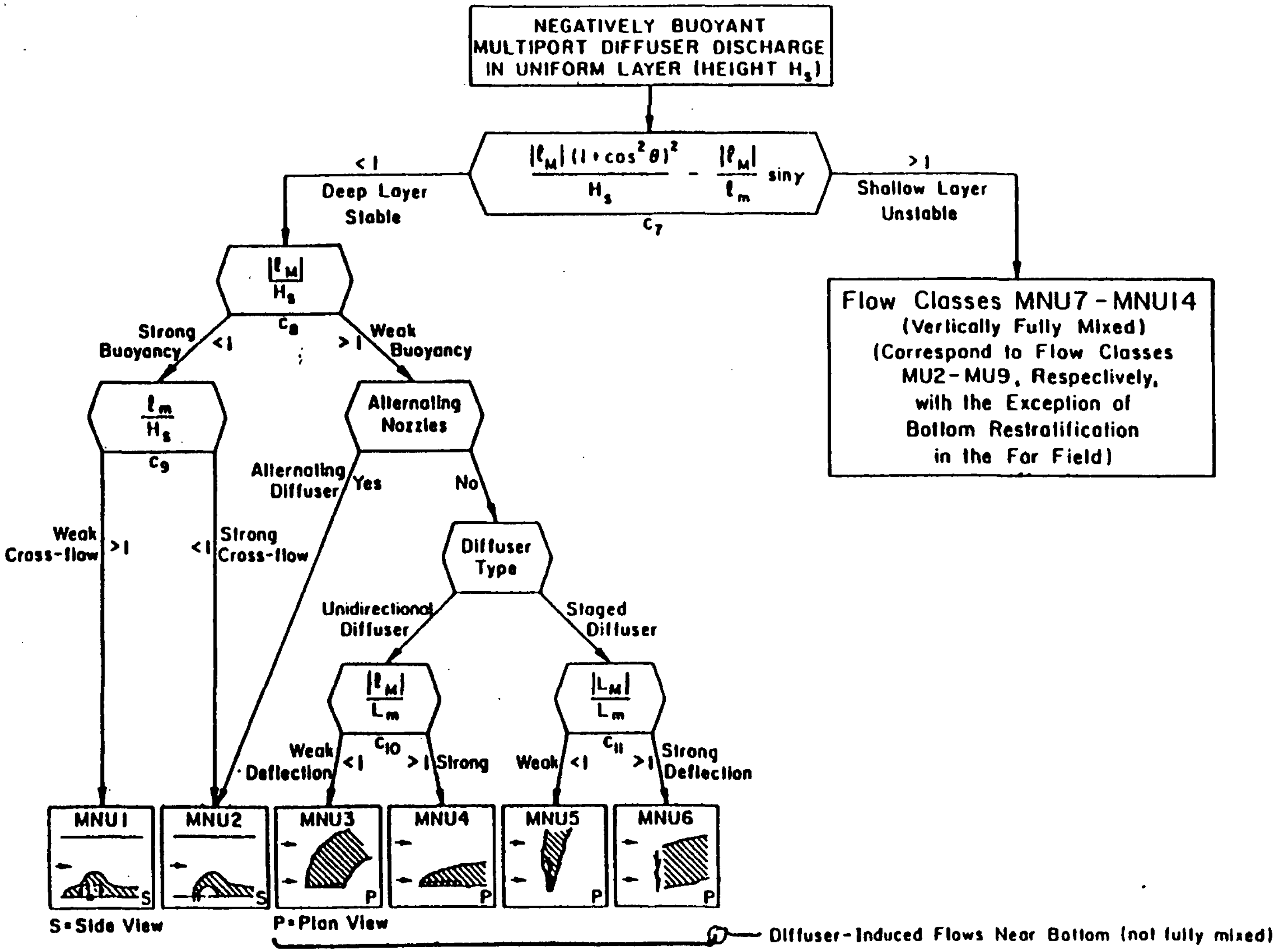


Figure A.7: CORMIX2 Classification: Behavior of negatively buoyant multiport diffuser discharges in uniform ambient layer flow

FLOW CLASSIFICATION FOR BUOYANT SURFACE DISCHARGES

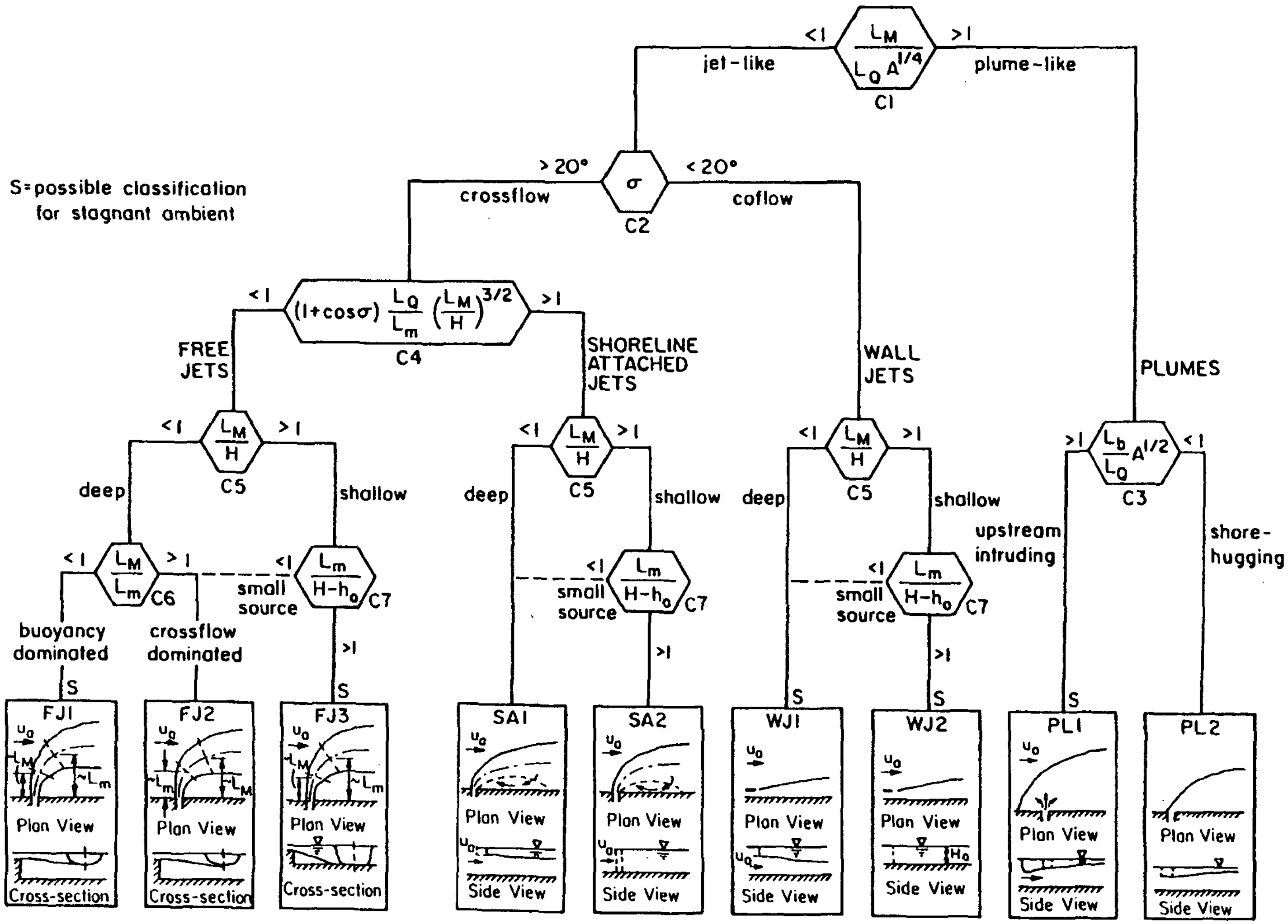


Figure A.8: CORMIX3 Classification: Assessment of buoyant surface discharges as free jets, shoreline-attached jets, wall jets, or

Appendix B
CORMIX1: Submerged Single Port Discharge in a Deep Reservoir

This case study illustrates the application of CORMIX1 to the prediction of the effluent from a small manufacturing plant into a large and deep stratified reservoir.

B.1 Problem Statement

A manufacturing plant (A-Plant) is discharging its effluent into an adjacent deep reservoir. The plant design flowrate is 3.5 mgd (≈ 0.15 m^3/s). The effluent contains heavy metal at a concentration of 3500 ppb, and is released at a temperature of 68 °F (= 20 °C). The density of the effluent at this low concentration can be considered equivalent to freshwater.

The existing reservoir has been formed by flooding a river valley. The reservoir length is about 60 miles. The water level in the reservoir is fluctuating depending on the release operation at the downstream dam with its hydropower installation. During summer conditions, the reservoir level is typically at an elevation of 710 ft above sea level. This results in a reservoir width of about 4000 ft (≈ 1200 m) and a maximum depth of 310 ft (≈ 95 m) at the discharge location. The mean river flow into the reservoir during the summer low-flow conditions is about 18,540 cfs (≈ 525 m^3/s). The typical temperature of the inflowing river water is 55 °F (≈ 13 °C).

Figure B.1 shows the local bathymetry (as obtained from a USGS map) in the vicinity of the proposed discharge. Since the discharge is very small relative to the reservoir size and the ambient flowrate, it is expected that mostly local conditions will be important, and not overall reservoir dimensions. (Note: Any such conjecture has to be verified against the final simulation results, and adjustments have to be made if needed.)

Temperature data as a function of depth obtained from field measurements in the center of the reservoir show a significant temperature stratification (see Figure B.2), as is typical for such deep reservoirs during summer conditions. The stratification can be expected to be horizontally uniform and therefore similar conditions will hold at the discharge site. Also, the river inflow is colder than the surface layer of the stratified reservoir. The reservoir has a selective withdrawal structure at the dam, therefore it can be expected that the river water will flow predominantly in a vertically limited layer, that may extend from a depth of about 35 m to the surface. The velocity of that flow is estimated at about 1.5 cm/s (≈ 0.015 m/s), given the 35 m thick layer and an about 1000 m width at that elevation. (Note: More detailed hydrodynamic investigations, using available models for stratified reservoir dynamics, can be used to obtain more precise estimates of the velocity field. Generally, however, it cannot be assumed that the velocity in stratified reservoirs is given by the simple average of the flowrate divided by the cross-sectional area.)

The proposed discharge location on the side slope of the cross-section is also shown in Figure B.1: a submerged single port discharge at an elevation of 610 ft above sea level, i.e. at a local depth of 100 ft (≈ 30.5 m) below the surface, is proposed in the initial design phase. The port diameter is 10 in (≈ 0.254 m) and is located 2 ft (≈ 0.6 m) above the local bottom. The discharge is pointing offshore and is angled upward at 10 °.

The discharge is subject to State mixing zone regulations whereby the mixing zone width is less than 10% of the width of the water body. Furthermore, the heavy metal in the effluent is considered toxic with CMC and CCC limits of 1200 and 600 ppb, respectively.

B.2 Problem Schematization and Data Preparation

Figure B.3 is the data checklist that summarizes the CORMIX1 input for the present problem. The ambient water body has been characterized as unbounded in line with the expectation that the discharge plume will be small

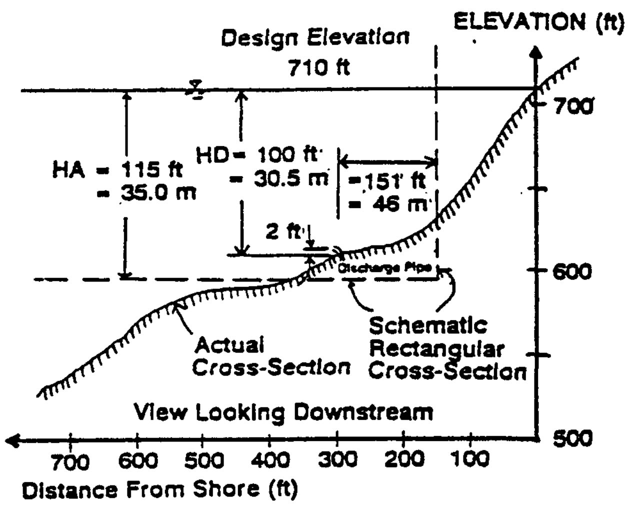


Figure B.1: Local details of Deep Reservoir cross-section and CORMIX1 schematization

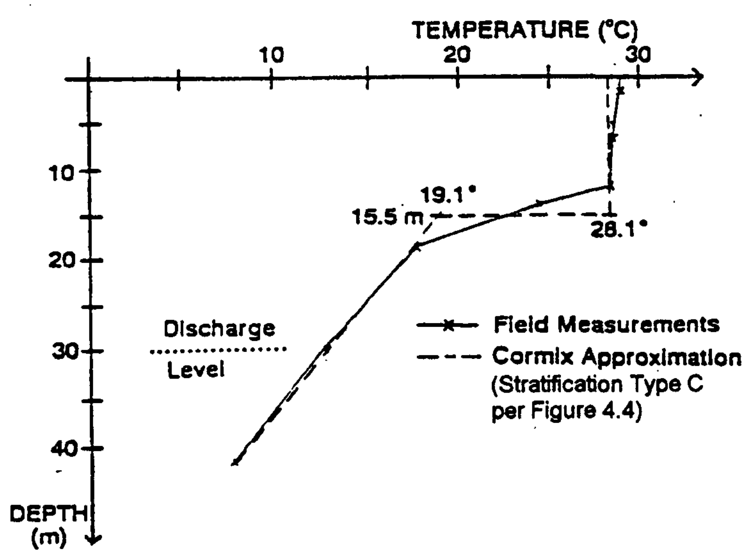


Figure B.2: Temperature field data as a function of depth and CORMIX1 representation of Type C temperature profile

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name: A-Plant Deep Reservoir — Date:
Design CASE: Summer Stratification — Prepared by: GHJ
DOS FILE NAME: Sample 1 (w/o extension)

AMBIENT DATA:

Water body depth: 35.0 m — Water body is ~~bounded~~/unbounded
Depth at discharge: 30.5 m — If bounded: Width - m
If steady: Ambient flowrate - m³/s or: Appearance ~~1/2/3~~
Ambient velocity: 0.015 m/s

If tidal: Tidal period ____ hr — Max. tidal velocity ____ m/s
At time ____ hr before/at/after slack: Tidal velocity at this time ____ m/s

Manning's n: 0.02 — or: Darcy-Weisbach f: -
Wind speed: 2 m/s

Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is fresh/~~salt~~ water — If fresh: Specify as ~~density~~/temp. values
If uniform: Average density/temp. ____
If stratified: ~~Density~~/temp. at surface: 28.1
Stratification type: ~~A/B~~/C — ~~Density~~/temp. at bottom: 11.0
If B/C: Pycnocline height: 15.5 m — If C: ~~Density~~/temp. jump: 9.0

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE – CORMIX1
Nearest bank is on: ~~left~~/right — Distance to nearest bank: 46.0 m
Vertical angle THETA: 10 ° — Horizontal angle SIGMA: 90 °
Port diameter: 0.254 m or: Port area: - m²
Port height: 0.6 m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2
Nearest bank is on: left/right — Distance to one endpoint ____ m
Diffuser length ____ m — to other endpoint ____ m
Total number of openings ____ m — Port height ____ m
Port diameter ____ m with contraction ratio ____
Diffuser arrangement/type: unidirectional / staged / alternating or vertical
Alignment angle GAMMA ____ ° — Horizontal angle SIGMA ____ °
Vertical angle THETA ____ ° — Relative orientation BETA ____ °

BUOYANT SURFACE DISCHARGE – CORMIX3
Discharge located on: left/right bank — Configuration: flush/protruding/co-flowing
Horizontal angle SIGMA ____ ° — If protruding: Dist. from bank ____ m
Depth at discharge ____ m — Bottom slope ____ °
If rectangular discharge channel: Width ____ m or: If circular pipe: Diameter ____ m
Depth ____ m — Bottom invert depth ____ m

Effluent: Flow rate: 0.153 m³/s or: Effluent velocity: - m/s
Effluent density: - kg/m³ or: Effluent temperature: 20.0 °C
Heated discharge?: ~~yes~~/no — If yes: Heat loss coefficient: - W/m²,°C
Concentration units: ppb — Effluent concentration: 3500
Conservative substance?: yes/~~no~~ — If no: Decay coefficient: - /day

MIXING ZONE DATA:
Is effluent toxic?: yes/~~no~~ — If yes: CMC 1200 — CCC 600
WQ stand./conventional poll.?: ~~yes~~/no — If yes: value of standard -
Any mixing zone specified?: yes/~~no~~ — If yes: distance - m or width 120 % or m
or area - % or m²

Region of interest: 3500 m — Grid intervals for display: 20

Figure B.3: Data preparation checklist for A-Plant Deep Reservoir design case study using CORMIX1 in size relative to the reservoir width. Furthermore, since (1) the discharge elevation is well above the lowest point of the reservoir and (2) the plume is expected to rise toward the surface, the ambient water depth is taken as 150 ft (≈35.0 m) only.

The depth at the discharge corresponds to the local depth at the discharge location. Because of the sloping bank from the discharge to the near shoreline, the distance to bank (46 m) corresponds to one-half of the actual distance from the outlet to the shoreline at the water surface. The ambient velocity corresponds to the estimate made above for the stratified water body. A Manning's n of 0.02 describes the smooth bottom.

Density data is simply entered via the temperature values of the fresh water body. A Stratification Type C is chosen to describe the actual temperature profile.

The discharge data values summarize the discharge situation as described above. Finally, the mixing zone specifications include a width value of 120 m, corresponding to 10 % of the actual width of 1200 m. Information is desired over about one mile (≈ 1600 m) which represents the region of interest (ROI) limitation.

B.3 CORMIX1 Session and Results

If desired by the user, CORMIX1 provides a summary of the data as they are entered, and then a full record of the simulation sequence and final results. This session summary report is shown in Table B.1. Of particular interest to the user are the evaluations in program element PARAM and CLASS. Note, that the computed length scales L_m' and $_bL'$ are quite small, indicating that the jet or plume will be trapped quickly by the ambient stratification; thus, this is the first numerical indication that the near-field jet/plume will indeed be small relative to the reservoir. The ambient flow related scales L_m and L_b are quite large, indicating that the ambient velocity is very weak. The resulting flow class S3 is dominated by the ambient stratification; the plume will be limited to the lower layer of the stratification. The user should also consult the description of flow class S3 that is available during the CORMIX1 session (not reproduced here). The detailed plume properties are computed in program element HYDRO, and are displayed in the Fortran CORMIX1 prediction file (see Table B.2, discussed in more detail further below).

Many important features of the plume prediction are summarized in program element SUM of the session record (see Table B.1). Notably, all aspects pertaining to mixing zone regulations are contained in that summary. For example, it can be seen quickly from that summary that the present discharge configuration meets all three toxic dilution zone (TDZ) criteria and also the regulatory mixing zone (RMZ) limitation. Obviously, other ambient conditions and discharge variations should be considered in additional simulations before a design such as this should be deemed fully satisfactory.

B.4 Graphical Displays of Detailed Plume Predictions

As for most engineering studies it is desirable to produce graphical displays for visualization of the predicted results. The data contained in the CORMIX1 prediction file (Table B.2) form the basis for such plots. Unfortunately, it is often difficult to display all plume features in one single plot because the plume may contain a lot of near-field details while extending over large distances into the far-field. A short examination of Table B.2 proves that point: The plume gets quickly trapped within a very limited near-field but with considerable mixing (see MOD110 = CORJET of the CORMIX1 prediction). Yet after that the plume extends over large distances into the far-field forming a wide thin layer within the stratified reservoir (see MOD142).

Using the graphics package CMXGRAPH, two plots have been prepared to display the jet/plume side view in the near-field, using distorted and undistorted 1:1 scales, respectively, (Figure B.4) and the plan view in the near-field and larger scale far-field (Figure B.5) of the effluent plume. Figure B.4 shows the initial trajectory of the slightly upward curved jet that rises to maximum level of 4.29 m and then gets trapped at an elevation of 3.44 m above the local bottom. In the trapping stage the jet undergoes a complicated transition (MOD137) to the horizontally spreading layer. CORMIX1 predicts

Table B.1
CORMIX Session Report for A-Plant discharge into Deep Reservoir with summer stratification

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                      CORMIX v.3.10         June 1995
SITE NAME/LABEL:                Sample 1
  DESIGN CASE:                  Summer Stratification
  FILE NAME:                    SAMPLE1
Using subsystem CORMIX1:        Submerged Single Port Discharges
  Start of session:             08/25/96--16:37:01
****************************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                          = unbounded
  Average depth                   HA     =          35 m
  Depth at discharge              HD     =        30.5 m
  Ambient velocity                UA     =        .015 m/s
  Darcy-Weisbach friction factor  F      =      0.0096
    Calculated from Manning's n          =         .02
  Wind velocity                   UW     =           2 m/s
Stratification Type               STRCND = C
  Surface temperature                    =        28.1 degC
  Bottom temperature                     =        11.0 degC
  Temperature below thermocline          =       19.10 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  =    996.2053 kg/m^3
  Bottom density                  RHOAB  =    999.6071 kg/m^3
  Stratification height           HINT   =        15.5 m (pycnocline level)
  Density below pycnocline        RHOAP  =    998.3866 kg/m^3
----------------------------------------------------------------------------
DISCHARGE PARAMETERS:             Submerged Single Port Discharge
  Nearest bank                           = right
  Distance to bank                DISTB  =         46. m
  Port diameter                   D0     =        .254 m
  Port cross-sectional area       A0     =      0.0506 m^2
  Discharge velocity              U0     =        3.01 m/s
  Discharge flowrate              Q0     =        .153 m^3/s
  Discharge port height           H0     =          .6 m
  Vertical discharge angle        THETA  =          10 deg
  Horizontal discharge angle      SIGMA  =         90. deg
  Discharge temperature (freshwater)     =        20.0 degC
    Corresponding density         RHO0   =    998.2051 kg/m^3
  Density difference              DRHO   =      1.3548 kg/m^3
  Buoyant acceleration            GP0    =       .0133 m/s^2
  Discharge concentration         C0     =         3500 PPB
  Surface heat exchange coeff.    KS     =           0 m/s
  Coefficient of decay            KD     =           0 /s
----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  =       0.22 m        Lm  =      45.31 m        Lb  =      602.57 m
  LM  =      12.42 m        Lm' =       4.94 m        Lb' =        3.11 m
----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Port densimetric Froude number  FR0    =      51.96
  Velocity ratio                  R      =     201.30
----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = yes
  CMC concentration               CMC    =            1200 PPB


  CCC concentration               CCC    =             600 PPB
  Water quality standard                 = given by CCC value
  Regulatory mixing zone                 = yes
  Regulatory mixing zone specification   = width
  Regulatory mixing zone value           =         120 m (m^2 if area)
  Region of interest                     =     3500.00 m
****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS  =       S3 |
  *------------------------*
  The specified ambient density stratification is important, the discharge
  near field flow is confined to the lower layer by the ambient density
  stratification.
  Applicable layer depth = lower layer depth =         15.5 m
****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
          46. m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
```

```
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =        98.2267 PPB
  Dilution at edge of NFR                =        35.6
  NFR Location:                        x =        98.19 m
    (centerline coordinates)           y =        24.63 m
                                       z =         3.43 m
  NFR plume dimensions:       half-width =       191.86 m
                               thickness =          .94 m
-----------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
  the surface.
-----------------------------------------------------------------------------
Stratification assessment:
  The specified ambient density stratification is dynamically important.
  The discharge near field flow is trapped within the linearly stratified
  ambient density layer.
-----------------------------------------------------------------------------
UPSTREAM INTRUSION SUMMARY:
Plume exhibits upstream intrusion due to low ambient velocity or strong
  discharge buoyancy.
  Intrusion length                         =        90.24 m
  Intrusion stagnation point               =       -87.98 m
  Intrusion thickness                      =         1.29 m
  Intrusion half width at impingement      =       191.86 m
  Intrusion half thickness at impingement =           .94 m
************************ TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
  Technical Support Document (TSD) for Water Quality-based Toxics Control,
  1991 (EPA/505/2-90-001).
  Criterion maximum concentration (CMC)  =             1200 PPB


  Corresponding dilution                 =        2.9
The CMC was encountered at the following plume position:
  Plume location:                      x =          .05 m
    (centerline coordinates)           y =         3.93 m
                                       z =         1.31 m
  Plume dimensions:           half-width =          .10 m
                               thickness =          .10 m
 CRITERION 1: This location is within 50 times the discharge length scale of
              Lq =        0.22 m.
 +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

 CRITERION 2: This location is within 5 times the ambient water depth of
              HD =          30.5 m.
 ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.+++++++++++

 CRITERION 3: This location is within one tenth the distance of the extent
              of the Regulatory Mixing Zone of        98.19 m downstream.
 +++++ The Regulatory Mixing Zone TEST for the TDZ has been SATISFIED. ++++++

 The diffuser discharge velocity is equal to         3.01 m/s.
   This exceeds the value of 3.0 m/s recommended in the TSD.

 *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
********************** REGULATORY MIXING ZONE SUMMARY ***********************
The plume conditions at the boundary of the specified RMZ are as follows:
  Pollutant concentration                =       98.226660 PPB
  Corresponding dilution                 =        35.6
  Plume location:                      x =        98.19 m
    (centerline coordinates)           y =        24.63 m
                                       z =         3.43 m
  Plume dimensions:           half-width =       191.86 m
                               thickness =          .94 m
At this position, the plume is CONTACTING the RIGHT bank.
Furthermore, the CCC for the toxic pollutant has indeed been met
  within the RMZ. In particular:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                    =              600 PPB
  Corresponding dilution                 =        5.8
  Plume location:                      x =          .21 m
    (centerline coordinates)           y =         7.82 m
                                       z =         2.12 m
  Plume dimensions:           half-width =          .10 m
                               thickness =          .10 m
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
*****************************************************************************
DESIGN CASE:                      Summer Stratification
FILE NAME:                        SAMPLE1
Subsystem CORMIX1:                Submerged Single Port Discharges
END OF SESSION/ITERATION:         08/26/96--05:37:41
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Table B.2
CORMIX1 Prediction File for A-Plant discharge into Deep Reservoir with summer stratification

```
CORMIX1 PREDICTION FILE:
1111111111111111111111111111111111111111111111111111111111111111111111111111
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:                                       Subsystem version:
 Submerged Single Port Discharges           CORMIX_v.3.1_________June_1995
----------------------------------------------------------------------------
----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          DEEP^RESERVOIR
 Design case:              A-PLANT^SUMMER^STRATIFICATION
 FILE NAME:                cormix\sim\SAMPLE1 .cx1
 Time of Fortran run:      06/24/95--22:29:54

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =     35.00 HD     =     30.50
 UA     =      .015 F      =      .010 USTAR = .5200E-03
 UW     =     2.000 UWSTAR= .2198E-02
 Density stratified environment
 STRCND= C          RHOAM =  997.6240
 RHOAS =  996.2053  RHOAB =  999.6072 RHOAH0=  999.5599 E      = .7730E-03
 DRHOJ =    2.1813  HINT  =     15.50 ES     = .2153E-02

DISCHARGE PARAMETERS (metric units)
 BANK  = RIGHT      DISTB =     46.00
 D0    =      .254  A0    =      .051 H0     =       .60
 THETA =     10.00  SIGMA =     90.00
 U0    =     3.020  Q0    =      .153        = .1530E+00
 RHO0  =  998.2051  DRHO0 = .1355E+01 GP0    = .1329E-01
 C0    = .3500E+04  CUNITS= PPB
 IPOLL = 1          KS    = .0000E+00 KD     = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .1530E+00  M0    = .4620E+00 J0     = .2034E-02 SIGNJ0=        1.0
 Associated length scales (meters)
 LQ    =       .23  LM    =     12.43 Lm     =     45.31 Lb    =     602.57
                                      Lmp    =      4.94 Lbp   =       3.12

NON-DIMENSIONAL PARAMETERS
 FR0   =     51.96  R     =    201.30

FLOW CLASSIFICATION
 111111111111111111111111111111111111111111
 1  Flow class (CORMIX1)       =    S3     1
 1  Applicable layer depth HS =    15.50  1
 111111111111111111111111111111111111111111

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .3500E+04  CUNITS= PPM
 NTOX  = 1          CMC   = .1200E+04 CCC    = CSTD
 NSTD  = 1          CSTD  = .6000E+03
 REGMZ = 1
 REGSPC= 2          XREG  =       .00 WREG   =    120.00 AREG  =        .00
 XINT  =   3500.00  XMAX  =   3500.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and below the center of the port:
        46.00 m  from the RIGHT bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
----------------------------------------------------------------------------
----------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

      X         Y         Z         S        C         B
     .00       .00       .60       1.0  .350E+04     .13

END OF MOD101: DISCHARGE MODULE
----------------------------------------------------------------------------
----------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
```

```
 Jet-like motion in linear stratification with weak crossflow.

 Zone of flow establishment:            THETAE=     10.00  SIGMAE=      89.45
  LE     =       1.25  XE     =       .01  YE     =       1.23  ZE     =        .82

 Profile definitions:
   B = Gaussian 1/e (37%) half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X         Y        Z        S        C        B
      .00       .00      .60      1.0  .350E+04     .13
      .01      1.23      .82      1.0  .350E+04     .14
      .02      2.30     1.01      1.7  .205E+04     .26
      .04      3.48     1.23      2.6  .136E+04     .39
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of   .120E+04
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
      .08      4.67     1.45      3.5  .101E+04     .53
      .13      5.97     1.72      4.4  .790E+03     .67
      .18      7.14     1.97      5.3  .658E+03     .80
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of   .600E+03 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      .24      8.32     2.24      6.2  .564E+03     .94
      .32      9.49     2.52      7.1  .493E+03    1.07
      .40     10.65     2.81      8.0  .437E+03    1.21
      .49     11.82     3.10      8.9  .393E+03    1.34
      .60     12.99     3.39      9.8  .357E+03    1.48
      .71     14.15     3.66     10.7  .328E+03    1.61
      .84     15.33     3.90     11.6  .303E+03    1.75
      .98     16.51     4.09     12.4  .281E+03    1.89
     1.13     17.70     4.23     13.3  .262E+03    2.03
     1.27     18.77     4.29     14.2  .247E+03    2.15
  Maximum jet height has been reached.
     1.45     19.96     4.27     15.1  .232E+03    2.29
     1.63     21.15     4.16     16.1  .218E+03    2.43
     1.83     22.32     3.97     17.1  .205E+03    2.57
     2.04     23.48     3.72     18.1  .193E+03    2.71
     2.26     24.63     3.44     19.1  .183E+03    2.85
  Terminal level in stratified ambient has been reached.
 Cumulative travel time =          63. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD137: TERMINAL LAYER INJECTION/UPSTREAM SPREADING

 UPSTREAM INTRUSION PROPERTIES:
        Maximum elevation of jet/plume rise      =       7.64 m
        Layer thickness in impingement region    =       1.29 m
        Upstream intrusion length                =      90.24 m
        X-position of upstream stagnation point  =     -87.99 m
        Thickness in intrusion region            =       1.29 m
        Half-width at downstream end             =     191.87 m
        Thickness at downstream end              =        .95 m

  Control volume inflow:
       X         Y        Z        S        C        B
     2.26     24.63     3.44     19.1  .183E+03    2.85

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X         Y        Z        S        C        BV        BH       ZU       ZL
   -87.99     24.63     3.44   9999.9  .000E+00     .00       .00     3.44     3.44
   -84.26     24.63     3.44     75.2  .465E+02     .33     27.13     3.60     3.27
   -66.02     24.63     3.44     31.3  .112E+03     .79     65.91     3.83     3.04
```

-47.77	24.63	3.44	23.8	.147E+03	1.04	89.17	3.96	2.92
-29.53	24.63	3.44	20.8	.169E+03	1.19	107.51	4.03	2.84
-11.28	24.63	3.44	19.4	.180E+03	1.28	123.15	4.07	2.80
6.96	24.63	3.44	19.3	.181E+03	1.29	137.02	4.08	2.79
25.21	24.63	3.44	22.5	.155E+03	1.22	149.61	4.05	2.82
43.45	24.63	3.44	27.7	.126E+03	1.11	161.21	3.99	2.88
61.70	24.63	3.44	32.1	.109E+03	1.02	172.04	3.95	2.93
79.95	24.63	3.44	34.4	.102E+03	.97	182.22	3.92	2.95
98.19	24.63	3.44	35.6	.982E+02	.95	191.87	3.91	2.96

Cumulative travel time = 6459. sec

END OF MOD137: TERMINAL LAYER INJECTION/UPSTREAM SPREADING

** End of NEAR-FIELD REGION (NFR) **

In this design case, the discharge is located CLOSE TO BANK/SHORE.
Some boundary interaction occurs at end of near-field.
This may be related to a design case with a very LOW AMBIENT VELOCITY.
The dilution values in one or more of the preceding zones may be too high.
Carefully evaluate results in near-field and check degree of interaction.

Consider locating outfall further away from bank or shore.
In the next prediction module, the plume centerline will be set
to follow the bank/shore.
** REGULATORY MIXING ZONE BOUNDARY is within the Near-Field Region (NFR) **

BEGIN MOD142: BUOYANT TERMINAL LAYER SPREADING

Plume is ATTACHED to RIGHT bank/shore.
Plume width is now determined from RIGHT bank/shore.

Profile definitions:
BV = top-hat thickness, measured vertically
BH = top-hat half-width, measured horizontally in Y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

Plume Stage 2 (bank attached):

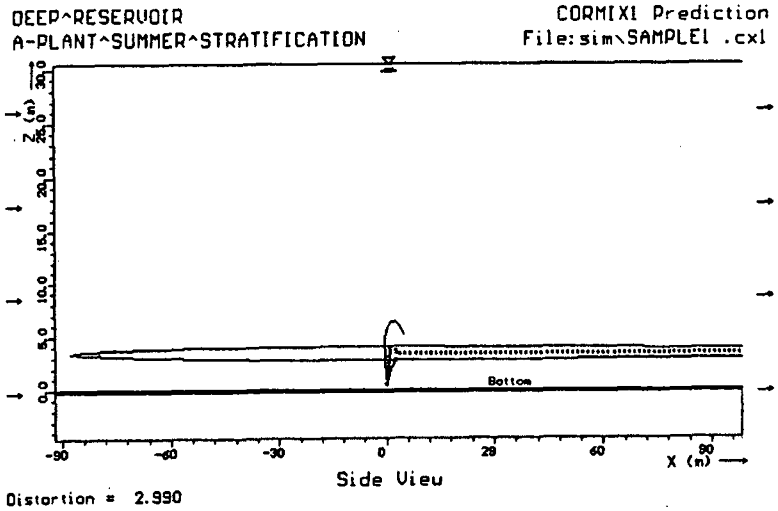
X	Y	Z	S	C	BV	BH	ZU	ZL
98.19	-46.00	3.44	35.6	.982E+02	1.38	262.50	4.13	2.74
268.28	-46.00	3.44	42.7	.820E+02	.93	468.27	3.90	2.97
438.37	-46.00	3.44	48.4	.722E+02	.81	609.62	3.84	3.03
608.46	-46.00	3.44	54.7	.640E+02	.77	728.17	3.82	3.05
778.55	-46.00	3.44	61.7	.568E+02	.75	836.14	3.81	3.06
948.64	-46.00	3.44	69.2	.505E+02	.75	938.66	3.81	3.06
1118.73	-46.00	3.44	77.3	.453E+02	.76	1038.24	3.82	3.06
1288.82	-46.00	3.44	85.9	.408E+02	.77	1136.20	3.82	3.05
1458.91	-46.00	3.44	94.8	.369E+02	.78	1233.26	3.83	3.04
1629.00	-46.00	3.44	104.0	.336E+02	.80	1329.86	3.84	3.04
1799.10	-46.00	3.44	113.6	.308E+02	.81	1426.23	3.84	3.03
1969.19	-46.00	3.44	123.4	.284E+02	.83	1522.53	3.85	3.02
2139.28	-46.00	3.44	133.5	.262E+02	.84	1618.85	3.86	3.02
2309.37	-46.00	3.44	143.8	.243E+02	.86	1715.24	3.86	3.01
2479.46	-46.00	3.44	154.4	.227E+02	.87	1811.74	3.87	3.00
2649.55	-46.00	3.44	165.2	.212E+02	.88	1908.37	3.88	2.99
2819.64	-46.00	3.44	176.2	.199E+02	.90	2005.12	3.88	2.99
2989.73	-46.00	3.44	187.4	.187E+02	.91	2102.02	3.89	2.98
3159.82	-46.00	3.44	198.7	.176E+02	.92	2199.06	3.90	2.98
3329.91	-46.00	3.44	210.3	.166E+02	.93	2296.24	3.90	2.97
3500.00	-46.00	3.44	222.1	.158E+02	.95	2393.56	3.91	2.96

Cumulative travel time = 233246. sec

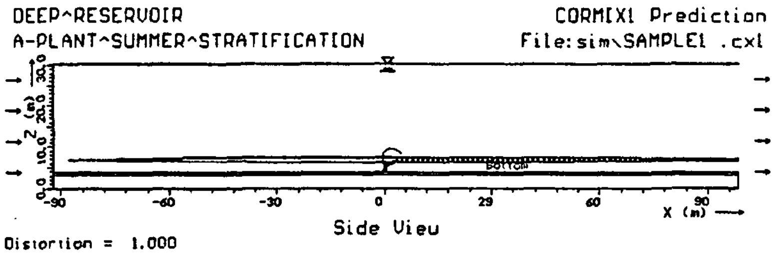
Simulation limit based on maximum specified distance = 3500.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD142: BUOYANT TERMINAL LAYER SPREADING

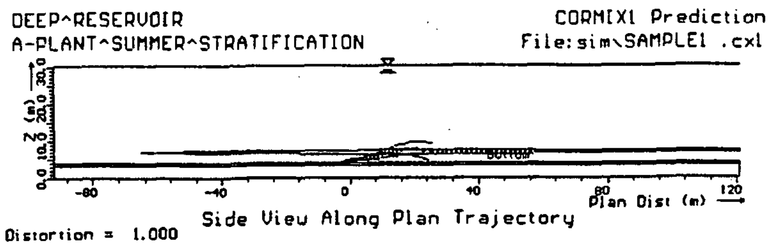
CORMIX1: Submerged Single Port Discharges End of Prediction File
1111111111111111111111111111111111111111111111111111111111111111111111111111



(a)

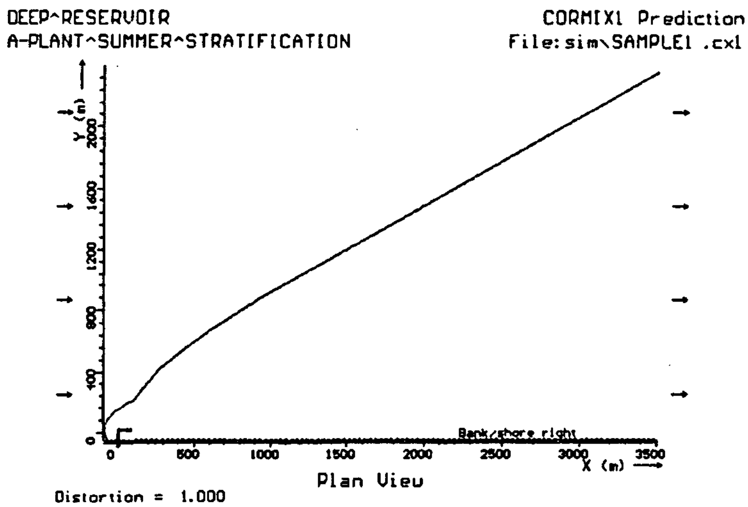


(b)

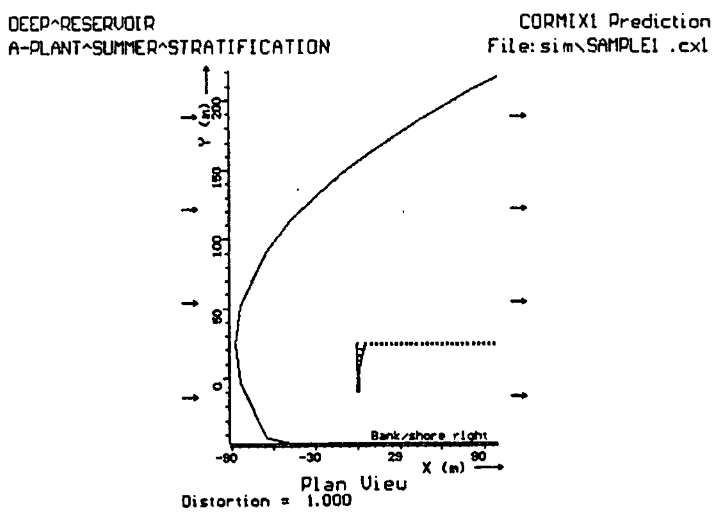


(c)

Figure B.4: Different side views of near-field jet/plume discharge in stratified reservoir. a) distorted un-scaled view, b) view with fixed undistorted scale, and c) undistorted view along trajectory (in the x-y plane).



(a)



(b)

Figure B.5: Plan view of diffuser plume in a) complete field (near- and far), and b) near-field only. (Note: since in this simulation the discharge was schematized as an unbounded cross-section, the resulting plume would actually contact far shoreline when the plume width exceeds the actual cross-section width of 1000 m. This occurs when BH ≅ 1000 m at x ≅ 1000 m downstream as shown in view a). Thus, if plume concentration data were required after far shoreline contact, a bounded cross-section would need to be specified (BS = 1000) in a new simulation.

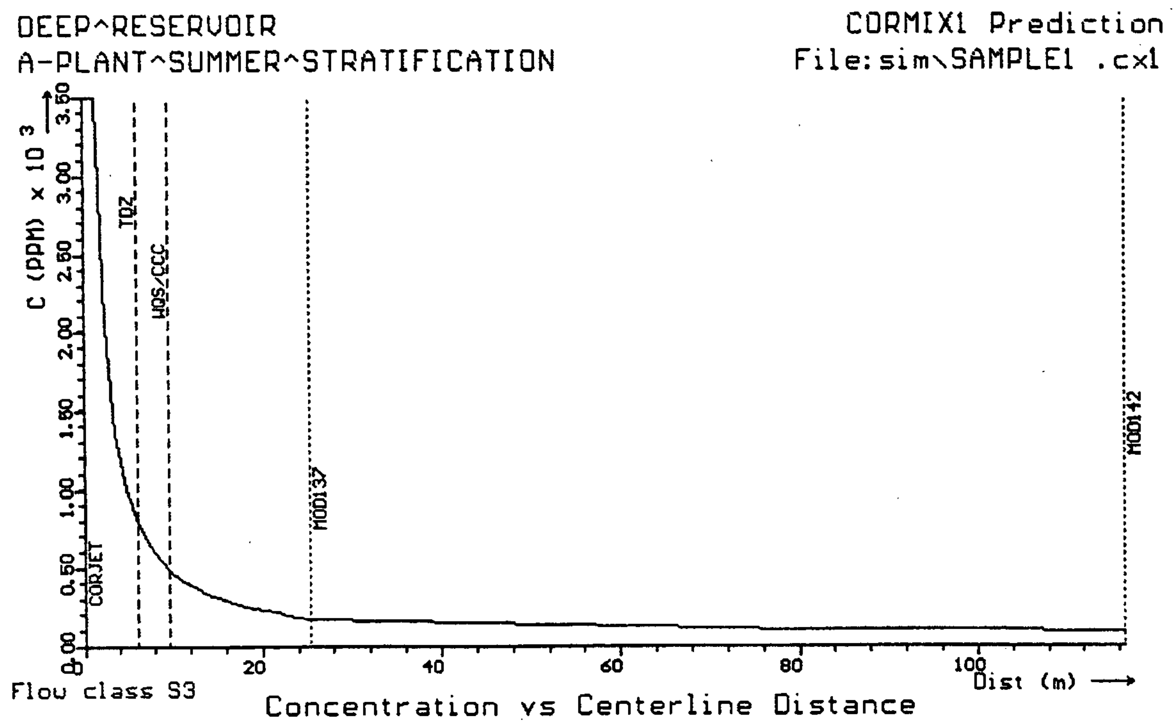


Figure B.6: Concentration distribution as a function of distance along plume centerline

a few parameters such as the upstream intrusion length, downstream width, and shape of the intrusion. As indicated in Figure B.5, reasonable transition boundaries can be assumed to provide smooth transitions to the far-field processes.

The side and plan views show the wide and thin layer that forms as the plume collapses laterally within the ambient stratification while it is advected by the weak ambient flow.

Some discontinuity in the predicted plume dimensions occurs in the transition from the control volume (MOD137) describing upstream spreading to the continuous prediction for ambient buoyant spreading (MOD142). The cause for this discontinuity is the simultaneous interaction of the plume with the channel boundary that occurs within MOD137. CORMIX1 detects such complicated simultaneous processes and warns the user who then can compensate by providing reasonable, mass-conserving transitions.

It is also possible to include concentration values, e.g. along the centerline, in plots of this type. This has not been done in these figures in order not to overload them. Alternatively, the concentration distribution following the centerline of the plume is plotted in Figure B.6. The rapid drop-off within the initial buoyant jet region is evident. Also, the thresholds for all water quality parameters and module boundaries have been exercised in the plot. Hence, the locations where the CMC (i.e. TDZ) and CCC values are met have been indicated.

B.5 Details of Buoyant Jet Near-field Mixing

The CORJET model option can be employed if further details within the very initial buoyant jet motion are desired. This option can be exercised internally at the conclusion of the CORMIX design case by choosing the post-processor. The CORJET output corresponding to this has already been shown as an example in

Section 6.1, namely as Table 6.2. That output agrees well with that listed in Table B.2.

More importantly, CORJET could also be used separately to examine different approximations to the ambient density profile and/or velocity distribution. The reader is encouraged to explore this approach, following the procedures explained in Section 6.1 and illustrated in Appendix E.

Appendix C
CORMIX1 and 2: Submerged Single Port Discharge and Multiport Diffuser in a Shallow River

The design modification of an existing (hypothetical situation) discharge from a plant into a shallow river is considered in this case study. This affords an opportunity to demonstrate the joint use of CORMIX and of a dye field study in order to analyze an existing effluent plume from a single port discharge and to suggest a design conversion to a multiport diffuser with improved mixing characteristics.

C.1 Problem Statement

An industrial plant (B-Plant) is currently discharging its effluent into an adjacent shallow river. The design flowrate is quite small at 2.1 mgd (≈ 0.092 m^3/s). The river is about 200 to 300 ft wide at the discharge location and the following downstream reach. Water depth is, of course, dependent on the river discharge that is seasonally variable. An examination of available streamflow records (USGS data) suggests a 7Q10 low flow discharge of 285 cfs (≈ 8.06 m^3/s).

Recent water quality studies in the discharge reach performed during low flow summer conditions have shown occasional coloration problems in the discharge plume that seem to be related to inadequate mixing characteristics of the present submerged single port discharge. For that reason the plant operator is considering an improvement of the discharge structure.

C.2 Existing Single Port Discharge: Dye Field Study and CORMIX1 Comparison

An initial field study was conducted in order (1) to measure the geometric and hydraulic characteristics of the discharge reach with special emphasis on the first 1000 ft downstream, and (2) to determine plume concentrations by means of a dye injection into the plant effluent.

Figure C.1 shows the plan geometry of the discharge reach. River cross-sections were determined by depth measurements at several stations as indicated. For example, Figure C.2 gives the cross-section at the discharge location. All cross-sections exhibit quite some non-uniformity as is typical for a gently meandering alluvial (gravel) river. The indicated water level corresponds to the river discharge of 840 cfs (≈ 23.7 m^3/s) that was measured during the field survey using the usual USGS stream-gaging methods. The ambient temperature at this flowrate was 20 °C. The discharge pipe (diameter = 8 in ≈ 0.2 m) is located about 95 ft from the right bank, and is pointing in the downstream direction.

In order to obtain a detailed description of the flow field in the river, reach discharge measurements were conducted at several more downstream stations (200, 400, 750, and 1000 ft, respectively). Figure C.1 includes the cumulative discharge isolines, expressed in % of the total discharge as measured from the right bank, for the reach. These lines provide a useful indication of the mean flow pattern in such a winding river for subsequent interpretation of observed plume features (see also comments on cumulative discharge method in Section 6.2).

A dye test was carried out by continuously discharging a fluorescein dye solution into the plant effluent. The dye concentration exiting the discharge pipe was 560 ppb with a temperature of 22 °C. Dye concentration were measured at the transects indicated in Figure C.1, and have been plotted in Figure C.3 as a function of distance from the right bank. The observed concentration profiles show decreasing peak (maximum) values with increasing downstream distances. Observations indicated a vertically mixed plume at all locations. In the display of Figure C.3 the plume centerline position is clearly shifting relative to the right bank, and the plume width occasionally appears to slightlycontract in width.

An initial CORMIX1 evaluation was carried out to ascertain its applicability in this somewhat

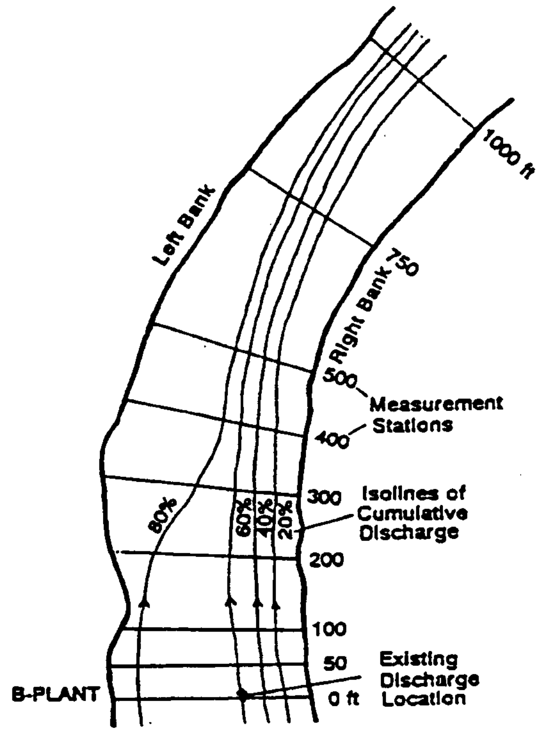


Figure C.1: Plan view of downstream reach of Shallow River with cumulative discharge measurement stations and distribution

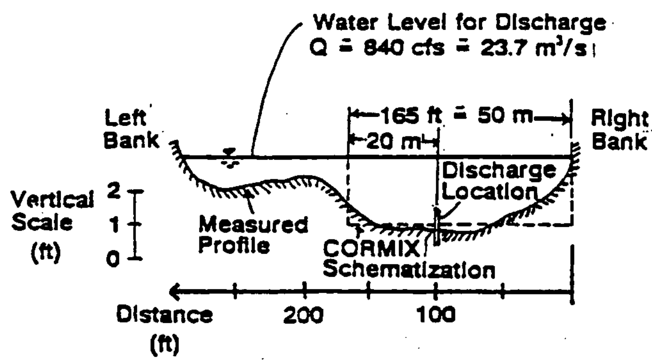


Figure C.2: River cross-section at discharge location

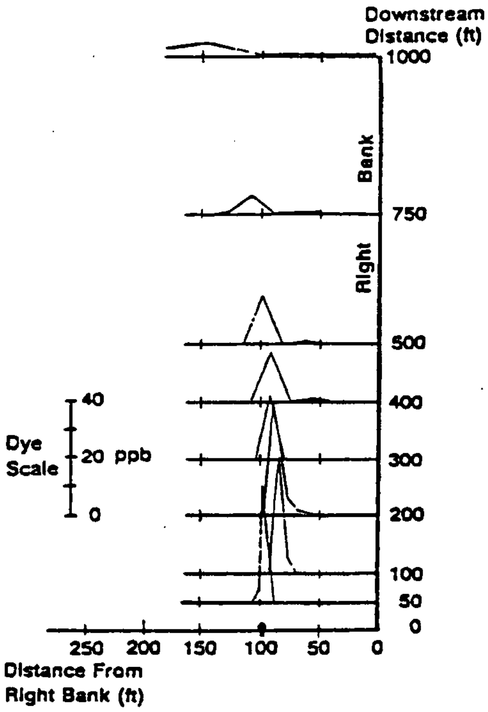


Figure C.3: Measured dye concentration plotted as a function of distance from right bank

irregular flow environment. For this purpose, the cross-section was schematized as a rectangular cross-section putting emphasis on the depth conditions around the discharge location. The average and local depths at this flow rate are both 1.9 ft or (» 0.6 m).

Information from the cumulative discharge data was used. Note that the cumulative discharge data shows the discharge located at the 60 % line, i.e. it is hydraulically closer to the left bank, while it appears geographically closer to the right! This is reflected in the schematization: Within the 165 ft (» 50 m) wide rectangular channel, the discharge is located 20 m from the left bank. The roughness of the slightly winding, but otherwise clean natural channel has been specified by a Manning's n value of 0.03.

Figure C.4 is the data checklist prepared for the CORMIX1 session, while Table C.1 represents the detailed CORMIX1 Prediction File (the session report is not given here). CORMIX1 predicts that the plume gets rapidly mixed over the shallow depth, and is primarily influenced by far-field mixing processes, a feature that is quite consistent with observations. The dye concentration distribution predicted by CORMIX1 in the schematic rectangular channel are plotted in Figure C.5 and show a much more regular mixing pattern than the earlier Figure C.3. However, matters can be readily reconciled when both field data and CORMIX1 predictions are interpreted as a function of **cumulative discharge** (for example by means of the far-field post-processor FFLOCATR, although the details of the FFLOCATR application are not shown herein).

This has been done in Figure C.6 where both distributions are directly superposed on the cumulative discharge pattern. The agreement is excellent. This entire procedure points out the need for high-quality field data if detailed interpretations and predictions of discharge plumes are desired.

C.3 Proposed Multiport Diffuser Discharge Under 7Q10 flow Conditions: CORMIX2 Predictions

The following strategy is pursued in order

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name: Shallow River — Date:
Design CASE: ~~Dye Test~~ — Prepared by: GHJ
DOS FILE NAME: Dye 1 (w/o extension)

AMBIENT DATA:

Water body depth 0.6 m
Depth at discharge 0.6 m
If steady: Ambient flowrate 23.7 m³/s or: Ambient velocity - m/s
Water body is bounded/~~unbounded~~
If bounded: Width 50 m
Appearance 1/2/3

If tidal: Tidal period ____ hr — Max. tidal velocity ____ m/s
At time ____ hr before/at/after slack: Tidal velocity at this time ____ m/s

Manning's n 0.03 or: Darcy-Weisbach f -
Wind speed 2 m/s

Density data:
UNITS: Density...kg/m³ / Temperature...°C
Water body is fresh/~~salt~~ water — If fresh: Specify as ~~density~~/temp. values
If uniform: Average ~~density~~/temp. 20.0

If stratified: Density/temp. at surface ____
Stratification type A/B/C — Density/temp. at bottom ____
If B/C: Pycnocline height ____ m — If C: Density/temp. jump ____

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1

Nearest bank is on left/~~right~~ — Distance to nearest bank 20.0 m
Vertical angle THETA 0 ° — Horizontal angle SIGMA 0 °
Port diameter 0.2 m or: Port area - m²
Port height 0.15 m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2

Nearest bank is on left/right — Distance to one endpoint ____ m
Diffuser length ____ m — to other endpoint ____ m
Total number of openings ____ m — Port height ____ m
Port diameter ____ m with contraction ratio ____
Diffuser arrangement/type unidirectional / staged / alternating or vertical
Alignment angle GAMMA ____ ° — Horizontal angle SIGMA ____ °
Vertical angle THETA ____ ° — Relative orientation BETA ____ °

BUOYANT SURFACE DISCHARGE -- CORMIX3

Discharge located on left/right bank — Configuration flush/protruding/co-flowing
Horizontal angle SIGMA ____ ° — If protruding: Dist. from bank ____ m
Depth at discharge ____ m — *Bottom slope* ____ °
If rectangular discharge channel: Width ____ m or: If circular pipe: Diameter ____ m
Depth ____ m — Bottom invert depth ____ m

Effluent: Flow rate 0.092 m³/s or: Effluent velocity - m/s
Effluent density - kg/m³ or: Effluent temperature 22.0 °C
Heated discharge? ~~yes~~/no — If yes: Heat loss coefficient - W/m²,°C
Concentration units ppb — Effluent concentration 560
Conservative substance? yes/~~no~~ — If no: Decay coefficient - /day

MIXING ZONE DATA:

Is effluent toxic? ~~Yes~~/no — If yes: CMC - CCC -
WQ stand./conventional poll.? ~~Yes~~/no — If yes: value of standard -
Any mixing zone specified? ~~Yes~~/no — If yes: distance - m or width - % or m
or area - % or m²

Region of interest 1000 m — Grid intervals for display 20

Figure C.4: Data preparation checklist for Shallow River dye test evaluation and verification using CORMIX1

Table C.1
CORMIX1 Prediction File for dye test in Shallow River

```
CORMIX1 PREDICTION FILE:
11111111111111111111111111111111111111111111111111111111111111111111111111111
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:                                         Subsystem version:
 Submerged Single Port Discharges           CORMIX_v.3.10_________June_1995
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          Shallow^River
 Design case:              Dye^Test
 FILE NAME:                cormix\sim\dye1     .cx1
 Time of Fortran run:      04/14/96--11:03:24

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =     50.00  AS    =     30.00  QA    =     23.70  ICHREG= 2
 HA     =       .60  HD    =       .60
 UA     =      .790  F     =      .084  USTAR = .8081E-01
 UW     =     2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U          RHOAM =  998.2051

DISCHARGE PARAMETERS (metric units)
 BANK  =  LEFT       DISTB =     20.00
 D0    =      .200  A0    =      .031  H0    =       .15
 THETA =       .00  SIGMA =       .00
 U0    =     2.929  Q0    =      .092        = .9200E-01
 RHO0  =  997.7714  DRHO0 = .4337E+00  GP0   = .4260E-02
 C0    = .5600E+03  CUNITS=  ppb
 IPOLL =  1         KS    = .0000E+00  KD    = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .9200E-01  M0    = .2694E+00  J0    = .3920E-03  SIGNJ0=       1.0
 Associated length scales (meters)
 LQ    =       .18  LM    =     18.89  Lm    =       .66  Lb    =       .00
                                       Lmp   =  99999.00  Lbp   =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0   =    100.31  R     =      3.70

FLOW CLASSIFICATION
 111111111111111111111111111111111111111111
 1  Flow class (CORMIX1)      =     H5-0    1
 1  Applicable layer depth HS =      .60   1
 111111111111111111111111111111111111111111

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .5600E+03  CUNITS=  ppb
 NTOX  =  0
 NSTD  =  0
 REGMZ =  0
 XINT  =   1000.00  XMAX  =   1000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and below the center of the port:
        20.00 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

 COANDA ATTACHMENT immediately following the discharge.

       X        Y        Z        S        C        B
      .00      .00      .00      1.0  .560E+03     .14

END OF MOD101: DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

 Bottom-attached jet motion.
```

Profile definitions:
B = Gaussian 1/e (37%) half-width, normal to trajectory
Half wall jet, attached to bottom.
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

X	Y	Z	S	C	B
.00	.00	.00	1.0	.560E+03	.10
1.05	.00	.00	1.2	.483E+03	.16
2.10	.00	.00	1.7	.337E+03	.21
3.15	.00	.00	2.1	.263E+03	.26
4.21	.00	.00	2.6	.216E+03	.29
5.26	.00	.00	3.0	.185E+03	.32
6.31	.00	.00	3.4	.163E+03	.35
7.36	.00	.00	3.8	.146E+03	.38
8.41	.00	.00	4.2	.132E+03	.40
9.46	.00	.00	4.6	.121E+03	.42
10.51	.00	.00	5.0	.112E+03	.44
11.56	.00	.00	5.3	.105E+03	.46
12.62	.00	.00	5.7	.983E+02	.48
13.67	.00	.00	6.0	.927E+02	.50
14.72	.00	.00	6.4	.878E+02	.51
15.77	.00	.00	6.7	.834E+02	.53
16.82	.00	.00	7.0	.795E+02	.55
17.87	.00	.00	7.4	.761E+02	.56
18.92	.00	.00	7.7	.729E+02	.57
19.97	.00	.00	8.0	.701E+02	.59
21.03	.00	.00	8.3	.675E+02	.60

Cumulative travel time = 14. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

BEGIN MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING

Control volume inflow:

X	Y	Z	S	C	B
21.03	.00	.00	8.3	.675E+02	.60

Profile definitions:
BV = layer depth (vertically mixed)
BH = top-hat half-width, in horizontal plane normal to trajectory
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH	ZU	ZL
20.43	.00	.60	8.3	.675E+02	.00	.00	.60	.60
20.55	.00	.60	8.3	.675E+02	.60	.11	.60	.00
20.67	.00	.60	8.3	.675E+02	.60	.15	.60	.00
20.79	.00	.60	8.3	.675E+02	.60	.19	.60	.00
20.91	.00	.60	8.3	.675E+02	.60	.22	.60	.00
21.03	.00	.60	8.3	.675E+02	.60	.24	.60	.00
21.15	.00	.60	8.8	.637E+02	.60	.27	.60	.00
21.27	.00	.60	9.9	.568E+02	.60	.29	.60	.00
21.39	.00	.60	10.8	.517E+02	.60	.31	.60	.00
21.51	.00	.60	11.4	.493E+02	.60	.33	.60	.00
21.63	.00	.60	11.6	.482E+02	.60	.35	.60	.00

Cumulative travel time = 15. sec

END OF MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING

BEGIN MOD153: VERTICALLY MIXED PLUME IN CO-FLOW

Phase 1: Vertically mixed, Phase 2: Re-stratified

Phase 1: The plume is VERTICALLY FULLY MIXED over the entire layer depth.
This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

```
END OF MOD153: VERTICALLY MIXED PLUME IN CO-FLOW
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor  3.25 to conserve the mass flux in the far-field!
 The correction factor is quite large because of the small ambient velocity
   relative to the strong mixing characteristics of the discharge!
   This indicates localized RECIRCULATION REGIONS and internal hydraulic JUMPS.
 Flow appears highly UNSTEADY and prediction results are UNRELIABLE!
-----------------------------------------------------------------------------
BEGIN MOD141: BUOYANT AMBIENT SPREADING

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD141: BUOYANT AMBIENT SPREADING
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD161: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)   =  .970E-02 m^2/s
  Horizontal diffusivity (initial value) =  .242E-01 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 1 (not bank attached):
        X          Y         Z         S         C         BV        BH        ZU        ZL
      21.63       .00       .60      11.6    .482E+02     .60      1.12       .60       .00
      70.55       .00       .60      25.3    .222E+02     .60      2.44       .60       .00
     119.47       .00       .60      33.8    .166E+02     .60      3.26       .60       .00
     168.39       .00       .60      40.5    .138E+02     .60      3.92       .60       .00
     217.30       .00       .60      46.3    .121E+02     .60      4.48       .60       .00
     266.22       .00       .60      51.5    .109E+02     .60      4.98       .60       .00
     315.14       .00       .60      56.1    .998E+01     .60      5.43       .60       .00
     364.06       .00       .60      60.5    .926E+01     .60      5.84       .60       .00
     412.98       .00       .60      64.5    .869E+01     .60      6.23       .60       .00
     461.90       .00       .60      68.3    .820E+01     .60      6.60       .60       .00
     510.81       .00       .60      71.9    .779E+01     .60      6.95       .60       .00
     559.73       .00       .60      75.3    .744E+01     .60      7.28       .60       .00
     608.65       .00       .60      78.5    .713E+01     .60      7.59       .60       .00
     657.57       .00       .60      81.7    .686E+01     .60      7.90       .60       .00
     706.49       .00       .60      84.7    .661E+01     .60      8.19       .60       .00
     755.41       .00       .60      87.6    .639E+01     .60      8.47       .60       .00
     804.33       .00       .60      90.4    .619E+01     .60      8.74       .60       .00
     853.24       .00       .60      93.2    .601E+01     .60      9.01       .60       .00
     902.16       .00       .60      95.8    .584E+01     .60      9.27       .60       .00
     951.08       .00       .60      98.4    .569E+01     .60      9.52       .60       .00
    1000.00       .00       .60     101.0    .555E+01     .60      9.76       .60       .00
 Cumulative travel time =          1249. sec

 Simulation limit based on maximum specified distance =    1000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD161: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX1: Submerged Single Port Discharges              End of Prediction File
11111111111111111111111111111111111111111111111111111111111111111111111111111
```

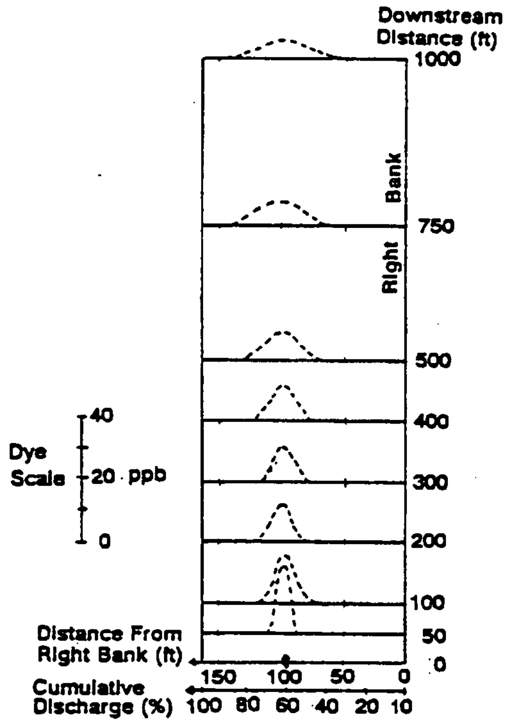


Figure C.5: Dye concentrations predicted by CORMIX1 plotted as a function of distance from right bank in schematized channel

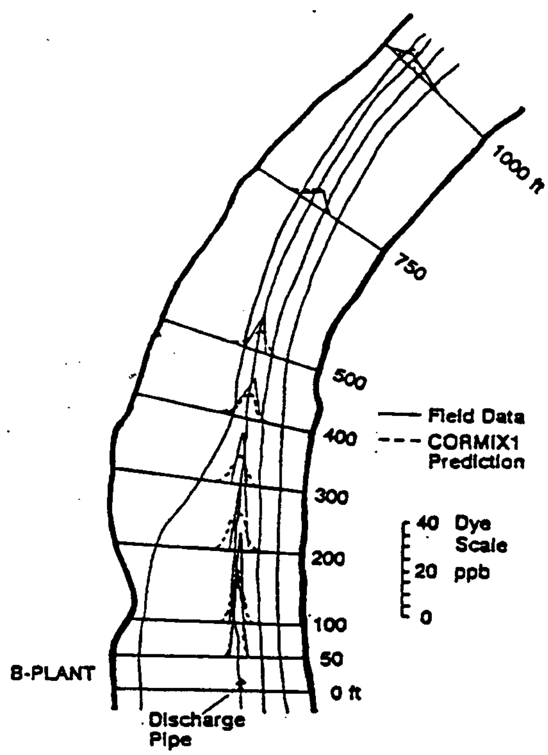


Figure C.6: Comparison of measured field dye distribution and CORMIX1 predictions within cumulative discharge pattern to improve the near-field mixing characteristics of the existing discharge: (1) Utilization of a multiport diffuser to increase the initial entrainment of ambient water into the multiple effluent jets, and (2) shifting of the discharge location toward the right bank to delay the contact with the left shoreline that -with the present installation-seems to occur at a downstream distance of 1000 ft.

The design study is carried out for the low flow ambient condition given by the 7Q10 discharge (285 cfs ≈ 8.1 m^3/s) as is typical for water quality studies on riverine sites. Temperatures of the discharge and ambient and channel roughness is assumed unchanged. The new local and average depth for this flowrate is calculated to be ≈ 0.3 m from the formula given in Section 4.3.1.

State water quality regulations call for a demonstration of plume concentrations at the edge of a mixing zone that is limited to one fourth (1/4) of the river width. With an average river width of 250 ft, this corresponds to a width limitation of 250/4 ≈ 62 ft (≈ 19 m). (Note: The actual width limitation must be handled within the schematized cross-sections as specified. For the schematic channel width of 50 m this represents a 19/50 = 38% width limitation specification as used in CORIMX2.)

Obviously, a number of design solutions, with different diffuser configurations and locations, need to be investigated. One of several feasible solutions is presented in the following: A 15 m (≈ 49 ft) long diffuser consisting of 7 nozzles is installed in perpendicular, co-flowing arrangement centered at the 40% cumulative discharge position. (Note: In the actual coordinate position, this corresponds to a distance of about 70 ft from the right bank; see Figure C.1.) The nozzle diameter is 2.5 in (≈ 0.0635 m).

The CORMIX2 simulation is summarized in Figure C.7 (data preparation checklist), Table C.2 (session report), and Table C.3 (prediction file).

Inspection of the session record and prediction file shows that the plume becomes rapidly mixed over the very shallow water depth. Furthermore, a high initial dilution of 29.8 is attained in a short region (labeled the "acceleration zone", MOD271) following the high velocity multiport discharge. These results are plotted in Figure C.8 using the graphics package CMXGRAPH. In order to illustrate the capabilities of the graphics program these plots include (a) the un-scaled plan view as it first appears on screen, (b) a re-scaled plan view that is undistorted (1:1) to show the actual long and narrow plume shape and river stretch, and (c) a side view of the near-field only with 1:2 vertical distortion. The user should explore the manifold features of the graphics package.

Obviously, predicted plan plume shapes should be interpreted with the **cumulative discharge method**. The far-field plume locator FFLOCATR (Section 6.2) is designed for exactly that purpose. The two data files examples in Section 6.2 (input: Table 6.4, output: Table 6.5) are, in fact, applications for the present design case. Hence, the results of Table 6.5 when plotted on the river plan view with the cumulative discharge isolines are shown in Figure C.9 and exhibit realistic plume shapes. After the rapid initial mixing in the near-field the plume is growing only very slowly in the far-field (MOD261). At the 1000 ft transect, the plume stays clear of the left bank.

The concentration distribution along the plume centerline is plotted in Figure C.10 for the near-field only, as very slow additional mixing occurs at larger distances (see Table C.3). As regards the **regulatory mixing zone (RMZ)** the prediction results indicate that it will be encountered at a considerable distance downstream, at about 354 m (≈ 1200 ft), i.e. outside the region plotted in Figure C.10. The dilution at that location is 33.5, corresponding to a local centerline concentration value of 3.0 %.

Finally, it is illuminating to compare the performance of the proposed multiport diffuser design with the existing single port situation, both under 7Q10 low flow. This is also included in Figure C.10 by plotting the plume centerline concentrations. (Note: The data sheet, session record, and output file for this CORMIX1 application are omitted for space reasons.) Clearly, the multiport design achieves much more rapid initial mixing by capturing more of the ambient entrainment flow as the diffuser is spread over portion of the river width. Figure C.10 also includes an additional CORMIX1 prediction for a single plume out of the 7-nozzle arrangement to provide more detail in the near-field; the user has been prompted by several messages within CORMIX2 to perform this additional prediction.

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name: B-Plant Shallow River Date:
Design CASE: Low Flow 7Q10 Prepared by: GHJ
DOS FILE NAME: Sample 2 (w/o extension)

AMBIENT DATA:

Water body depth 0.3 m
Depth at discharge 0.3 m
If steady: Ambient flowrate 8.1 m^3/s or: Ambient velocity - m/s
Water body is bounded/~~unbounded~~
If bounded: Width 50 m
Appearance ~~1~~/2/~~3~~

If tidal: Tidal period ____ hr Max. tidal velocity ____ m/s
At time ____ hr before/at/after slack: Tidal velocity at this time ____ m/s

Manning's n 0.03 or: Darcy-Weisbach f -
Wind speed 2 m/s

Density data:
UNITS: Density...kg/m^3 / Temperature...°C
Water body is fresh/~~salt~~ water
If fresh: Specify as ~~density~~/temp. values
If uniform: Average ~~density~~/temp. 20.0

If stratified:
Stratification type A/B/C Density/temp. at surface ____
If B/C: Pycnocline height ____ m Density/temp. at bottom ____
If C: Density/temp. jump ____

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

~~SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1~~
~~Nearest bank is on left/right Distance to nearest bank ____ m~~
~~Vertical angle THETA ____ ° Horizontal angle SIGMA ____ °~~
~~Port diameter ____ m or: Port area ____ m^2~~
~~Port height ____ m~~

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2
Nearest bank is on ~~left~~/right Distance to one endpoint 12.5 m
Diffuser length 15 m to other endpoint 27.5 m
Total number of openings 7 m Port height 0.09 m
Port diameter 0.0635 m with contraction ratio 1.0
Diffuser arrangement/type unidirectional /~~staged~~ /~~alternating or vertical~~
Alignment angle GAMMA 90 ° Horizontal angle SIGMA 0 °
Vertical angle THETA 0 ° Relative orientation BETA 90 °

~~BUOYANT SURFACE DISCHARGE -- CORMIX3~~
~~Discharge located on left/right bank Configuration flush/protruding/co-flowing~~
~~Horizontal angle SIGMA ____ ° If protruding: Dist. from bank ____ m~~
~~Depth at discharge ____ m Bottom slope ____ °~~
~~If rectangular discharge channel: Width ____ m or: Depth ____ m~~
~~If circular pipe: Diameter ____ m Bottom invert depth ____ m~~

Effluent: Flow rate 0.092 m^3/s or: Effluent velocity - m/s
Effluent density - kg/m^3 or: Effluent temperature 22.0 °C
Heated discharge? ~~yes~~/no If yes: Heat loss coefficient - W/m^2,°C
Concentration units % Effluent concentration 100
Conservative substance? yes/~~no~~ If no: Decay coefficient - /day

MIXING ZONE DATA:
Is effluent toxic? ~~yes~~/no If yes: CMC - CCC -
WQ stand./conventional poll.? ~~yes~~/no If yes: value of standard -
Any mixing zone specified? yes/~~no~~ If yes: distance - m or width 38 % ~~or m~~
or area - % or m^2

Region of interest 1000 m Grid intervals for display 20

Figure C.7: Data preparation checklist for Shallow River design case for multiport diffuser using CORMIX2

Table C.2
CORMIX Session Report for B-Plant discharge into Shallow River with multiport diffuser

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                      CORMIX v.3.10          June 1995
SITE NAME/LABEL:                  B-PLANT SHALLOW-RIVER
  DESIGN CASE:                    LOW-FLOW 7Q10
  FILE NAME:                      SAMPLE2
Using subsystem CORMIX2:          Submerged Multiport Diffuser Discharges
  Start of session:               06/24/95--22:35:06
******************************************************************************
SUMMARY OF INPUT DATA:
------------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                          = bounded
  Width                           BS     =        50.0 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA     =         8.1 m^3/s
  Average depth                   HA     =        0.30 m
  Depth at discharge              HD     =        0.30 m
  Ambient velocity                UA     =      0.5400 m/s
  Darcy-Weisbach friction factor  F      =      0.1054
    Calculated from Manning's n          =        0.03
  Wind velocity                   UW     =           2 m/s
Stratification Type               STRCND = U
  Surface temperature                    =        20.0 degC
  Bottom temperature                     =        20.0 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  =    998.2051 kg/m^3
  Bottom density                  RHOAB  =    998.2051 kg/m^3
------------------------------------------------------------------------------
DISCHARGE PARAMETERS:             Submerged Multiport Diffuser Discharge
  Diffuser type                   DITYPE = unidirectional perpendicular
  Diffuser length                 LD     = 15.0 m
  Nearest bank                           = right
  Diffuser endpoints              YB1    =     12.5 m;    YB2 =     27.5 m
  Number of openings              NOPEN  =           7
  Spacing between risers/openings SPAC   =        2.50 m
  Port/Nozzle diameter            D0     =      0.0635 m
  Equivalent slot width           B0     =      0.0014 m
  Total area of openings          A0     =      0.0031 m^2
  Discharge velocity              U0     =        4.14 m/s
  Total discharge flowrate        Q0     =       0.092 m^3/s
  Discharge port height           H0     =        0.09 m
  Nozzle arrangement              BETYPE = unidirectional without fanning
  Diffuser alignment angle        GAMMA  =          90 deg
  Vertical discharge angle        THETA  =           0 deg
  Horizontal discharge angle      SIGMA  =           0 deg
  Relative orientation angle      BETA   =          90 deg
  Discharge temperature (freshwater)     =        22.0 degC
    Corresponding density         RHO0   =    997.7714 kg/m^3
  Density difference              DRHO   =      0.4336 kg/m^3
  Buoyant acceleration            GP0    =       .0043 m/s^2
  Discharge concentration         C0     =             100 PERCENT
  Surface heat exchange coeff.    KS     =           0 m/s
  Coefficient of decay            KD     =           0 /s
------------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)         q0     =    0.006133 m^2/s
  Momentum flux                   m0     =    0.025452 m^3/s^2
  Buoyancy flux                   j0     =    0.000026 m^3/s^3
------------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m      lm  =        0.08 m        lM  =       28.80 m
  lm' =    99999.0 m      lb' =     99999.0 m        la  =     99999.0 m
  (These refer to the actual discharge/environment length scales.)
------------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number              FR0    =     1653.66
  Port/nozzle Froude number       FRD0   =      252.28
  Velocity ratio                  R      =        7.68
------------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = no
  Regulatory mixing zone                 = yes
  Regulatory mixing zone specification   = width
  Regulatory mixing zone value           =          19 m (m^2 if area)
  Region of interest                     =     1000.00 m
```

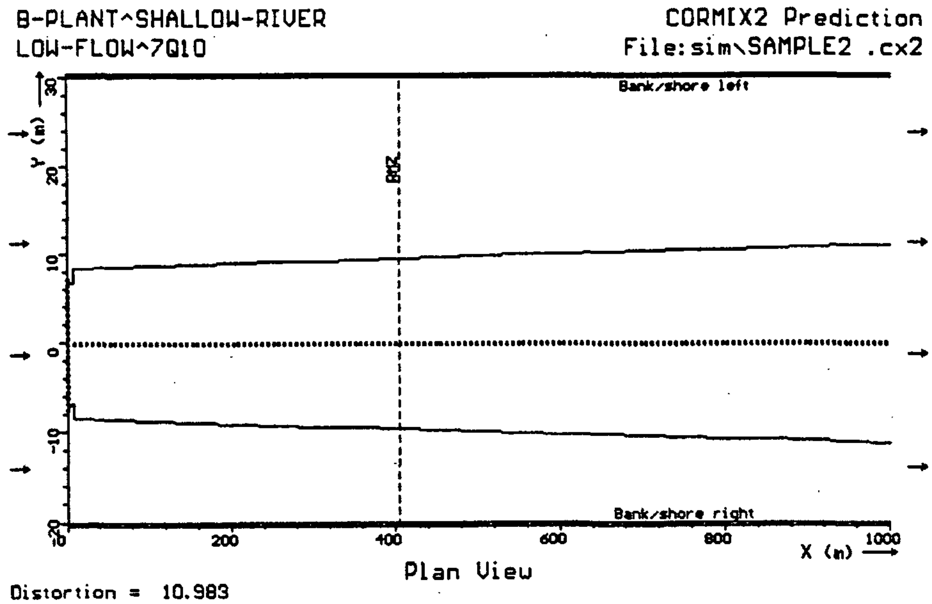
```
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS  =     MU2 |
  *------------------------*
  This flow configuration applies to a layer corresponding to the full water
  depth at the discharge site.
  Applicable layer depth = water depth =         0.30 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
            20 m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =          3.3538 PERCENT
    (centerline coordinates)           y =           .00 m
                                       z =           .30 m
  NFR plume dimensions:        half-width =         6.73 m
                                thickness =          .30 m
-----------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
  the surface.
-----------------------------------------------------------------------------
Near-field instability behavior:
  The diffuser flow will experience instabilities with full vertical mixing
  in the near-field.
  There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed ALREADY IN NEAR-FIELD at        7.50 m
  downstream and continues as vertically mixed into the far-field.
************************ TOXIC DILUTION ZONE SUMMARY ************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY **********************
The plume conditions at the boundary of the specified RMZ are as follows:
  Pollutant concentration                =          2.955534 PERCENT
  Corresponding dilution                 =          33.8
  Plume location:                      x =        384.55 m
    (centerline coordinates)           y =           .00 m
                                       z =           .30 m
  Plume dimensions:           half-width =          9.50 m
                               thickness =           .30 m
********************* FINAL DESIGN ADVICE AND COMMENTS *********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
  the actual three-dimensional diffuser geometry.  Thus, it approximates
  the details of the merging process of the individual jets from each
  port/nozzle.
In the present design, the spacing between adjacent ports/nozzles
  (or riser assemblies) is somewhat greater (in the range between
  three times to ten times) the local water depth.  It is unlikely
  that sufficient lateral interaction of adjacent jets will
  occur in the near-field.  However, the individual jets/plumes may merge
  soon after in the intermediate-field or in the far-field.

CORMIX2 may have LIMITED APPLICABILITY for this discharge situation.
  The results may be somewhat unrealistic in the near-field (minimum
  dilution may be overpredicted), but appear to be applicable for the
  intermediate- and far-field processes.
The user is advised to use a subsequent CORMIX1 (single port discharge)
  analysis, using discharge data for an individual diffuser jet/plume,
  in order to compare to the present near-field prediction.
-----------------------------------------------------------------------------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
*****************************************************************************
DESIGN CASE:                    LOW-FLOW 7Q10
FILE NAME:                      SAMPLE2
Subsystem CORMIX2:              Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:       04/14/96--11:16:37
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Table C.3
CORMIX2 Prediction File for B-Plant discharge into Shallow River with multiport diffuser

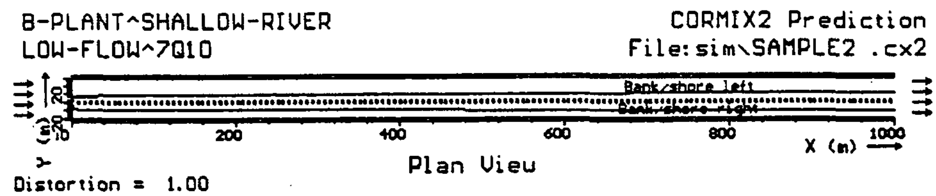
```
CORMIX2 PREDICTION FILE:
2222222222222222222222222222222222222222222222222222222222222222222222222222222
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                          Subsystem version:
 Submerged Multiport Diffuser Discharges    CORMIX_v.3.00_________July_1994
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          B-PLANT^SHALLOW-RIVER
 Design case:             ,LOW-FLOW^7Q10
 FILE NAME:                cormix\sim\SAMPLE2 .cx2
 Time of Fortran run:      06/24/95--22:36:15

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =     50.00  AS     =     15.00  QA     =      8.10  ICHREG= 2
 HA     =       .30  HD     =       .30
 UA     =      .540  F      =      .105  USTAR = .6199E-01
 UW     =     2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U          RHOAM =  998.2051

DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:      DITYPE= unidirectional_perpendicular
 BANK  =  RIGHT      DISTB =     20.00  YB1    =     12.50  YB2    =     27.50
 LD     =     15.00  NOPEN =     7      SPAC   =      2.50
 D0     =      .064  A0     =      .003  H0     =       .09
 Nozzle/port arrangement:   unidirectional_without_fanning
 GAMMA =     90.00  THETA =       .00  SIGMA =       .00  BETA   =     90.00
 U0     =     4.150  Q0     =      .092         = .9200E-01
 RHO0  =  997.7714  DRHO0 = .4337E+00  GP0    = .4260E-02
 C0     = .1000E+03  CUNITS=  PERCENT
 IPOLL =  1          KS     = .0000E+00  KD     = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .6133E-02  m0     = .2545E-01  j0     = .2613E-04  SIGNJ0=      1.0
 Associated 2-d length scales (meters)
 lQ=B  =       .001  lM     =     28.81  lm     =       .09
 lmp   =  99999.00  lbp    =  99999.00  la     =  99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .9200E-01  M0     = .3818E+00  J0     = .3920E-03
 Associated 3-d length scales (meters)
 LQ     =       .15  LM     =     24.53  Lm     =      1.14  Lb     =       .00
                                         Lmp    =  99999.00  Lbp    =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0   =   1653.66  FRD0  =    252.28  R      =      7.68
 (slot)              (port/nozzle)

FLOW CLASSIFICATION
 222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)        =    MU2    2
 2  Applicable layer depth HS =       .30  2
 222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .1000E+03  CUNITS=  PERCENT
 NTOX  =  0
 NSTD  =  0
 REGMZ =  1
 REGSPC=  2          XREG   =       .00  WREG   =     19.00  AREG   =       .00
 XINT  =   1000.00  XMAX   =   1000.00

X-Y-Z COORDINATE SYSTEM:
   ORIGIN is located at the bottom and the diffuser mid-point:
       20.00 m  from the RIGHT bank/shore.
   X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE
```

```
Due to complex near-field motions:  EQUIVALENT SLOT DIFFUSER (2-D) GEOMETRY

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

      X        Y        Z        S        C        BV       BH
     .00      .00      .09      1.0  .100E+03     .00     7.50

END OF MOD201: DIFFUSER DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

 In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY
  MIXED over the entire layer depth (HS =     .30m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

      X        Y        Z        S        C        BV       BH
     .00      .00      .09      1.0  .100E+03     .00     7.50
     .38      .00      .09     11.2  .894E+01     .08     7.39
     .75      .00      .10     15.4  .649E+01     .15     7.30
    1.13      .00      .10     18.6  .536E+01     .23     7.22
    1.50      .00      .10     21.4  .468E+01     .30     7.15
    1.88      .00      .11     23.8  .420E+01     .30     7.09
    2.25      .00      .11     26.0  .385E+01     .30     7.04
    2.63      .00      .11     28.0  .358E+01     .30     6.99
    3.00      .00      .11     29.8  .335E+01     .30     6.95
    3.38      .00      .12     29.8  .335E+01     .30     6.91
    3.75      .00      .12     29.8  .335E+01     .30     6.87
    4.13      .00      .12     29.8  .335E+01     .30     6.84
    4.50      .00      .13     29.8  .335E+01     .30     6.82
    4.88      .00      .13     29.8  .335E+01     .30     6.80
    5.25      .00      .13     29.8  .335E+01     .30     6.78
    5.63      .00      .14     29.8  .335E+01     .30     6.76
    6.00      .00      .14     29.8  .335E+01     .30     6.75
    6.38      .00      .14     29.8  .335E+01     .30     6.74
    6.75      .00      .14     29.8  .335E+01     .30     6.74
    7.13      .00      .15     29.8  .335E+01     .30     6.74
    7.50      .00      .15     29.8  .335E+01     .30     6.73
 Cumulative travel time =         11. sec

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

 Phase 1: Vertically mixed, Phase 2: Re-stratified

 Phase 1: The diffuser plume is VERTICALLY FULLY MIXED over the
          entire layer depth.
 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.
-----------------------------------------------------------------------------
 Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor  1.24 to conserve the mass flux in the far-field!
-----------------------------------------------------------------------------
BEGIN MOD241: BUOYANT AMBIENT SPREADING

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.
```

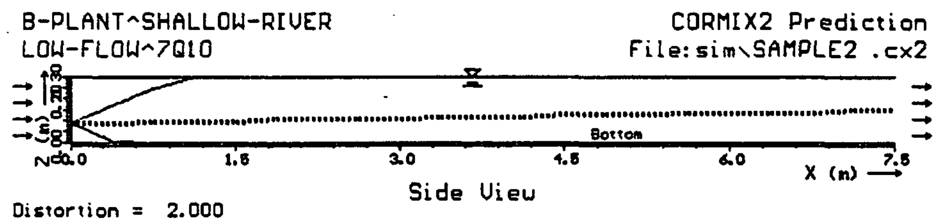
```
END OF MOD241: BUOYANT AMBIENT SPREADING
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)   =  .372E-02 m^2/s
  Horizontal diffusivity (initial value) =  .930E-02 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 1 (not bank attached):
       X         Y         Z         S        C        BV        BH        ZU        ZL
      7.50      .00       .30      29.8  .335E+01     .30      8.37       .30       .00
     57.13      .00       .30      30.4  .329E+01     .30      8.53       .30       .00
    106.75      .00       .30      30.9  .323E+01     .30      8.68       .30       .00
    156.38      .00       .30      31.5  .318E+01     .30      8.83       .30       .00
    206.00      .00       .30      32.0  .313E+01     .30      8.98       .30       .00
    255.63      .00       .30      32.5  .308E+01     .30      9.13       .30       .00
    305.25      .00       .30      33.0  .303E+01     .30      9.27       .30       .00
    354.88      .00       .30      33.5  .298E+01     .30      9.42       .30       .00
 ** REGULATORY MIXING ZONE BOUNDARY **
 In this prediction interval the TOTAL plume width meets or exceeds
   the regulatory value =    19.00 m.
 This is the extent of the REGULATORY MIXING ZONE.
    404.50      .00       .30      34.0  .294E+01     .30      9.56       .30       .00
    454.13      .00       .30      34.5  .290E+01     .30      9.69       .30       .00
    503.75      .00       .30      35.0  .286E+01     .30      9.83       .30       .00
    553.38      .00       .30      35.5  .282E+01     .30      9.96       .30       .00
    603.00      .00       .30      36.0  .278E+01     .30     10.10       .30       .00
    652.63      .00       .30      36.4  .275E+01     .30     10.23       .30       .00
    702.25      .00       .30      36.9  .271E+01     .30     10.36       .30       .00
    751.88      .00       .30      37.3  .268E+01     .30     10.48       .30       .00
    801.50      .00       .30      37.8  .265E+01     .30     10.61       .30       .00
    851.13      .00       .30      38.2  .262E+01     .30     10.73       .30       .00
    900.75      .00       .30      38.7  .259E+01     .30     10.86       .30       .00
    950.38      .00       .30      39.1  .256E+01     .30     10.98       .30       .00
   1000.00      .00       .30      39.5  .253E+01     .30     11.10       .30       .00
 Cumulative travel time =        1828. sec

 Simulation limit based on maximum specified distance =    1000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
Because of the fairly LARGE SPACING between adjacent risers/nozzles/ports,
  the above results may be unreliable in the immediate near-field of
  the diffuser.
A SUBSEQUENT APPLICATION OF CORMIX1 IS RECOMMENDED to provide more detail
  for one of the individual jets/plumes in the initial region
before merging.
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CORMIX2: Submerged Multiport Diffuser Discharges       End of Prediction File
22222222222222222222222222222222222222222222222222222222222222222222222222222
```



(a)



(b)



(c)

Figure C.8: CORMIX2 prediction for B-Plant multiport diffuser discharge in Shallow River. Examples of different graphics plots: a) Plan view over entire reach, b) equivalent undistorted plan view, and c) side view of near-field only.

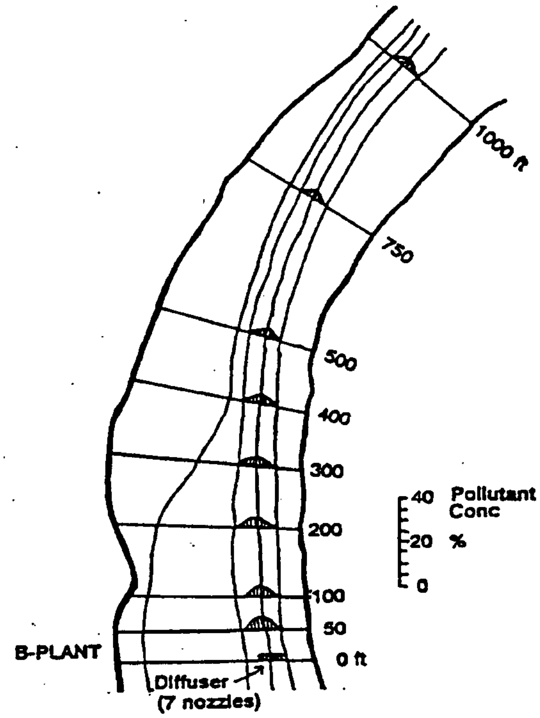


Figure C.9: Results of cumulative discharge interpretation of CORMIX2 prediction for B-Plant multiport diffuser discharge in Shallow River

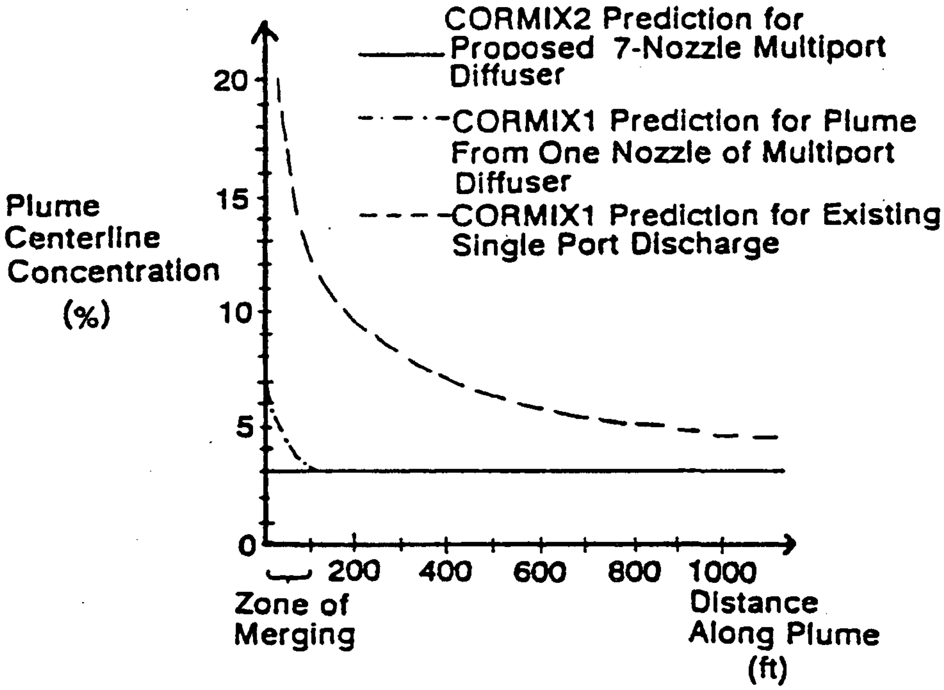


Figure C.10: Predicted plume centerline concentrations for multiport diffuser design (CORMIX1) in comparison to single port design (CORMIX2)

Appendix D
CORMIX3: Buoyant Surface Discharge In An Estuary

Estuarine conditions are characterized by highly variable ambient conditions during the tidal cycle. This case study provides a short application example for a buoyant surface discharge from a large manufacturing plant discharging its process water into an estuary.

D.1 Problem Statement

A manufacturing plant (C-Plant) is using process water at a capacity of 2.2 m^3/s (≈ 50 mgd). The process water is essentially fresh water with a discharge temperature of 20.0 °C and contains copper at a concentration of 80 μg/l.

The plant is located at the shore of an estuary. Figure D.1 shows the bottom bathymetry at the plant location; two transects have been measured and show a relatively rapid drop-off from the MSL line to a depth of about 5 m below MSL. It is proposed to build a discharge channel with a bottom elevation of about 1.0 m below MSL and a width of 2.0 m. Thus, given the tidal variation at the discharge location indicated in Figure D.1, the actual channel depth will vary from a maximum of about 1.8 m at MHW to a minimum of about 0.5 at MLW, with corresponding adjustments in the discharge velocity.

Figure D.2 shows data from oceanographic field surveys near the discharge site with ambient velocity variations from about +0.7 m/s for flood tide and to about -0.7 m/s for ebb tide. Figure D.2 also shows the tidal elevation variations from -.7 m above MLW at ebb to +1.1 m above MLW at flood. The estuary has brackish water with mean salinity of about 26 ppt, yielding a density of about 1018 kg/m^3 (see Figure 4.3 as an aid).

State regulations specify a mixing zone of about 250 m extending in any direction from the discharge point. The CMC and CCC values for copper are 25 and 15 μg/l, respectively.

D.2 Steady State Simulation (for reference)

Although it is to be expected that the surface discharge plume for this situation will be quite variable in appearance and mixing characteristics due to the tidal reversal, a steady state simulation will be performed to illustrate the basic CORMIX3 application in a time invariant ambient receiving water. Furthermore, this simulation will be used as a basis for comparison in the next selection, where tidal CORMIX simulations are appropriately performed in order to determine the time evolution in this highly unsteady environment.

Assume that the conditions one hour after low water slack tide (t = 11.7 h) represent that in a large steady river (see condition (b), Figure D.2). This design condition is represented by a water level 0.35 m below MSL and an ambient velocity of 0.22 m/s. As shown in Figure D.1, the ambient water body is schematized as unbounded, with an average depth of 6 m at MSL, a local depth of 2.5 m at MSL (1.5 m below the discharge channel mouth), and a bottom slope of 11°.

Figure D.3 presents the input data checklist and Table D.1 shows the CORMIX3 prediction file (the session report is omitted here for brevity) for the steady state reference condition one hour after low water slack (LWS). The shallow discharge channel (depth of 0.65 m) produces a relatively weak free jet (flow class FJ1). After only 4.5 m offshore distance, the initial jet momentum is overwhelmed by the high discharge buoyancy, and forms a surface plume which is weakly deflected by the ambient crossflow (MOD313). In this region, buoyant forces rapidly thin and spread the plume horizontally. Both the CCC and CMC are met within this region, (and also within the regulatory mixing zone) as is displayed by CORMIX in the prediction file. The plume then becomes strongly deflected (MOD323) and finally contacts the shoreline some 1560 m downstream. The plume then becomes attached to the shoreline, and spreads through passive ambient diffusion and weak buoyant forces (MOD341), until the end of the region of interest (2000 m). Figure D.4 shows the above behavior.

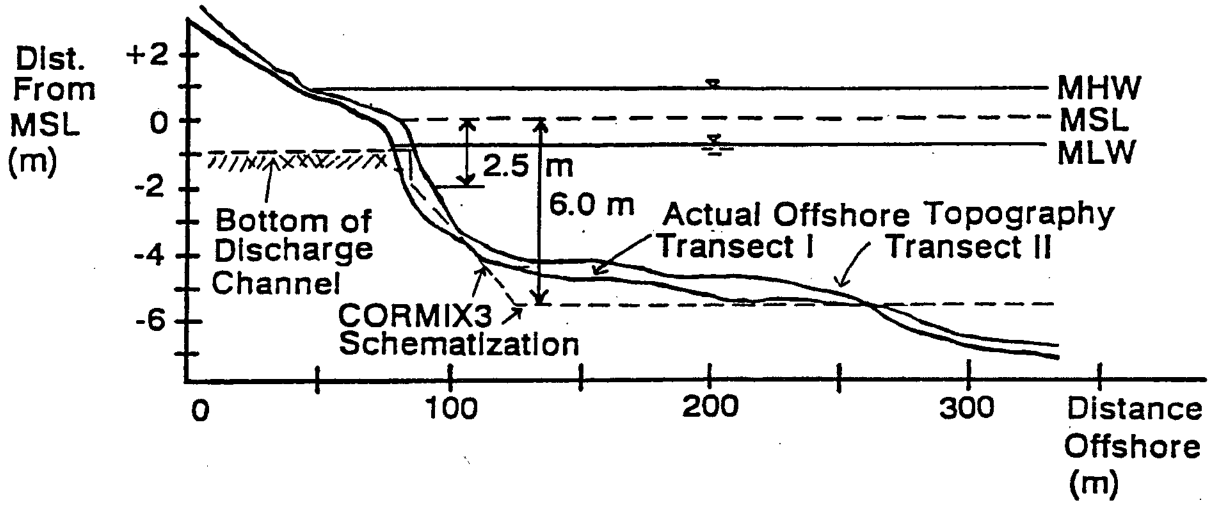


Figure D.1: Bathymetric conditions in Estuary in vicinity of C-Plant surface discharge

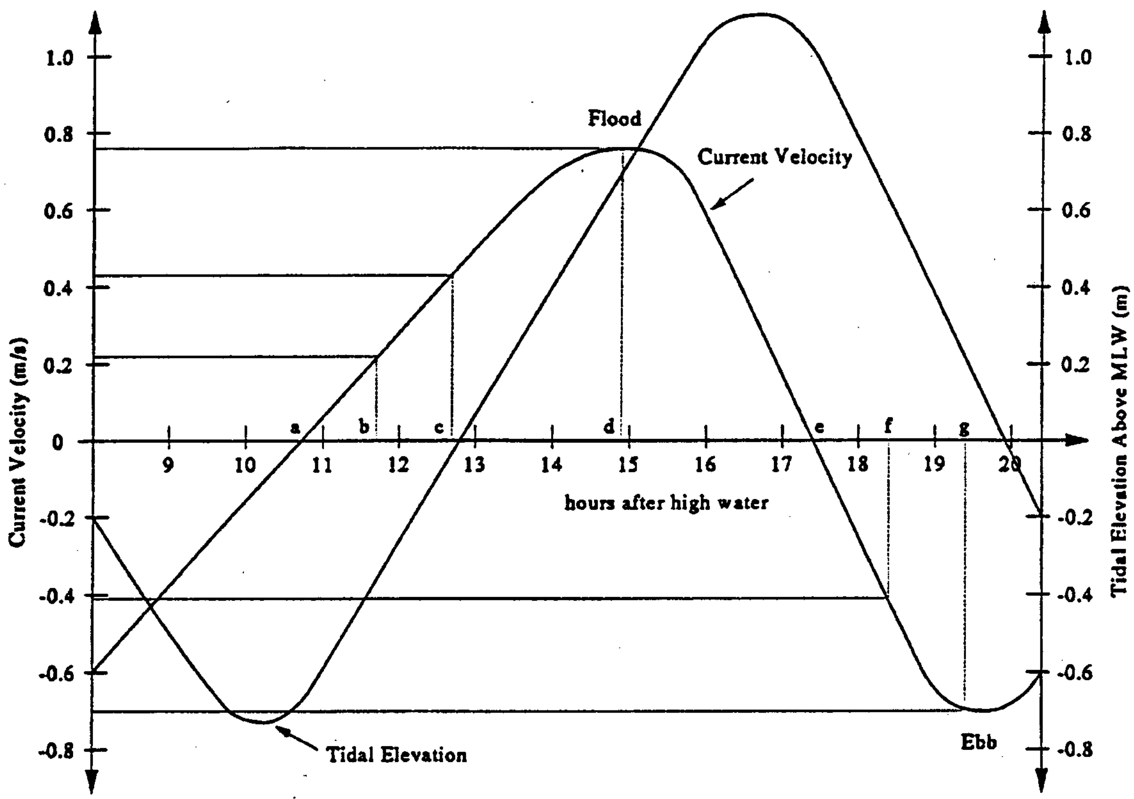


Figure D.2: Oceanographic data for Estuary showing tidal elevation and current. A complete tidal analysis might include simulations for all time instances labeled a to g.

CHECKLIST FOR DATA PREPARATION

CORMIX – CORNELL MIXING ZONE EXPERT SYSTEM – Version 3.10

SITE Name C-Plant Estuary Date:
Design CASE Steady State - 1 hr. after slack Prepared by: RLD
DOS FILE NAME Sample1 (w/o extension)

AMBIENT DATA:

Water body is ~~bounded~~/unbounded
Water body depth 5.65 m
If bounded: Width ____ m
Depth at discharge 5.65 m
Appearance ~~1/2/3~~x
If steady: Ambient flowrate ____ m^3/s or: Ambient velocity 0.22 m/s
~~If tidal:~~ Tidal period ____ hr
Max. tidal velocity ____ m/s
At time ____ hr before/at/after slack: Tidal velocity at this time ____ m/s
Manning's n ____ or: Darcy-Weisbach f 0.025
Wind speed 2 m/s
UNITS: Density...kg/m^3 / Temperature...°C
Density data:
Water body is ~~fresh~~/salt water
If fresh: Specify as density/~~temp.~~ values
If uniform:
Average density/temp. 1018.0
If stratified:
Density/temp. at surface ____
Stratification type A/B/C
Density/temp. at bottom ____
If B/C: Pycnocline height ____ m
If C: Density/temp. jump ____

DISCHARGE DATA:
Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE – CORMIX1
Nearest bank is on left/right
Distance to nearest bank ____ m
Vertical angle THETA ____ °
Horizontal angle SIGMA ____ °
Port diameter ____ m or: Port area ____ m^2
Port height ____ m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2
Nearest bank is on left/right
Distance to one endpoint ____ m
Diffuser length ____ m
to other endpoint ____ m
Total number of openings ____ m
Port height ____ m
Port diameter ____ m with contraction ratio ____
Diffuser arrangement/type unidirectional / staged / alternating or vertical
Alignment angle GAMMA ____ °
Horizontal angle SIGMA ____ °
Vertical angle THETA ____ °
Relative orientation BETA ____ °

BUOYANT SURFACE DISCHARGE – CORMIX3
Discharge located on ~~left~~/right bank
Configuration flush/~~protruding/co-flowing~~
Horizontal angle SIGMA 90 °
If protruding: Dist. from bank ____ m
Depth at discharge 2.15 m
Bottom slope 11 °
If rectangular discharge channel: Width 2 m or: If circular pipe: Diameter ____ m
Depth 0.65 m
Bottom invert depth ____ m

Effluent: Flow rate 2.2 m^3/s or: Effluent velocity ____ m/s
Effluent density - kg/m^3 or: Effluent temperature 22 °C
Heated discharge? ~~yes~~/no
If yes: Heat loss coefficient - W/m^2,°C
Concentration units mug-p-L
Effluent concentration 80
Conservative substance? yes/~~no~~
If no: Decay coefficient ____ /day

MIXING ZONE DATA:
Is effluent toxic? yes/~~no~~ If yes: CMC 25 CCC 15
WQ stand./conventional poll.? yes/no If yes: value of standard ____
Any mixing zone specified? yes/~~no~~ If yes: distance 250 m or width - % or m
or area - % or m^2

Region of interest 2000 m
Grid intervals for display 20

Figure D.3: **Data preparation checklist for CORMIX3 steady-state simulation for C-Plant estuary discharge**

Table D.1
CORMIX3 Prediction Steady-Sate Prediction File for Surface Buoyant Discharge

```
CORMIX3 PREDICTION FILE:
333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                          Subsystem version:
 Buoyant Surface Discharges                   CORMIX_v.3.10__________June_1995
---------------------------------------------------------------------------
---------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          C-PLANT^ESTUARY
 Design case:              STEADY^SIMULATION^ONE^HOUR^AFTER^SLACK
 FILE NAME:                cormix\sim\SAMPLE3 .cx3
 Time of Fortran run:      06/24/95--22:32:20

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =      5.65 HD     =       5.65
 UA     =      .220 F      =       .025 USTAR = .1230E-01
 UW     =     2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U           RHOAM = 1018.0000

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT       DISTB =       .00  Configuration: flush_discharge
 SIGMA =     90.00 HD0    =       2.15  SLOPE =     11.00
 Rectangular channel geometry:
 B0     =     2.000 H0     =       .650 A0     = .1300E+01  AR     =       .325
 U0     =     1.692 Q0     =      2.200        = .2200E+01
 RHO0   =  998.2051 DRHO0 = .1979E+02  GP0    = .1907E+00
 C0     = .8000E+02 CUNITS=  MUG-P-L
 IPOLL  = 1          KS    = .0000E+00  KD     = .0000E+00

FLUX VARIABLES (metric units)
 Q0     = .2200E+01  M0    = .3723E+01  J0     = .4195E+00
 Associated length scales (meters)
 LQ     =      1.14  LM    =       4.14  Lm     =      8.77  Lb     =     39.40

NON-DIMENSIONAL PARAMETERS
 FR0    =      3.62  FRCH  =       4.80  R      =      7.69

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)        =    FJ1    3
 3  Applicable layer depth HS =     5.65  3
 333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .8000E+02  CUNITS=  MUG-P-L
 NTOX   =  1         CMC   = .2500E+02  CCC    =  CSTD
 NSTD   =  1         CSTD  = .1500E+02
 REGMZ  =  1
 REGSPC=  1          XREG  =    250.00  WREG   =       .00  AREG   =       .00
 XINT   =   2000.00  XMAX  =   2000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:       .00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 20 display intervals per module
---------------------------------------------------------------------------
        TRJBUO     TRJATT     TRJBND     TRJNBY     TRJCOR     DILCOR
C        3.401      1.000      1.000      1.000      3.400      1.000
---------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
       X         Y        Z        S        C        BV        BH
      .00       .00     0.00      1.0   .800E+02    .65      1.00

END OF MOD301: DISCHARGE MODULE
```

```
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

  Control volume inflow:
       X        Y        Z        S        C        BV       BH
      .00      .00     0.00      1.0  .800E+02     .65     1.00

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

  Control volume outflow:
       X        Y        Z        S        C        BV       BH
      .13     4.11     0.00      1.4  .576E+02    1.09     1.41
 Cumulative travel time =           2. sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD311: WEAKLY DEFLECTED JET (3-D)

 Surface JET into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      .13     4.11     0.00      1.4  .576E+02    1.28     1.65
      .13     4.14     0.00      1.4  .575E+02    1.28     1.66
      .13     4.16     0.00      1.4  .574E+02    1.28     1.66
      .13     4.18     0.00      1.4  .573E+02    1.28     1.66
      .13     4.20     0.00      1.4  .572E+02    1.29     1.66
      .14     4.23     0.00      1.4  .571E+02    1.29     1.67
      .14     4.25     0.00      1.4  .570E+02    1.29     1.67
      .14     4.27     0.00      1.4  .569E+02    1.29     1.67
      .14     4.29     0.00      1.4  .568E+02    1.30     1.67
      .15     4.32     0.00      1.4  .567E+02    1.30     1.68
      .15     4.34     0.00      1.4  .566E+02    1.30     1.68
      .15     4.36     0.00      1.4  .565E+02    1.30     1.68
      .15     4.38     0.00      1.4  .564E+02    1.30     1.68
      .15     4.41     0.00      1.4  .563E+02    1.31     1.69
      .16     4.43     0.00      1.4  .562E+02    1.31     1.69
      .16     4.45     0.00      1.4  .561E+02    1.31     1.69
      .16     4.47     0.00      1.4  .560E+02    1.31     1.69
      .16     4.50     0.00      1.4  .559E+02    1.32     1.70
      .17     4.52     0.00      1.4  .558E+02    1.32     1.70
      .17     4.54     0.00      1.4  .558E+02    1.32     1.70
      .17     4.56     0.00      1.4  .557E+02    1.32     1.70
 Cumulative travel time =           3. sec

END OF MOD311: WEAKLY DEFLECTED JET (3-D)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD313: WEAKLY DEFLECTED PLUME

 Surface PLUME into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      .17     4.56     0.00      1.4  .557E+02    1.32     1.70
      .41     6.86     0.00      2.3  .343E+02     .82     4.48
      .67     9.16     0.00      2.9  .279E+02     .66     6.76
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .250E+02
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
```

```
       .96    11.46     0.00      3.3  .244E+02    .58     8.88
      1.28    13.76     0.00      3.6  .220E+02    .52    10.93
      1.62    16.05     0.00      4.0  .202E+02    .48    12.95
      1.99    18.35     0.00      4.3  .188E+02    .45    14.94
      2.38    20.65     0.00      4.5  .177E+02    .42    16.93
      2.80    22.95     0.00      4.8  .167E+02    .40    18.92
      3.25    25.25     0.00      5.0  .159E+02    .38    20.91
      3.72    27.54     0.00      5.3  .152E+02    .36    22.90
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of   .150E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      4.22    29.84     0.00      5.5  .146E+02    .35    24.90
      4.75    32.14     0.00      5.7  .140E+02    .33    26.92
      5.30    34.44     0.00      5.9  .135E+02    .32    28.93
      5.87    36.74     0.00      6.1  .131E+02    .31    30.96
      6.48    39.03     0.00      6.3  .126E+02    .30    33.00
      7.11    41.33     0.00      6.5  .123E+02    .29    35.05
      7.76    43.63     0.00      6.7  .119E+02    .28    37.11
      8.44    45.93     0.00      6.9  .116E+02    .28    39.18
      9.15    48.23     0.00      7.1  .113E+02    .27    41.25
      9.88    50.52     0.00      7.2  .110E+02    .26    43.34
 Cumulative travel time =         248. sec

END OF MOD313: WEAKLY DEFLECTED PLUME
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD323: STRONGLY DEFLECTED PLUME

 Profile definitions:
   BV = top-hat thickness,measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

        X         Y        Z         S        C         BV       BH
      9.88    50.52     0.00      7.2  .110E+02    .26    43.34
     84.15   123.86     0.00      7.5  .107E+02    .23    60.96
    158.42   154.39     0.00      7.8  .103E+02    .22    77.07
    232.69   176.11     0.00      8.1  .985E+01    .22    92.39
 ** REGULATORY MIXING ZONE BOUNDARY **
 In this prediction interval the plume distance meets or exceeds
   the regulatory value =    250.00 m.
 This is the extent of the REGULATORY MIXING ZONE.
    306.96   193.50     0.00      8.6  .934E+01    .22   107.24
    381.23   208.23     0.00      9.1  .876E+01    .23   121.77
    455.50   221.14     0.00      9.8  .815E+01    .25   136.02
    529.77   232.70     0.00     10.7  .750E+01    .26   150.02
    604.04   243.21     0.00     11.7  .685E+01    .28   163.77
    678.31   252.88     0.00     12.9  .621E+01    .30   177.26
    752.58   261.87     0.00     14.3  .560E+01    .32   190.49
    826.84   270.29     0.00     15.9  .504E+01    .34   203.46
    901.11   278.21     0.00     17.7  .452E+01    .36   216.17
    975.38   285.70     0.00     19.7  .406E+01    .39   228.65
   1049.65   292.82     0.00     21.9  .365E+01    .41   240.91
   1123.92   299.61     0.00     24.4  .328E+01    .44   252.95
   1198.18   306.11     0.00     27.1  .295E+01    .47   264.79
   1272.45   312.34     0.00     30.0  .267E+01    .50   276.45
   1346.72   318.34     0.00     33.1  .241E+01    .54   287.93
   1420.99   324.11     0.00     36.5  .219E+01    .57   299.25
   1495.25   329.69     0.00     40.1  .199E+01    .61   310.43
 Cumulative travel time =        7000. sec

END OF MOD323: STRONGLY DEFLECTED PLUME
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD341: BUOYANT AMBIENT SPREADING

 Profile definitions:
   BV = top-hat thickness,measured vertically
   BH = top-hat half-width, measured horizontally from bank/shoreline
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
```

Plume Stage 1 (not bank attached):

X	Y	Z	S	C	BV	BH
1495.25	329.69	0.00	40.1	.199E+01	.63	319.79
1498.55	329.69	0.00	40.3	.199E+01	.63	320.29
1501.84	329.69	0.00	40.5	.198E+01	.63	320.79
1505.13	329.69	0.00	40.6	.197E+01	.63	321.29
1508.42	329.69	0.00	40.8	.196E+01	.63	321.79
1511.72	329.69	0.00	41.0	.195E+01	.64	322.29
1515.01	329.69	0.00	41.1	.195E+01	.64	322.78
1518.30	329.69	0.00	41.3	.194E+01	.64	323.28
1521.59	329.69	0.00	41.5	.193E+01	.64	323.78
1524.89	329.69	0.00	41.6	.192E+01	.64	324.27
1528.18	329.69	0.00	41.8	.191E+01	.64	324.77
1531.47	329.69	0.00	42.0	.191E+01	.65	325.27
1534.77	329.69	0.00	42.1	.190E+01	.65	325.76
1538.06	329.69	0.00	42.3	.189E+01	.65	326.26
1541.35	329.69	0.00	42.5	.188E+01	.65	326.75
1544.64	329.69	0.00	42.6	.188E+01	.65	327.25
1547.94	329.69	0.00	42.8	.187E+01	.65	327.74
1551.23	329.69	0.00	43.0	.186E+01	.65	328.23
1554.52	329.69	0.00	43.2	.185E+01	.66	328.73
1557.81	329.69	0.00	43.3	.185E+01	.66	329.22
1561.11	329.69	0.00	43.5	.184E+01	.66	329.71

Cumulative travel time = 7299. sec

Plume is ATTACHED to RIGHT bank/shore.
Plume width is now determined from RIGHT bank/shore.

Plume Stage 2 (bank attached):

X	Y	Z	S	C	BV	BH
1561.11	.00	0.00	43.5	.184E+01	.66	659.39
1583.05	.00	0.00	44.6	.179E+01	.67	662.33
1605.00	.00	0.00	45.7	.175E+01	.69	665.27
1626.94	.00	0.00	46.8	.171E+01	.70	668.21
1648.89	.00	0.00	48.0	.167E+01	.71	671.16
1670.83	.00	0.00	49.1	.163E+01	.73	674.11
1692.78	.00	0.00	50.3	.159E+01	.74	677.06
1714.72	.00	0.00	51.4	.156E+01	.76	680.01
1736.66	.00	0.00	52.6	.152E+01	.77	682.97
1758.61	.00	0.00	53.8	.149E+01	.78	685.92
1780.55	.00	0.00	55.0	.146E+01	.80	688.88
1802.50	.00	0.00	56.2	.142E+01	.81	691.83
1824.44	.00	0.00	57.4	.139E+01	.83	694.79
1846.39	.00	0.00	58.6	.136E+01	.84	697.75
1868.33	.00	0.00	59.9	.134E+01	.85	700.71
1890.28	.00	0.00	61.1	.131E+01	.87	703.67
1912.22	.00	0.00	62.4	.128E+01	.88	706.62
1934.17	.00	0.00	63.6	.126E+01	.90	709.58
1956.11	.00	0.00	64.9	.123E+01	.91	712.54
1978.05	.00	0.00	66.2	.121E+01	.93	715.50
2000.00	.00	0.00	67.5	.118E+01	.94	718.46

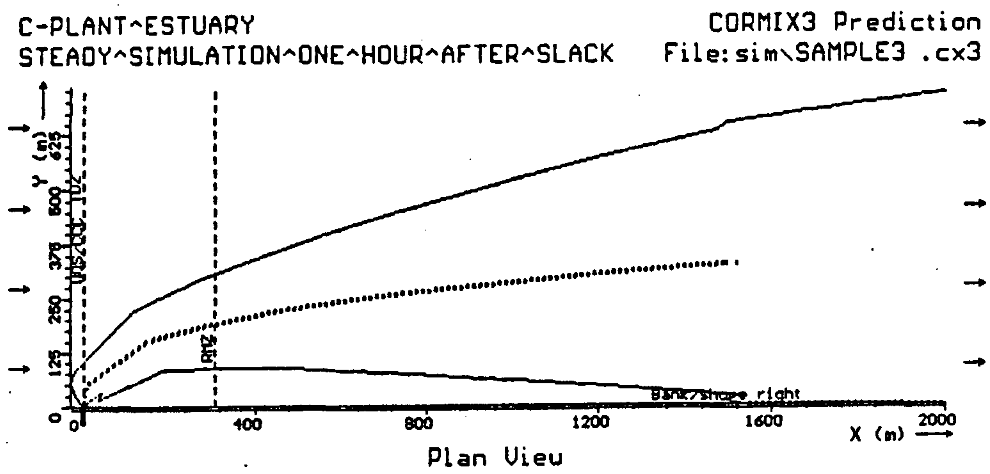
Cumulative travel time = 9294. sec

Simulation limit based on maximum specified distance = 2000.00 m.
This is the REGION OF INTEREST limitation.

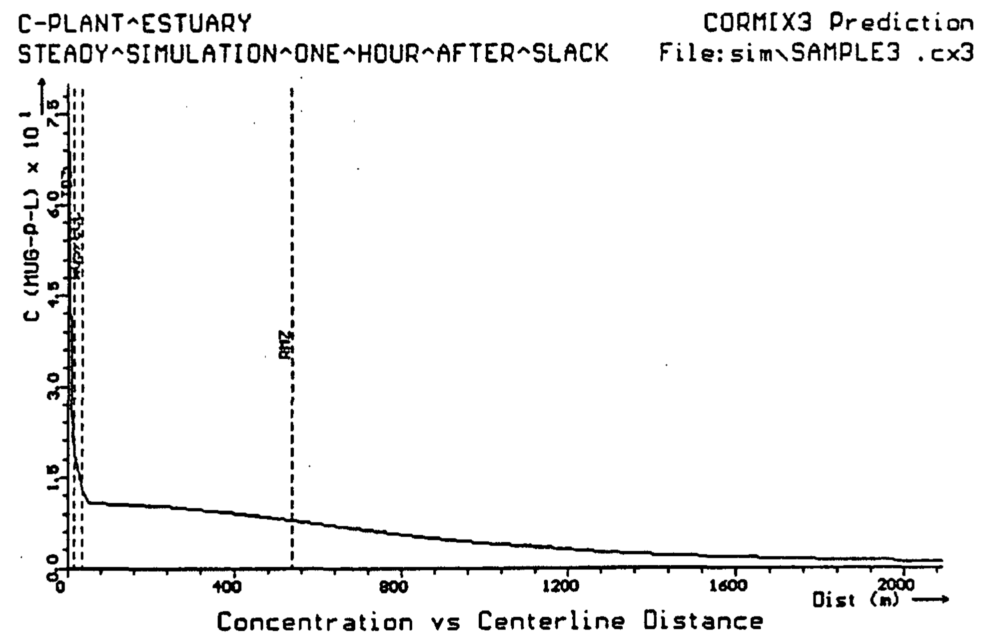
END OF MOD341: BUOYANT AMBIENT SPREADING

CORMIX3: Buoyant Surface Discharges End of Prediction File

333333333333333333333333333333333333333333333333333333333333333333333333333333



(a)



(b)

Figure D.4: CORMIX3 prediction of surface discharge from C-Plant into Estuary using a steady-state simulation. a) Plume shape in near- and far-field, and b) concentration along plume centerline.

D.3 Detailed Tidal Simulations

A high variation in both ambient velocity and tidal elevation occurs during the tidal episode shown in Figure D.2. The changing water height produces a discharge velocity which varies from 0.61 m/s (at high water slack) to 2.2 m/s (at low water slack). When combined with the large buoyancy flux, this produces flows which change from momentum dominated jets to highly buoyant plumes in a short period of time. Simultaneously, the time-variant ambient velocity (which ranges from stagnant to 0.75 m/s) produces flows which are free and unattached at slack tide, yet become strongly shore-hugging at maximum flood or ebb currents.

In such highly time-variant ambient conditions, it is recommended that several CORMIX predictions be performed at **critical tidal conditions** throughout a reversal episode. These critical tidal conditions are identified as:

1) *Shortly after slack tide*: Effects of re-entrainment of discharge from the previous half-cycle are greatest. However, the flow is evolving rapidly in time, causing CORMIX tidal predictions to be limited in spatial extent. Several predictions should be made at hourly or half hourly intervals following the reversal.
2) *Maximum flood and ebb currents*: These represent extremes of along-shore extent and shoreline interaction. Re-entrainment will be less important at these times.

For the present scenario, it is suggested that up to seven simulations be performed at the times indicated on Figure D.2 by the letters a-g. In the following section, a detailed simulation is performed corresponding to time b, one hour after slack tide. The results are contrasted for that case to the steady-state assumption simulated in the preceding.

D.4 Tidal simulation one hour after slack tide

A detailed example of the tidal simulation capability of CORMIX is presented in this section, using conditions corresponding to those in Section D.2 (see Figure D.2, time b). To perform a CORMIX tidal simulation, four additional pieces of data are required:

1) the tidal period (usually 12.4 hours for a semi-diurnal tidal cycle)
2) the time of simulation (in hours relative to slack tide)
3) the ambient velocity at the time of simulation
4) the maximum velocity which occurs during the tidal cycle

From this data, CORMIX calculates the rate of reversal (du_a/dt) and related unsteady length scales (L_u, T_u, $[L_m]_{min}$, see Table 5.4), and determines the spatial extent of CORMIX applicability and the re-entrainment and build-up caused by the reversal of ambient current. (Note: If a simulation is performed at slack tide, then the time of simulation is t = 0 h, and the ambient velocity is set to u_a = 0 m/s.) However, in order to calculate the reversal rate, CORMIX requires input of the ambient velocity at an other time near reversal (for example, at one hour before or after slack tide). This information is only used to determine the limit of spatial applicability for the slack tide simulation.

For this application, the time of simulation is one hour after slack tide. The ambient velocity at this time is u_a = 0.22 m/s, and the ambient and discharge channel depths are the same as in Section D.2. The maximum ambient velocity during the tidal cycle is 0.75 m/s. For this simulation, the data preparation checklist is given in Figure D.5.

Table D.2 lists the CORMIX session report and Table D.3 the CORMIX3 prediction file for this tidal application. Two important consequences are evident when comparing Table D.3 and Table D.1 (corresponding steady-state simulation): 1) a concentration build-up in the near-field, and 2) the termination of the plume prediction after some distance. The latter distance is the region over which a reasonably steady-state plume can establish itself within the time-varying tidal environment. The theoretical background for these procedures is given in the report on recent CORMIX enhancements (8).

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name: C-Plant Estuary — Date:
Design **CASE**: Tidal simulation 1 hr after slack — Prepared by: GHJ
DOS FILE NAME: Sample 3T (w/o extension)

AMBIENT DATA:

Water body depth	5.65 m	Water body is	~~bounded~~/unbounded
Depth at discharge	5.65 m	If bounded: Width	- m
		Appearance	~~1/2/3~~
If steady: Ambient flowrate	- m³/s or:	Ambient velocity	- m/s
If tidal: Tidal period	12.4 hr	Max. tidal velocity	0.75 m/s
At time 1.0 hr ~~before~~/at/after slack:		Tidal velocity at this time	0.22 m/s
Manning's n	- or:	Darcy-Weisbach f	0.025
Wind speed	2 m/s		

Density data: UNITS: Density...kg/m³ / Temperature...°C

Water body is	~~fresh~~/salt water	If fresh: Specify as	density/~~temp.~~ values
If uniform:		Average density/~~temp.~~	1018.0
If stratified:		Density/temp. at surface	
Stratification type	A/B/C	Density/temp. at bottom	
If B/C: Pycnocline height	m	If C: Density/temp. jump	

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

~~**SUBMERGED SINGLE PORT DISCHARGE – CORMIX1**~~

Nearest bank is on	left/right	Distance to nearest bank	m
Vertical angle THETA	°	Horizontal angle SIGMA	°
Port diameter	m or:	Port area	m²
Port height	m		

~~**SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2**~~

Nearest bank is on	left/right	Distance to one endpoint	m
Diffuser length	m	to other endpoint	m
Total number of openings	m	Port height	m
Port diameter	m with	contraction ratio	
Diffuser arrangement/type	unidirectional / staged / alternating or vertical		
Alignment angle GAMMA	°	Horizontal angle SIGMA	°
Vertical angle THETA	°	Relative orientation BETA	°

BUOYANT SURFACE DISCHARGE – CORMIX3

Discharge located on	~~left~~/right bank	Configuration	flush/~~protruding~~/~~co-flowing~~
Horizontal angle SIGMA	90 °	If protruding: Dist. from bank	- m
Depth at discharge	2.15 m	Bottom slope	11 °
If rectangular Width	2.0 m or:	If circular Diameter	- m
discharge channel: Depth	0.65 m	pipe: Bottom invert depth	- m

Effluent: Flow rate	2.20 m³/s or:	Effluent velocity	- m/s
Effluent density	- kg/m³ or:	Effluent temperature fresh	22.0 °C
Heated discharge?	~~yes~~/no	If yes: Heat loss coefficient	- W/m²,°C
Concentration units	mug-p-L	Effluent concentration	80
Conservative substance?	yes/~~no~~	If no: Decay coefficient	- /day

MIXING ZONE DATA:

Is effluent toxic?	yes/~~no~~	If yes: CMC 25	CCC 15
WQ stand./conventional poll.?	~~yes~~/no	If yes: value of standard	-
Any mixing zone specified?	yes/~~no~~	If yes: distance 250 m	or width - % or m
			or area - % or m²
Region of interest	2000 m	Grid intervals for display	10

Figure D.5: Data preparation checklist for C-Plant discharge into Estuary design case for unsteady tidal conditions using CORMIX3

Table D.2
CORMIX Session Report for C-Plant discharge into Estuary with unsteady tidal conditions

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM

SITE NAME/LABEL:                C-PLANT ESTUARY
  DESIGN CASE:                  TIDAL SIMULATION ONE HOUR AFTER SLACK
  FILE NAME:                    SAMPLE3T
Using subsystem CORMIX3:        Buoyant Surface Discharges
  Start of session:             06/24/95--22:33:33
******************************************************************************
SUMMARY OF INPUT DATA:
------------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                        = unbounded
  Average depth                HA      =         5.65 m
  Depth at discharge           HD      =         5.65 m
  Darcy-Weisbach friction factor F     =         .025
  Wind velocity                UW      =            2 m/s
TIDAL SIMULATION at time       Tsim    =            1 hours
  Instantaneous ambient velocity UA    =          .22 m/s
  Maximum tidal velocity       UaMAX   =          .75 m/s
  Rate of tidal reversal       dUA/dt  =       0.2200 (m/s)/hour
  Period of reversal           T       =         12.4 hours
Stratification Type            STRCND  = U
  Surface density              RHOAS   =         1018 kg/m^3
  Bottom density               RHOAB   =         1018 kg/m^3
------------------------------------------------------------------------------
DISCHARGE PARAMETERS:          Buoyant Surface Discharge
  Discharge located on                 = right bank/shoreline
  Discharge configuration              = flush discharge
  Distance from bank to outlet DISTB   =          0.0 m
  Discharge angle              SIGMA   =           90 deg
  Depth near discharge outlet  HD0     =         2.15 m
  Bottom slope at discharge    SLOPE   =           11 deg
  Rectangular discharge:
    Discharge cross-section area A0    =       1.3000 m^2
    Discharge channel width    B0      =            2 m
    Discharge channel depth    H0      =          .65 m
    Discharge aspect ratio     AR      =         0.32
  Discharge flowrate           Q0      =     2.199990 m^3/s
  Discharge velocity           U0      =         1.69 m/s
  Discharge temperature (freshwater)   =           20 degC
    Corresponding density      RHO0    =     998.2051 kg/m^3
  Density difference           DRHO    =      19.7948 kg/m^3
  Buoyant acceleration         GP0     =        .1907 m/s^2
  Discharge concentration      C0      =               80 MUG-P-L
  Surface heat exchange coeff. KS      =            0 m/s
  Coefficient of decay         KD      =            0 /s
------------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  =       1.14 m        Lm  =       8.77 m         Lb  =      39.39 m
  LM  =       4.13 m
UNSTEADY TIDAL SCALES:
  Tu  =     0.2228 hours    Lu  =      39.34 m         Lmin=       2.57 m
------------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number    FR0     =         3.62 (based on LQ)
  Channel densimetric Froude no. FRCH  =         4.80 (based on H0)
  Velocity ratio               R       =         7.69
------------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                      = yes
  CMC concentration            CMC     =               25 MUG-P-L
  CCC concentration            CCC     =               15 MUG-P-L
  Water quality standard               = given by CCC value
  Regulatory mixing zone               = yes
  Regulatory mixing zone specification = distance
  Regulatory mixing zone value         =          250 m (m^2 if area)
  Region of interest                   =      3500.00 m
******************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS  =    PJ1  |
  *------------------------*
******************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
------------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at water surface and at centerline of discharge channel:
           0.0 m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
```

```
-------------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =          .0000 MUG-P-L
  Dilution at edge of NFR                =          .0
  NFR Location:                        x =          .00 m
    (centerline coordinates)           y =          .00 m
                                       z =          .00 m
  NFR plume dimensions:       half-width =          .00 m
                               thickness =          .00 m
-------------------------------------------------------------------------------
UNSTEADY TIDAL ASSESSMENT:
  Because of the unsteadiness of the ambient current during the tidal
  reversal, CORMIX predictions have been TERMINATED at:
                                       x =       282.05 m
                                       y =       187.66 m
                                       z =          .00 m
  For this condition AFTER TIDAL REVERSAL, mixed water from the previous
  half-cycle becomes re-entrained into the near field of the discharge,
  increasing pollutant concentrations compared to steady-state predictions.
  A pool of mixed water formed at slack tide will be advected downstream
  in this phase.
************************ TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
  Technical Support Document (TSD) for Water Quality-based Toxics Control,
  1991 (EPA/505/2-90-001).
  Criterion maximum concentration (CMC)  =               25 MUG-P-L
  Corresponding dilution                 =         3.2
The CMC was encountered at the following plume position:
  Plume location:                      x =         1.04 m
    (centerline coordinates)           y =        12.05 m
                                       z =          .00 m
  Plume dimensions:           half-width =         9.41 m
                               thickness =          .56 m
 CRITERION 1: This location is within 50 times the discharge length scale of
            Lq =       1.14 m.
 +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

 CRITERION 2: This location is within 5 times the ambient water depth of
            HD =         5.65 m.
 ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.+++++++++++

 CRITERION 3: This location is within one tenth the distance of the extent
            of the Regulatory Mixing Zone of       250.00 m downstream.
 +++++ The Regulatory Mixing Zone TEST for the TDZ has been SATISFIED. ++++++

 The diffuser discharge velocity is equal to        1.69 m/s.
   This is below the value of 3.0 m/s recommended in the TSD.

 *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
********************** REGULATORY MIXING ZONE SUMMARY **********************
The plume conditions at the boundary of the specified RMZ are as follows:
  Pollutant concentration                =        17.960500 MUG-P-L
  Corresponding dilution                 =          4.4
  Plume location:                      x =       250.00 m
    (centerline coordinates)           y =       176.10 m
                                       z =          .00 m
  Plume dimensions:           half-width =        95.88 m
                               thickness =          .21 m
At this position, the plume is NOT IN CONTACT with any bank.
However, the CCC for the toxic pollutant has not been met within the RMZ.
  In particular:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                    =               15 MUG-P-L
  Corresponding dilution                 =         5.3
  Plume location:                      x =         6.02 m
    (centerline coordinates)           y =        37.32 m
                                       z =          .00 m
  Plume dimensions:           half-width =        31.48 m
                               thickness =          .30 m
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
*****************************************************************************
DESIGN CASE:                    TIDAL SIMULATION ONE HOUR AFTER SLACK
FILE NAME:                      SAMPLE3T
Subsystem CORMIX3:              Buoyant Surface Discharges
END OF SESSION/ITERATION:       04/14/96--11:24:13
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

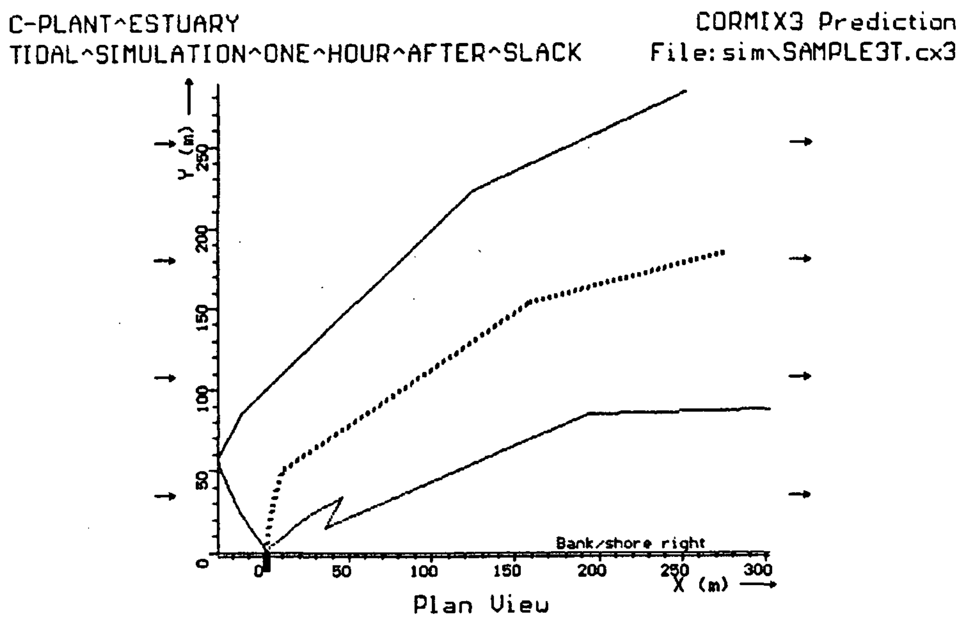
Table D.3
CORMIX3 Prediction File for C-Plant discharge into Estuary with unsteady tidal conditions

```
CORMIX3 PREDICTION FILE:
33333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                           Subsystem version:
 Buoyant Surface Discharges                  CORMIX_v.3.10_________June_1995
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         C-PLANT^ESTUARY
 Design case:             TIDAL^SIMULATION^ONE^HOUR^AFTER^SLACK
 FILE NAME:               cormix\sim\SAMPLE3T.cx3
 Time of Fortran run:     06/24/95--22:34:03

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =       5.65  HD     =       5.65
 Tidal Simulation at TIME =      1.000 h
 PERIOD=     12.40 h UAmax =       .750 dUa/dt=       .220 (m/s)/h
 UA     =       .220 F      =       .025 USTAR = .1230E-01
 UW     =      2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U          RHOAM = 1018.0000

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT      DISTB =        .00  Configuration: flush_discharge
 SIGMA =     90.00  HD0    =       2.15  SLOPE =      11.00
 Rectangular channel geometry:
 B0     =      2.000 H0     =       .650 A0     = .1300E+01  AR     =       .325
 U0     =      1.692 Q0     =      2.200        = .2200E+01
 RHO0  =  998.2051  DRHO0 = .1979E+02  GP0    = .1907E+00
 C0    = .8000E+02  CUNITS=  MUG-P-L
 IPOLL =  1          KS     = .0000E+00  KD     = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .2200E+01  M0     = .3723E+01  J0     = .4195E+00
 Associated length scales (meters)
 LQ     =      1.14  LM     =      4.14  Lm     =      8.77  Lb     =     39.40
 Tidal:              Tu     =     .2229 h Lu     =    39.347 Lmin   =     2.573

NON-DIMENSIONAL PARAMETERS
 FR0    =      3.62  FRCH   =      4.80  R      =      7.69

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)       =    FJ1    3
 3  Applicable layer depth HS =     5.65  3
 333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .8000E+02  CUNITS=  MUG-P-L
 NTOX  =  1          CMC    = .2500E+02  CCC    =  CSTD
 NSTD  =  1          CSTD   = .1500E+02
 REGMZ =  1
 REGSPC=  1          XREG   =    250.00  WREG   =        .00  AREG   =       .00
 XINT  =   2500.00  XMAX   =   3500.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:        .00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 20 display intervals per module
-----------------------------------------------------------------------------
        TRJBUO     TRJATT     TRJBND     TRJNBY     TRJCOR     DILCOR
C        3.401      1.000      1.000      1.000      3.400      1.000
-----------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
       X         Y         Z         S         C        BV        BH
      .00       .00      0.00       1.0  .800E+02      .65      1.00
```

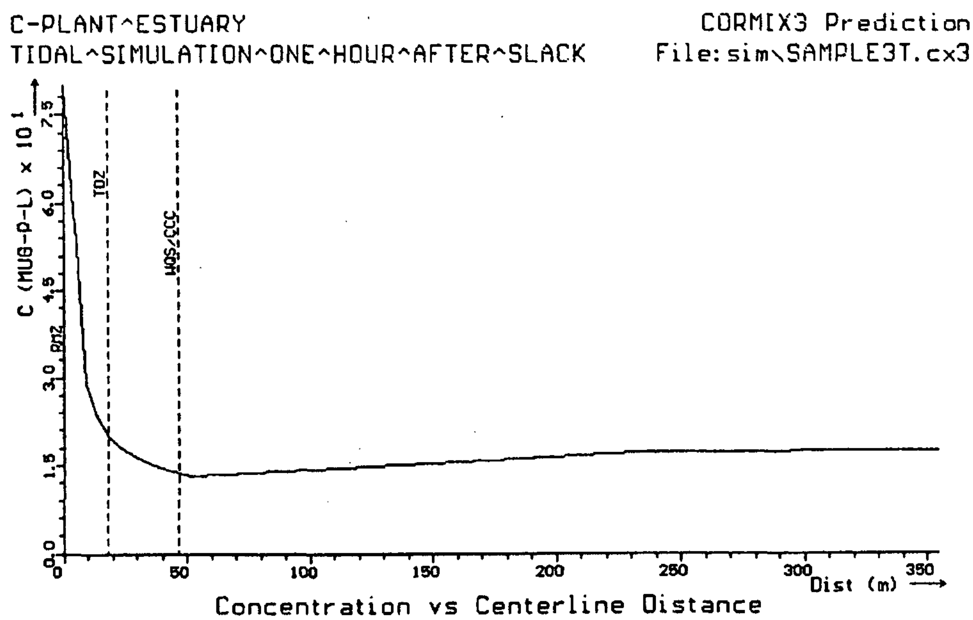
```
END OF MOD301: DISCHARGE MODULE
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

  Control volume inflow:
      X        Y        Z        S       C         BV       BH
     .00      .00     0.00      1.0  .800E+02     .65     1.00

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

  Control volume outflow:
      X        Y        Z        S       C         BV       BH
     .13     4.11     0.00      1.4  .586E+02    1.09     1.41
 Cumulative travel time =          2. sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD311: WEAKLY DEFLECTED JET (3-D)

 Surface JET into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

      X        Y        Z        S       C         BV       BH
     .13     4.11     0.00      1.4  .586E+02    1.28     1.65
     .13     4.14     0.00      1.4  .585E+02    1.28     1.66
     .13     4.16     0.00      1.4  .584E+02    1.28     1.66
     .13     4.18     0.00      1.4  .583E+02    1.28     1.66
     .13     4.20     0.00      1.4  .582E+02    1.29     1.66
     .14     4.23     0.00      1.4  .581E+02    1.29     1.67
     .14     4.25     0.00      1.4  .580E+02    1.29     1.67
     .14     4.27     0.00      1.4  .580E+02    1.29     1.67
     .14     4.29     0.00      1.4  .579E+02    1.30     1.67
     .15     4.32     0.00      1.4  .578E+02    1.30     1.68
     .15     4.34     0.00      1.4  .577E+02    1.30     1.68
     .15     4.36     0.00      1.4  .576E+02    1.30     1.68
     .15     4.38     0.00      1.4  .575E+02    1.30     1.68
     .15     4.41     0.00      1.4  .574E+02    1.31     1.69
     .16     4.43     0.00      1.4  .573E+02    1.31     1.69
     .16     4.45     0.00      1.4  .572E+02    1.31     1.69
     .16     4.47     0.00      1.4  .571E+02    1.31     1.69
     .16     4.50     0.00      1.4  .571E+02    1.32     1.70
     .17     4.52     0.00      1.4  .570E+02    1.32     1.70
     .17     4.54     0.00      1.4  .569E+02    1.32     1.70
     .17     4.56     0.00      1.4  .568E+02    1.32     1.70
 Cumulative travel time =          3. sec

END OF MOD311: WEAKLY DEFLECTED JET (3-D)
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD313: WEAKLY DEFLECTED PLUME

 Surface PLUME into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

      X        Y        Z        S       C         BV       BH
     .17     4.56     0.00      1.4  .568E+02    1.32     1.70
     .41     6.86     0.00      2.3  .354E+02     .82     4.48
     .67     9.16     0.00      2.8  .291E+02     .66     6.76
     .96    11.46     0.00      3.1  .256E+02     .58     8.88
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .250E+02
```

```
  in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
      1.28     13.76     0.00      3.4  .233E+02    .52     10.93
      1.62     16.05     0.00      3.7  .216E+02    .48     12.95
      1.99     18.35     0.00      3.9  .203E+02    .45     14.94
      2.38     20.65     0.00      4.2  .192E+02    .42     16.93
      2.80     22.95     0.00      4.4  .184E+02    .40     18.92
      3.25     25.25     0.00      4.5  .176E+02    .38     20.91
      3.72     27.54     0.00      4.7  .170E+02    .36     22.90
      4.22     29.84     0.00      4.9  .164E+02    .35     24.90
      4.75     32.14     0.00      5.0  .159E+02    .33     26.92
      5.30     34.44     0.00      5.2  .155E+02    .32     28.93
      5.87     36.74     0.00      5.3  .151E+02    .31     30.96
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .150E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      6.48     39.03     0.00      5.4  .147E+02    .30     33.00
      7.11     41.33     0.00      5.6  .144E+02    .29     35.05
      7.76     43.63     0.00      5.7  .141E+02    .28     37.11
      8.44     45.93     0.00      5.8  .138E+02    .28     39.18
      9.15     48.23     0.00      5.9  .136E+02    .27     41.25
      9.88     50.52     0.00      6.0  .134E+02    .26     43.34
 Cumulative travel time =         248. sec

END OF MOD313: WEAKLY DEFLECTED PLUME
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD323: STRONGLY DEFLECTED PLUME

 Profile definitions:
   BV = top-hat thickness,measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

        X         Y        Z         S        C         BV       BH
      9.88     50.52     0.00      6.0  .134E+02    .26     43.34
     84.15    123.86     0.00      4.9  .163E+02    .23     60.96
    158.42    154.39     0.00      4.6  .174E+02    .22     77.07
    232.69    176.11     0.00      4.5  .178E+02    .22     92.39
 ** REGULATORY MIXING ZONE BOUNDARY **
 In this prediction interval the plume distance meets or exceeds
   the regulatory value =    250.00 m.
 This is the extent of the REGULATORY MIXING ZONE.
    282.05    187.67     0.00      4.5  .177E+02    .22    102.26
 Cumulative travel time =        1485. sec

 CORMIX prediction has been TERMINATED at last prediction interval.
   Limiting distance due to TIDAL REVERSAL has been reached.

END OF MOD323: STRONGLY DEFLECTED PLUME
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX3: Buoyant Surface Discharges                      End of Prediction File
33333333333333333333333333333333333333333333333333333333333333333333333333333
```

The results of the tidal simulations are shown graphically in Figure D.6. The most obvious difference in the tidal CORMIX prediction at this time is that the maximum predicted downstream distance is limited to 275 m in the x-direction. Furthermore, a significant increase in the pollutant concentration (copper) is observed at the edge of the RMZ (compare Figure D.4b and D.6b at a distance of 250 m downstream) in the tidal application as a result of tidal re-entrainment. As a result, the copper concentration at the RMZ is 18 μg/L as opposed to 10 μg/L for the steady state simulation, which exceeds the CCC at this distance.



(a)



(b)

Figure D.6: CORMIX3 prediction of surface discharge from C-Plant into Estuary using a unsteady tidal simulation. a) Plume shape in near-field only (prediction is terminated after this region), and b) concentration along plume centerline.

Appendix E
Two Applications of CORJET

Two case studies are presented here illustrating the application of the post-processing model included within CORMIX, namely CORJET, the Cornell buoyant jet integral model. As discussed in Section 6.1 is an important tool for predicting additional details within the near-field of a submerged discharge. Both case studies are included in the normal CORMIX installation package.

It is repeated here that CORJET, as any jet integral model, if used alone and by an inexperienced analyst, is **not a safe methodology for mixing zone analysis**. It is advised to use it only in conjunction with the more comprehensive CORMIX system. Therefore, in case of engineering design applications, **CORJET should be employed after prior use of the expert system CORMIX has indicated that the buoyant jet will not experience any instabilities due to shallow water or due to attachment to boundaries**.

E.1 Submerged multiport diffuser in deep water

A short diffuser consisting of 11 ports and a total length of 20 m is discharging fresh water at a temperature of 30 °C into the stratified coastal ocean. The diffuser ports are each 0.5 m in diameter and well-rounded in their internal hydraulic design so that no further exit flow contraction will occur. The nozzles are oriented with a vertical angle of 45 ° upward and a horizontal angle of 45 ° pointing into the ambient crossflow (see multiport diffuser definition diagram, Figures 4.6 and 4.7). The diffuser has an alignment of 60 ° with respect to the ambient current. The discharge flow has a concentration of 100 % of some conservative substance.

Detailed measurements in the water column give the distribution of temperature, salinity and current velocity as a function of vertical distance. The current at each level flows in the same direction, i.e. along the coastline. The water depth at the discharge location is of the order of 30 m.

The CORJET data preparation checklist for this design case is given as Figure E.1. Density data is specified in this case via temperature and salinity. The program computes internally the actual density distribution using the full (UNESCO) equation of state. It should be noted that in case of multiple ambient levels CORJET assumes outside the specified range (e.g. above 15 m in this case) that the data are linearly continued from the last specified interval. If uniform ambient conditions exist only a single level must be specified.

The port height H0 in the input data specification is set to 0.0 m; thus, the coordinate system is conveniently set at the discharge height. Another value for the actual height above the water bottom could be used too, but remember that CORJET, as all integral models, does not compute actual bottom interaction effects (see Section 6.1.1). A maximum computation height of 30 m and distance of 200 m is specified to stop the computation. The number of print intervals is set to 10, in order to provide sufficient detail.

A prior application of CORMIX (using a linear density approximation Type A) has shown that a stable multiport diffuser flow class MS results for this case. The reader is encouraged to ascertain that! Thus, CORJET is indeed applicable for this case.

Table E.1 shows the input data file as prepared externally using a line editor. The CORJET prediction file is shown in Table E.2. The file echoes the input data, but also lists the computed density values, and all important parameters and non-dimensional numbers. Note that all parameters and scales are referenced to the values of ambient conditions <u>at the level of discharge</u>. The second half of the output table gives the predicted plume conditions.

CHECKLIST FOR DATA PREPARATION

CORJET -- CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.1

DOS File Name: CASE5MPD.INP   **Date:** 4/12/96
Prepared by: GHJ

Label: Case 5: MULTIPORT DIFFUSER, STRATIFIED, VARIABLE CURRENT

Fluid/Density:

Fluid: 1 (water) ~~2 (air)~~   Density specification: 1 (via temp./sal.) ~~2 (direct)~~   Number of ambient levels: 3 (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)	Velocity (m/s)	Angle of velocity (deg)
1	0	12.0	30.0	-	0.5	0
2	5	15.0	29.5	-	0.8	0
3	15	20.0	28.0	-	1.2	0

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
11	0.5	0.0	3.0	45.0	45.0

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m^3)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)
100	0	30.0	0.0	-	20.0	60.

Program Control:

Max. vertical distance (m): 30.0   Min. vertical distance (m): 0.0   Max. distance along trajectory (m): 200.0   Print intervals: (best 5 to 10) 10

Figure E.1: Data preparation checklist for CORJET simulation of multiport diffuser discharge into stratified coastal waters with arbitrary velocity distribution

Table E.1

CORJET input data file for multiport diffuser discharge into stratified coastal waters

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case5: MULTIPORT DIFFUSER: STRATIFIED, VARIABLE CURRENT
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (½):    Density option (½):    Ambient levels (1-10):
1              1                       3
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA     TA      SA      RHOA    UA      TAUA
1      0.     12.     30.             0.5     0.
2      5.     15.     29.5            0.8     0.
3      15.    20.     28.             1.2     0.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0     H0     U0     THETA0 SIGMA0 C0     KD     T0     S0     RHO0   LD     ALIGN
11     0.5    0.     3.0    45.    45.    100.   0.     30.    0.            20.    60.
#Program control:
#ZMAX  ZMIN   DISMAX NPRINT
30.    0.     200.   10
```

Table E.2

CORJET prediction file for multiport diffuser discharge into stratified coastal waters

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.1, April 1996
--------------------------------------------------------------------------
FILE NAME:                  post\cj\case5mpd.OUT
 Label/identifier:          Case5: MULTIPORT DIFFUSER: STRATIFIED, VARIABLE CU
 Time of CORJET run:        4/13/96--15:56:58

Ambient conditions:         No. of levels: 3   Fluid: Water    Density option: 1
   LEV      ZA       TA      SA    RHOA      UA     TAUA
    1       .00    12.00   30.00 1022.71     .50     .00
    2      5.00    15.00   29.50 1021.74     .80     .00
    3     15.00    20.00   28.00 1019.43    1.20     .00

Discharge conditions (metric):  For each port:
   D0       H0        U0    THETA0 SIGMA0     C0       KD       T0       S0      RHO0
   .500     .00      3.00   45.00   45.00 .10E+03 .00E+0    30.0       .0    995.65
 MULTIPORT DIFFUSER conditions:
   NOPEN    LD        SPAC   ALIGN    Q0total
     11    20.00      2.00   60.00    6.480 = .6480E+01

Program control:
   ZMAX     ZMIN    DISMAX  NPRINT
   30.00     .00    200.00      10

Flux variables (based on ambient at discharge level):   For each port:
 Q0     =  .589E+00  M0     =  .177E+01  J0     =  .153E+00  GP0    =  .259E+00
 QT0    =  .106E+02  QS0    = -.177E+02
 For multiport diffuser (per unit length):
 q0     =  .324E+00  m0     =  .972E+00  j0     =  .841E-01

Length scales (m) and parameters:    For each port:
 LQ     =       .44  LM     =      3.92  Lm     =      2.66  Lb     =      1.22
 Lmp    =      5.61  Lbp    =      6.71
 For multiport diffuser (per unit length):
 lQ=B   =      .108  lM     =      5.07  lm     =      3.89  lq*    =       .74
 lmp    =      8.16  lbp    =     10.37
 FR0    =      8.33  FR02   =     17.92  Fa     =      1.14  R      =      6.00
 (port)              (2-D slot)
Zone of flow establishment (m):
 LE     =      1.30  XE     =       .75  YE     =       .62  ZE     =       .86
 THETAE=      38.34  SIGMAE=      34.00  GAMMAE=      49.43

--------------------------------------------------------------------------
CORJET PREDICTION:                Stepsize =     .2659  Printout every  10 steps
 Individual jet/plumes before merging:
    X        Y        Z      Sc       Cc        B  |  DIST    Save     Gpc     dTc dSALc
    .00      .00      .00    1.0  .100E+03    .25|    .00     1.0  .26E+00  18.0-30.0
    .75      .62      .86    1.0  .100E+03    .25|   1.30     1.4  .27E+00  20.8-34.7
   2.80     1.50     2.27    3.0  .333E+02    .64|   3.96     4.6  .83E-01   5.2 -9.9
 Merging of individual jet/plumes to form plane jet/plume:
```

Horizontal jet/plume half-width BH = B + 10.00

4.26	1.78	2.85	4.5	.223E+02	.82	5.55	6.6	.54E-01	3.1	-6.5
5.31	1.84	3.01	6.3	.159E+02	.90	6.62	6.4	.38E-01	2.1	-4.7
7.96	1.88	3.22	7.4	.136E+02	1.09	9.27	7.5	.32E-01	1.6	-3.9
10.61	1.89	3.41	8.4	.118E+02	1.27	11.93	8.6	.28E-01	1.3	-3.4
13.26	1.89	3.59	9.5	.105E+02	1.45	14.59	9.7	.24E-01	1.1	-3.0
15.91	1.89	3.77	10.6	.940E+01	1.63	17.25	10.7	.21E-01	.8	-2.7
18.57	1.89	3.94	11.7	.852E+01	1.81	19.91	11.8	.19E-01	.6	-2.4
21.22	1.89	4.11	12.8	.779E+01	1.99	22.57	12.9	.17E-01	.5	-2.2
23.88	1.89	4.27	13.9	.717E+01	2.17	25.23	14.0	.15E-01	.3	-2.0
26.53	1.89	4.43	15.1	.664E+01	2.34	27.89	15.1	.14E-01	.2	-1.8
29.18	1.89	4.58	16.2	.619E+01	2.51	30.54	16.1	.13E-01	.1	-1.7
31.84	1.89	4.73	17.2	.580E+01	2.68	33.20	17.2	.12E-01	.0	-1.6
34.49	1.89	4.87	18.3	.545E+01	2.85	35.86	18.2	.11E-01	-.1	-1.5
37.15	1.89	5.01	19.4	.515E+01	3.02	38.52	19.3	.97E-02	-.2	-1.4
39.80	1.89	5.15	20.5	.488E+01	3.18	41.18	20.3	.89E-02	-.2	-1.3
42.46	1.89	5.28	21.5	.464E+01	3.34	43.84	21.4	.82E-02	-.3	-1.2
45.11	1.89	5.41	22.6	.443E+01	3.49	46.50	22.4	.75E-02	-.3	-1.1
47.77	1.89	5.53	23.6	.424E+01	3.64	49.15	23.4	.69E-02	-.4	-1.0
50.43	1.89	5.65	24.6	.407E+01	3.79	51.81	24.3	.63E-02	-.4	-1.0
53.08	1.89	5.77	25.6	.391E+01	3.94	54.47	25.3	.58E-02	-.5	-.9
55.74	1.89	5.88	26.5	.377E+01	4.08	57.13	26.2	.54E-02	-.5	-.9
58.39	1.89	5.99	27.5	.364E+01	4.22	59.79	27.1	.49E-02	-.6	-.8
61.05	1.89	6.09	28.4	.352E+01	4.35	62.45	28.0	.45E-02	-.6	-.8
63.71	1.89	6.20	29.3	.342E+01	4.48	65.11	28.9	.42E-02	-.6	-.7
66.36	1.89	6.29	30.1	.332E+01	4.61	67.77	29.7	.38E-02	-.7	-.7
69.02	1.89	6.39	31.0	.323E+01	4.73	70.42	30.5	.35E-02	-.7	-.7
71.68	1.89	6.48	31.8	.315E+01	4.85	73.08	31.3	.32E-02	-.7	-.6
74.34	1.89	6.57	32.6	.307E+01	4.96	75.74	32.1	.29E-02	-.8	-.6
76.99	1.89	6.65	33.3	.300E+01	5.07	78.40	32.8	.27E-02	-.8	-.6
79.65	1.89	6.74	34.1	.293E+01	5.17	81.06	33.5	.24E-02	-.8	-.6
82.31	1.89	6.81	34.8	.287E+01	5.27	83.72	34.2	.22E-02	-.9	-.5
84.97	1.89	6.89	35.5	.282E+01	5.37	86.38	34.9	.20E-02	-.9	-.5
87.62	1.89	6.96	36.1	.277E+01	5.46	89.03	35.5	.18E-02	-.9	-.5
90.28	1.89	7.03	36.7	.272E+01	5.54	91.69	36.1	.16E-02	-.9	-.5
92.94	1.89	7.09	37.3	.268E+01	5.62	94.35	36.6	.14E-02	-.9	-.5
95.60	1.89	7.16	37.8	.264E+01	5.70	97.01	37.1	.12E-02	-1.0	-.4
98.26	1.89	7.22	38.3	.261E+01	5.77	99.67	37.6	.11E-02	-1.0	-.4
100.91	1.89	7.27	38.8	.258E+01	5.83	102.33	38.1	.93E-03	-1.0	-.4
103.57	1.89	7.33	39.2	.255E+01	5.89	104.99	38.5	.80E-03	-1.0	-.4
106.23	1.89	7.38	39.6	.252E+01	5.95	107.65	38.9	.67E-03	-1.0	-.4
108.89	1.89	7.43	40.0	.250E+01	6.00	110.30	39.2	.56E-03	-1.1	-.4
111.55	1.89	7.47	40.3	.248E+01	6.04	112.96	39.5	.45E-03	-1.1	-.4
114.20	1.89	7.51	40.6	.246E+01	6.08	115.62	39.8	.35E-03	-1.1	-.4
116.86	1.89	7.55	40.8	.245E+01	6.11	118.28	40.0	.26E-03	-1.1	-.3
119.52	1.89	7.59	41.0	.244E+01	6.13	120.94	40.2	.17E-03	-1.1	-.3
122.18	1.89	7.62	41.1	.243E+01	6.15	123.60	40.3	.94E-04	-1.1	-.3
124.84	1.89	7.65	41.2	.243E+01	6.16	126.26	40.3	.23E-04	-1.1	-.3
125.90	1.89	7.66	41.2	.243E+01	6.15	127.32	40.3	-.35E-05	-1.1	-.3

Terminal level in stratified ambient has been reached. PROGRAM STOPS!

END OF CORJET PREDICTION: Total number of integration steps = 475

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Note: CORJET has been used outside the CORMIX system, assuming unlimited receiving water. Carefully examine all results for possible boundary effects due to surface, bottom, or lateral boundaries!

The CORJET program when called within the normal CORMIX installation after its execution automatically links to the graphics package CMXGRAPH so the user can inspect the predicted plume, rather than looking at the output file. Many graphics options (see Section 5.3) exist to fully evaluate the plume geometry and concentration distributions. Three examples of graphics output are shown in Figures E.2 and E.3.

Figure E.2 shows the plan view, side view, and side view along the trajectory, respectively, of the plume, all with a plot scale fixed to 1:1, i.e. undistorted. All these figures have been produced with the Postscript-file print option (I) of CMXGRAPH (in contrast to all the figures in Appendices B to D that were made with the screen print (C) option). Such an undistorted is always preferable for the viewer of such plots in order to get an unbiased picture of the mixing pattern. Note the merging of the individual jets in the plan view. Figure E.3 gives the concentration distribution along the plume centerline trajectory, showing the rapid drop-off in this jet mixing process.

E.2 Smoke plume in stratified atmosphere with skewed wind velocity

As mentioned in Section 6.1 CORJET is also applicable for atmospheric conditions in which case the concept of potential density based on the perfect gas equation with adiabatic conditions is employed. Furthermore, the wind conditions in the lower atmospheric boundary layer with its greater freedom laterally often has a skewed velocity distribution with different wind directions at different levels above the ground. This is the topic of this case study.

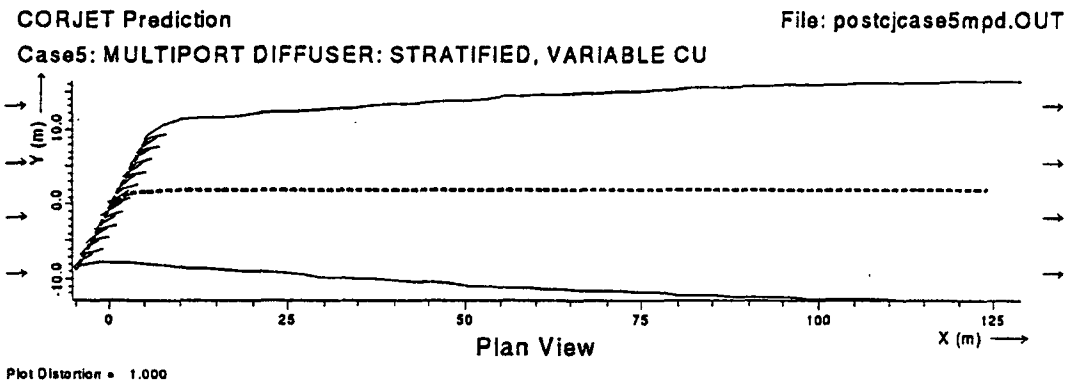
An industrial chimney with a height of 40 m above ground discharges hot gases at a temperature of 200 °C into the atmosphere. The discharge has a diameter of 3 m and an exit velocity of 10 m/s. A discharge concentration of 100 % exists for a fairly rapidly decaying substance with a decay rate of 1 per 10 min or 0.0028 /s.

Typical measurements, for example using a tracked rising balloon, give the distribution of temperature and wind velocity as a function of height above the ground. This is shown in the CORJET data preparation checklist given as Figure E.4. Density data is specified in this case as air temperature, the program will convert density inputs internally to potential density as a function of temperature. The wind velocity vector with increasing height deviates increasingly from the direction at ground level. In this example the coordinate system has been set at ground level so that the chimney (i.e."port") height is equal to 40 m.

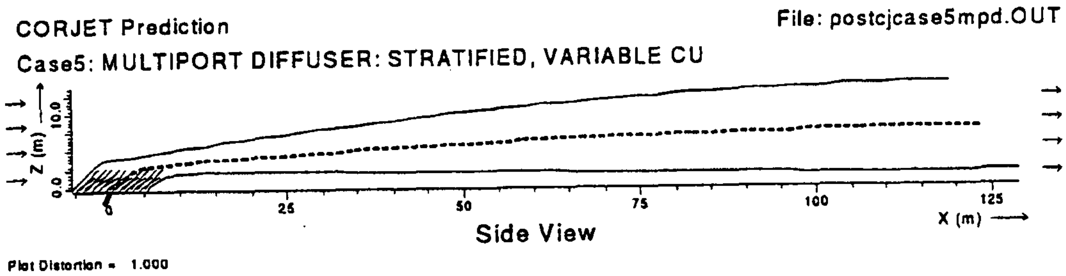
Table E.3 shows the input data file for this case, while Table E.4 is the CORJET prediction file. The file echoes the input data, but also lists the potential density values, and all important parameters and non-dimensional numbers.

Predicted plume properties are shown graphically as Figures E.5 and E.6. Figure E.5 shows the plan view and the side view, respectively, of the plume, both with a plot scale fixed to 1:1, i.e. undistorted. The plan view shows that the plume follows the variable direction of the wind as it rises to higher levels.

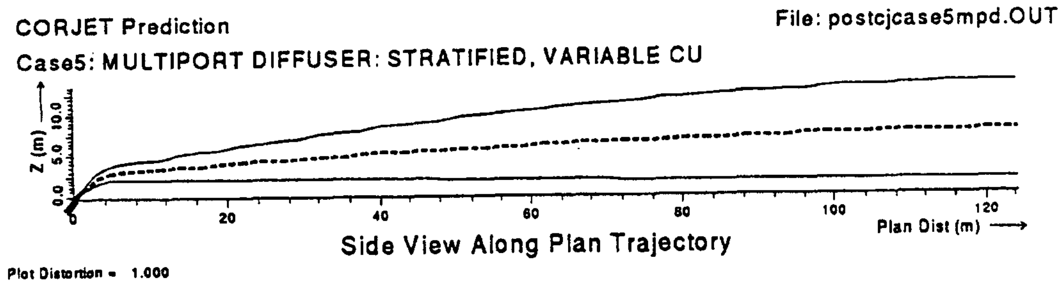
Figure E.6 gives the concentration distribution along the plume centerline trajectory. The added effect of plume decay would be discernible only in the detailed output file (Table E.4) where the centerline concentration is not merely the inverse of the hydrodynamic centerline dilution (the effect of pure mixing) but lower because of the internal chemical decay effect.



(a)



(b)



(c)

Figure E.2: CORJET prediction for multiport diffuser discharge into stratified coastal waters as plotted with graphics package. a) Plan view, b) side view, and c) side view along trajectory both with plot scale fixed at 1:1 (undistorted).

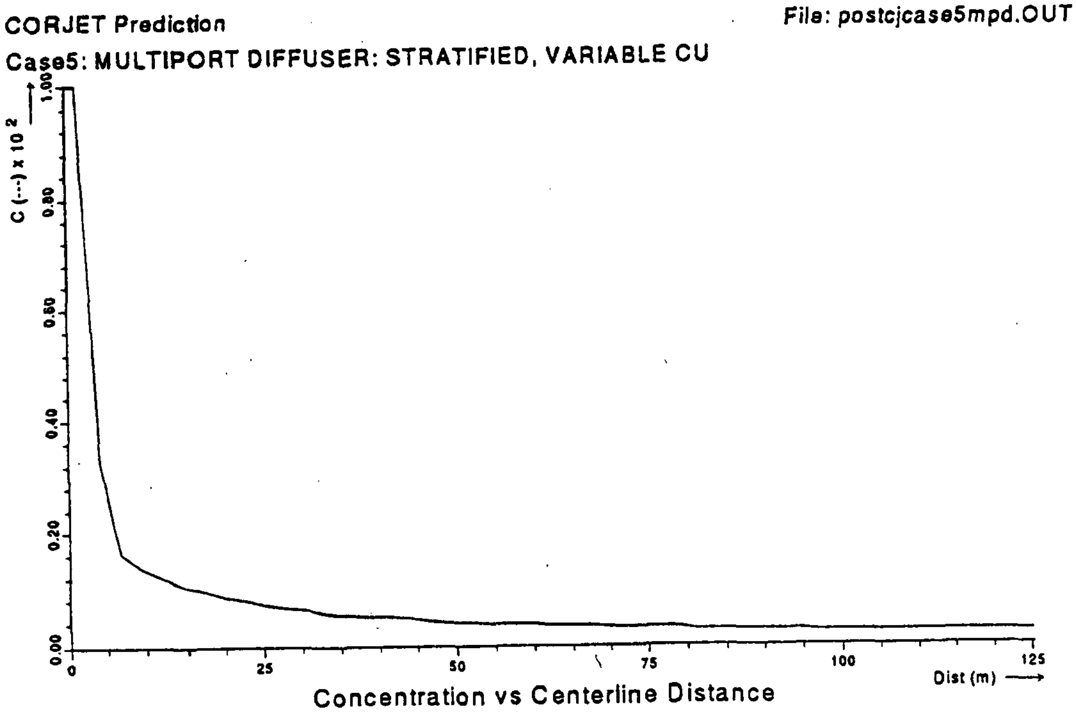


Figure E.3: CORJET prediction for multiport diffuser discharge into stratified coastal waters as plotted with graphics package. Concentration along centerline trajectory.

CHECKLIST FOR DATA PREPARATION

CORJET -- CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.1

DOS File Name: CASE3AIR.INP

Date: 4/12/96
Prepared by: GHJ

Label: Case 3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND

Fluid/Density:

Fluid: ~~1 (water)~~ 2 (air)   Density specification: 1 (via temp./~~sal.~~) ~~2 (direct)~~   Number of ambient levels: 4 (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)	Velocity (m/s)	Angle of velocity (deg)
1	0	12.0	-	-	2.0	0
2	50	12.0	-	-	5.0	15
3	100	12.5	-	-	6.0	25
4	200	13.0	-	-	6.5	30

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
1	3.0	40.0	10.0	90.0	0.0

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m^3)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)
100	0.0028	200.	-	-	0.0	0.0

Program Control:

Max. vertical distance (m): 200   Min. vertical distance (m): 0   Max. distance along trajectory (m): 1000   Print intervals: (best 5 to 10) 30

Figure E.4: Data preparation checklist for CORJET simulation of chimney discharge into stratified atmosphere with skewed wind velocity distribution

Table E.3
CORJET input data file for chimney discharge into stratified atmosphere with skewed wind

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (1/2):    Density option (1/2):    Ambient levels (1-10):
2               1                        4
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA      TA      SA     RHOA    UA      TAUA
1      0.      12.0                   2.0     0.
2      50.     12.0                   5.0     15.
3      100.    12.5                   6.0     25
4      200.    13.0                   6.5     30.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0    H0     U0     THETA0 SIGMA0 C0     KD     T0     S0     RHO0    LD    ALIGN
1      3.0  40.    10.0   90.    0.     100.   .0028  200.                  0.    0.
#Program control:
#ZMAX  ZMIN   DISMAX NPRINT
200.   0.     1000.  30
```

Table E.4
CORJET prediction file for chimney discharge into stratified atmosphere with skewed wind

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL           Version 4.1, April 1996
-----------------------------------------------------------------------------
FILE NAME:                  post\cj\case3air.OUT
 Label/identifier:          Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND
 Time of CORJET run:         4/13/96--16:12:15

Ambient conditions:         No. of levels: 4    Fluid: Air      Density option: 1
   LEV      ZA        TA       SA    RHOA       UA    TAUA
    1        .00     12.00      .00    1.24     2.00      .00
    2      50.00     12.00      .00    1.24     5.00    15.00
    3     100.00     12.50      .00    1.24     6.00    25.00
    4     200.00     13.00      .00    1.23     6.50    30.00

Discharge conditions (metric):  SINGLE PORT
   D0       H0        U0    THETA0 SIGMA0     C0       KD      T0      S0       RHO0
   3.000  40.00     10.00  90.00     .00 .10E+03 .28E-0  200.0      .0        .75

Program control:
   ZMAX     ZMIN   DISMAX  NPRINT
  200.00     .00 1000.00      30

Flux variables (based on ambient at discharge level):
 Q0    =  .707E+02  M0    =  .707E+03  J0    =  .275E+03  GP0    =  .390E+01
 QT0   =  .133E+05  QS0   =  .000E+00

Length scales (m) and parameters:
 LQ    =      2.66  LM    =      8.26  Lm    =       6.04  Lb     =      3.23
 Lmp   =     11.97  Lbp   =     14.42
 FR0   =      2.92  R     =      2.27
Zone of flow establishment (m):
 LE    =       .00  XE    =       .00  YE    =        .00  ZE     =     40.00
 THETAE=     41.69  SIGMAE=     12.00  GAMMAE=      41.69
-----------------------------------------------------------------------------
CORJET PREDICTION:                Stepsize =     .6042  Printout every  30 steps
 Single jet/plume:
    X        Y       Z       Sc       Cc       B  |  DIST    Save    Gpc    dTc dSALc
     .00      .00  40.00    1.0  .100E+03  1.50 |     .00    1.0  .39E+01188.0    .0
     .00      .00  40.00    1.0  .100E+03  1.50 |     .00    1.4  .41E+01204.4    .0
   15.18     3.42  49.21    4.5  .221E+02  3.53 |   18.13    6.6  .12E+01 41.6    .0
   31.38     7.54  56.20    9.6  .104E+02  5.18 |   36.25   13.8  .63E+00 19.5    .0
   47.86    12.09  62.22   15.8  .634E+01  6.64 |   54.38   22.5  .39E+00 11.8    .0
   64.47    16.97  67.60   22.7  .440E+01  7.96 |   72.51   32.2  .27E+00  8.1    .0
```

81.13	22.13	72.51	30.3	.330E+01	9.18	90.64	42.8	.20E+00	6.0	.0
97.83	27.54	77.06	38.4	.260E+01	10.30	108.76	54.0	.16E+00	4.7	.0
114.52	33.18	81.30	47.0	.213E+01	11.36	126.89	65.8	.13E+00	3.8	.0
131.21	39.03	85.29	55.9	.179E+01	12.35	145.02	78.1	.11E+00	3.1	.0
147.88	45.08	89.05	65.1	.154E+01	13.29	163.15	90.7	.90E-01	2.6	.0
164.52	51.31	92.63	74.5	.134E+01	14.18	181.27	103.7	.77E-01	2.3	.0
181.14	57.72	96.03	84.2	.119E+01	15.02	199.40	116.9	.67E-01	2.0	.0
197.71	64.29	99.27	94.0	.106E+01	15.83	217.53	130.4	.58E-01	1.7	.0
214.26	71.02	102.38	103.9	.963E+00	16.60	235.66	144.1	.52E-01	1.5	.0
230.77	77.88	105.37	113.8	.879E+00	17.35	253.78	157.8	.47E-01	1.4	.0
247.25	84.85	108.25	123.7	.808E+00	18.06	271.91	171.7	.42E-01	1.2	.0
263.71	91.92	111.04	133.8	.747E+00	18.75	290.04	185.6	.39E-01	1.1	.0
280.14	99.07	113.75	143.9	.695E+00	19.42	308.17	199.6	.35E-01	1.0	.0
296.56	106.30	116.39	154.1	.649E+00	20.07	326.29	213.7	.32E-01	.9	.0
312.96	113.58	118.96	164.4	.608E+00	20.71	344.42	228.0	.30E-01	.9	.0
329.34	120.93	121.47	174.7	.572E+00	21.33	362.55	242.3	.27E-01	.8	.0
345.70	128.34	123.91	185.1	.540E+00	21.93	380.67	256.7	.25E-01	.7	.0
362.05	135.79	126.30	195.6	.511E+00	22.52	398.80	271.1	.23E-01	.7	.0
378.39	143.29	128.64	206.1	.485E+00	23.10	416.93	285.7	.22E-01	.6	.0
394.72	150.83	130.92	216.6	.462E+00	23.66	435.06	300.2	.20E-01	.6	.0
411.03	158.41	133.16	227.2	.440E+00	24.21	453.18	314.8	.19E-01	.5	.0
427.33	166.03	135.35	237.8	.421E+00	24.75	471.31	329.5	.17E-01	.5	.0
443.62	173.69	137.49	248.4	.403E+00	25.28	489.44	344.1	.16E-01	.5	.0
459.90	181.39	139.58	259.0	.386E+00	25.80	507.57	358.8	.15E-01	.4	.0
476.17	189.11	141.64	269.6	.371E+00	26.31	525.69	373.5	.14E-01	.4	.0
492.43	196.87	143.65	280.3	.357E+00	26.80	543.82	388.1	.13E-01	.4	.0
508.68	204.66	145.62	290.9	.344E+00	27.29	561.95	402.7	.12E-01	.3	.0
524.92	212.48	147.54	301.4	.332E+00	27.76	580.08	417.3	.11E-01	.3	.0
541.15	220.33	149.43	312.0	.321E+00	28.23	598.20	431.9	.10E-01	.3	.0
557.37	228.20	151.28	322.5	.310E+00	28.68	616.33	446.4	.95E-02	.3	.0
573.58	236.11	153.10	333.0	.300E+00	29.13	634.46	460.9	.88E-02	.3	.0
589.79	244.03	154.87	343.5	.291E+00	29.57	652.59	475.2	.81E-02	.2	.0
605.98	251.98	156.61	353.8	.283E+00	30.00	670.71	489.6	.74E-02	.2	.0
622.17	259.96	158.31	364.2	.275E+00	30.42	688.84	503.8	.68E-02	.2	.0
638.36	267.96	159.98	374.4	.267E+00	30.83	706.97	517.9	.63E-02	.2	.0
654.53	275.98	161.61	384.6	.260E+00	31.23	725.09	532.0	.57E-02	.2	.0
670.69	284.03	163.21	394.8	.253E+00	31.62	743.22	545.9	.52E-02	.2	.0
686.85	292.09	164.77	404.8	.247E+00	32.01	761.35	559.7	.47E-02	.1	.0
703.01	300.18	166.30	414.8	.241E+00	32.39	779.48	573.4	.42E-02	.1	.0
719.15	308.28	167.79	424.6	.235E+00	32.76	797.60	587.0	.38E-02	.1	.0
735.29	316.41	169.25	434.4	.230E+00	33.12	815.73	600.4	.34E-02	.1	.0
751.42	324.56	170.68	444.1	.225E+00	33.47	833.86	613.8	.30E-02	.1	.0
767.54	332.72	172.08	453.6	.220E+00	33.82	851.99	626.9	.26E-02	.1	.0
783.66	340.90	173.44	463.1	.216E+00	34.16	870.11	639.9	.22E-02	.1	.0
799.77	349.10	174.77	472.5	.212E+00	34.49	888.24	652.8	.18E-02	.1	.0
815.88	357.32	176.07	481.7	.208E+00	34.81	906.37	665.5	.15E-02	.0	.0
831.98	365.55	177.34	490.8	.204E+00	35.13	924.50	678.0	.12E-02	.0	.0
848.07	373.80	178.57	499.8	.200E+00	35.43	942.62	690.3	.87E-03	.0	.0
864.16	382.07	179.78	508.6	.197E+00	35.73	960.75	702.5	.57E-03	.0	.0
880.24	390.35	180.95	517.4	.193E+00	36.03	978.88	714.5	.29E-03	.0	.0
896.32	398.65	182.09	525.9	.190E+00	36.31	997.01	726.2	.15E-04	.0	.0
897.39	399.20	182.17	526.5	.190E+00	36.33	998.21	727.0	-.19E-05	.0	.0

Terminal level in stratified ambient has been reached.   PROGRAM STOPS!

END OF CORJET PREDICTION: Total number of integration steps = 1653

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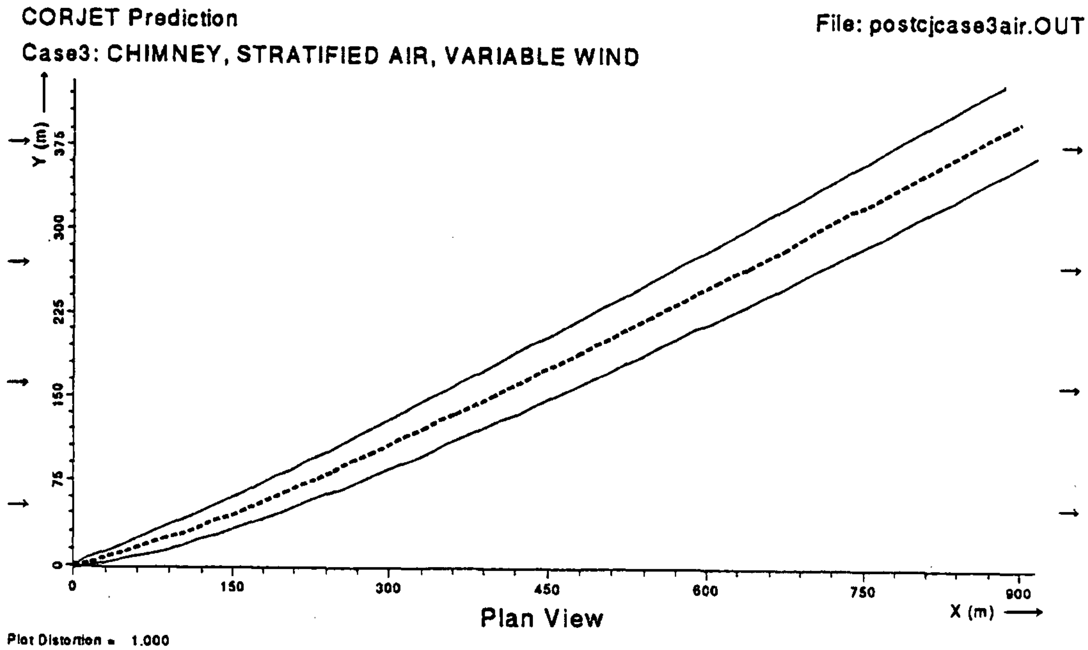
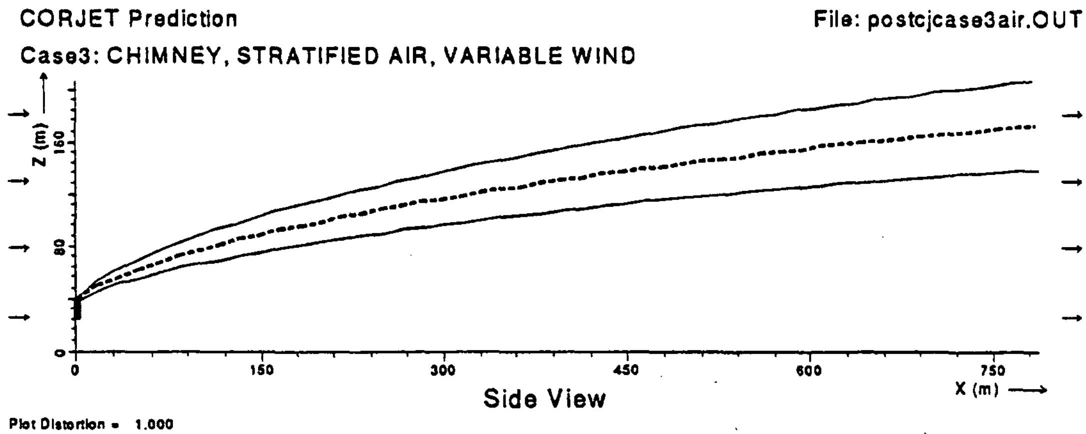


(a)



(b)

Figure E.5: CORJET prediction for chimney discharge into stratified atmosphere with skewed wind profile as plotted with graphics package. a) Plan view, and b) side view along trajectory both with plot scale fixed at 1:1 (undistorted).

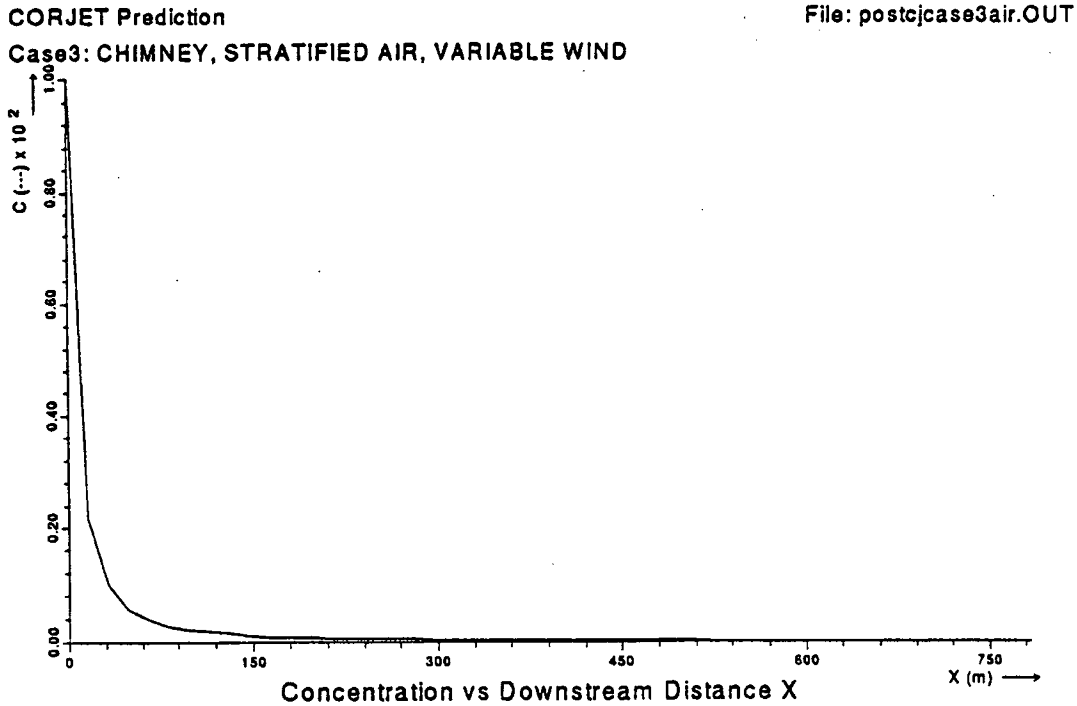


Figure E.6: CORJET prediction for chimney discharge into stratified atmosphere with skewed wind profile as plotted with graphics package. Concentration along centerline trajectory.

TVA **NPG Standard Programs and Processes**	**TITLE** **Fleet Ground Water Protection Program**	**SPP-5.15** **Rev. 0000** **Page 1 of 23** Quality Related ☐ Yes ☑ No Effective Date 12-19-2008

Responsible Peer Team/Working Group: Chemistry

Approved by:	William A. Nurnberger III	12-16-08
	Corporate Functional Manager	Date

Revision Log

Revision or Change Number	Effective Date	Affected Page Numbers	Description of Revision/Change
0	12/19/08	All	Initial issue.

Table of Contents

1.0 PURPOSE

A. The purpose of this Standard Program and Process is to define the essential elements of the TVA Nuclear Power Group (NPG) Ground Water Protection Program (GWPP) which implements the requirements specified in NEI 07-07. The fleet GWPP provides guidance and instructions for implementing requirements of the Nuclear Energy Institute's Industry Ground Water Protection Initiative - Final Guidance Document (August 2007) in response to industry radiological ground water contamination. This document establishes for the sites a long-term ground water monitoring program as described in NEI 07-07, Objective 1.3.d.

B. The purpose of this procedure is to minimize the potential for inadvertent releases to the environment from plant activities. Implementation of this initiative demonstrates a commitment to the control of licensed material through prevention, early detection, and mitigation and remediation of impacts associated with potential ground water and subsurface contamination.

C. This procedure also incorporates as applicable the guidance set forth in the EPRI Report 1015118, Ground Water Protection Guidelines for Nuclear Power Plants, for implementing a ground water protection program.

2.0 SCOPE

A. This procedure is applicable to all plant activities which may involve the potential for radiological ground water contamination.

B. This procedure does not apply to the following:

1. Normal or routine planned radioactive releases that are managed in accordance with the Offsite Dose Calculation Manual (ODCM).
2. Planned or routine releases that are within the scope of the approved facility design or operation as provided in the License, Technical Specifications, ODCM, UFSAR, plant drawings, procedures, or related documents.
3. Radioactive material that is not licensed material.
4. Events that are reported under the Emergency Response Plan.

C. This procedure embodies the elements necessary to implement NEI 07-07. The appendices to this procedure are provided as guidance (one method) for satisfying the program requirements.

3.0 PROCESS

3.1 Roles and Responsibilities

3.1.1 Corporate Responsibilities

A. Technical Programs Reliability - Corporate Program Manager

1. Develops and maintains NPG GWPP programs and procedures.
2. Provides guidance, assistance, information and coordination for implementing and maintaining the NPG GWPP.
3. Ensures consistency and standardization in the implementation of the GWPP across NPG.
4. Provides governance and oversight for the site GWPP programs.
5. Provides technical assistance or guidance to the sites for significant ground water anomalies identified which may warrant prompt remediation or augmented resources.
6. Informs the sites of any significant GWPP related Operating Experiences (OEs) at other facilities.

B. Technical Programs Reliability - Environmental Radiological Monitoring and Instrumentation (ERMI) Manager

Provides support, guidance and assistance to NPG sites regarding analyses related to GWPP sampling.

C. Communications/Governmental Affairs

Notifies media and key stakeholders of events and unusual conditions in accordance with communication policies and plans.

D. Radiation Protection

1. Develops and maintains Radiation Protection departmental procedures to support and maintain NPG GWPP.
2. Provides guidance and assistance in the implementation of the GWPP across NPG.

3.1.2 Site Responsibilities

A. Site Chemistry Manager

1. Provides overall coordination for development and implementation of the GWPP at the site.
2. Develops and maintains the GWPP as prescribed in this procedure.

3.1.2 Site Responsibilities (continued)

3. Provides dose pathway analysis expertise for inadvertent ground water spills or leaks.

4. Provides technical support and assistance to the other site departments that periodically assess and effectively implement aspects of the GWPP.

5. Provides lead interface with contractors or vendors selected to support the GWPP sampling and analysis activities.

6. Supports Radiation Protection by providing response support for radioactive spills with the potential to impact ground water.

7. Supports Radiation Protection in performing internal and external communications of events or conditions in accordance with NPG procedure for communicating inadvertent radiological spills/leaks to outside agencies.

8. Ensures the implementation of all aspects of the GWPP, including onsite sampling, collection, analysis and transportation of ground water, water and material samples.

9. Ensures that monitoring wells be maintained.

10. Ensures that the characterization of site geology and hydrology is current based upon updated site conditions.

11. Coordinates and oversees programmatic self-assessments associated with the GWPP.

12. Provides contractor oversight, if applicable.

13. Prepares NRC 30-day written reports for onsite ground water sample results that exceed the criteria for REMP reporting for offsite water sample results, if required.

B. Site Radiation Protection Manager

1. Provides radiation protection program support including the incorporation of radiation protection controls into work activities, including outdoor operating and maintenance work with the risk of spilling or leaking radioactive material, and other activities that require radiological control aspects.

2. Maintains the files documentating any spills or leaks of licensed radioactive material that are important for decommissioning (e.g., 10 CFR 50.75(g)).

3. Responsible for implementing SPP-5.14, Guide for Communicating Inadvertent Radiological Spills/Leaks to Outside Agencies.

3.1.2 Site Responsibilities (continued)

C. Site Operations Manager

1. Reports spills, leaks or inadvertent releases of radioactive material to the environment and associated corrective actions that have been implemented to management and to the Radiation Protection and Chemistry Departments.

2. Incorporates leak reduction and detection practices into operational rounds, inspections and surveillance activities and procedures.

3. Identifies system line-ups/maintenance/testing which may result in radioactive releases to soil or ground water.

D. Site Engineering Manager

1. Ensures that plant construction and modification projects are evaluated to address and minimize the potential for impact of radioactive materials to ground water.

2. Ensures the performance of initial and periodic updates for risk assessments of Systems, Structures, and Components (SSCs) that are expected to contain licensed radioactive material that could impact ground water.

E. Site Maintenance Manager

1. Incorporates leak reduction practices and capture/collection techniques into maintenance, repairs, and construction projects and procedures to reduce the potential for radioactive materials reaching ground water.

3.2 Instructions

The primary elements of the NPG GWPP are prevention, early detection, and mitigation of impacts associated with potential subsurface and/or ground water contamination. The NPG GWPP includes the administration of the program through this procedure, SPP-5.14, Guide for Communicating Inadvertent Radiological Spills/Leaks to Outside Agencies, and RCDP-11, Protocol for Remediation of Inadvertent Spills or Leaks of Contaminated Liquids.

References to sections of NEI 07-07 are noted by [ ].

3.2.1 Prevention of Inadvertent Releases to Ground Water

The primary barrier against inadvertent releases of radioactive materials to ground water and the environment is to reduce the risk and potential from leakage from SSCs in the nuclear plant that contain or convey radioactive material and that can reach the environment and potentially get into ground water. This also includes work practices involving SSCs, temporary systems, or any equipment that contain or convey radioactive material that can reach the environment and potentially enter ground water.

A. Risk Assessments of Systems, Structures, and Components

3.2.1 Prevention of Inadvertent Releases to Ground Water (continued)

Engineering shall perform an evaluation of SSCs that contain or could contain licensed material and for which there is a credible mechanism for the licensed material to reach ground water. The evaluation shall include:

1. Identify each SSC that involves or could reasonably be expected to involve licensed material and for which there is a credible mechanism for the licensed material to reach ground water. [1.2.a]

2. Identify existing leak detection methods for each SSC that is identified in Step 3.2.1.A.1. [1.2.b]

3. The risk assessment of SSCs shall be reviewed every five years to evaluate if any modifications have been performed that may change the potential for contamination to reach ground water.

B. Risk Assessment of Work Practices

1. Work practices shall be evaluated that involve licensed material and for which there is a credible mechanism for the licensed material to reach ground water. Only those work practices that have a credible potential for causing or allowing the release of radioactive liquid to soil or ground water need to be considered. [1.2.b]

2. The evaluation of work practices shall be reviewed every five years to evaluate if any work practices have been revised that may change the potential for contamination to reach ground water.

C. Availability of Risk Assessments

Each site SSC risk assessment shall be readily available for review and use by applicable engineering, maintenance planning and other relevant site disciplines as a routine "ground water risk tool" for new designs, changes, or modifications, preventive maintenance work and for outage management planning. A database or spreadsheet should be used for the collection of data pertaining to SSCs to ensure that summary results are documented, retained, and readily retrievable.

3.2.2 Risk Reduction

Each site shall identify potential enhancements to reduce the risk of inadvertent releases to ground water. These enhancements may consider the following:

A. SSC modifications that would lower the risk of inadvertent releases from reaching ground water (e.g., enhancement to leak detection systems, resealing or paving surfaces, installing spill containment, capture devices for vents, drains, or overflows). [1.2.d]

B. Establish long- term programs to perform preventive maintenance or surveillance activities to minimize the potential for inadvertent releases of licensed materials due to equipment failure. [1.2.f]

3.2.2 Risk Reduction (continued)

C. Program enhancements such as surveillance or preventive maintenance which would lower the risk of inadvertent releases (e.g., additional or increased frequency of rounds, walkdowns, inspections, integrity testing, or equipment maintenance/replacement). [1.2.c]

3.2.3 Early Detection and Remediation

A. Site Hydrology and Geology

Each site shall ensure site characterization of geology and hydrology was performed providing an understanding of predominant ground water gradients onsite and immediately offsite based upon current site conditions. This includes:

1. A review of existing hydrologic and geologic studies, historical environmental studies, and permits or license related reports to assess the level of understanding of surface and ground water characteristics. [1.1.b]

2. An update, as necessary, of hydrologic and geologic studies (i.e., Site Conceptual Model) to determine predominant ground water flow characteristics and gradients based on current site design and environmental factors.

   a. The Site Conceptual Model (SCM) shall identify ground water flow characteristics and gradients. [1.1.a]

   b. The SCM shall take into consideration the existence of bodies of water such as holding ponds, cooling canals, wetlands or estuaries onsite and down-gradient from the site.

   c. The SCM shall address site-specific complexities in stratigraphy such as bedrock, clay lenses, geologic materials, or aquifers that may have the potential to affect contaminant flow.

3. Identification of potential pathways for ground water migration from onsite locations to offsite locations through ground water. This includes determining the source(s) of water that represent potential exposure to the public (e.g., drinking water, or food / feed irrigation water); both onsite and offsite including locations near the utility owned and controlled property. The uses of such water sources shall also be identified and documented in the ODCM. The Chemistry Manager should be notified if there are any changes which could impact the calculation of offsite dose to the public due to inadvertent releases to ground water. [1.1.c]

4. That the Updated Final Safety Analysis Report is in agreement with the characteristics the site hydrology and geology. [1.1.e]

5. A hydrogeologic evaluation review every five years by a qualified hydrogeologist or when the following occurs [1.1.d.]:

   a. Substantial onsite construction,

   b. Substantial disturbance of site property,

3.2.3 Early Detection and Remediation (continued)

c. Substantial changes in onsite or nearby offsite use of water, or

d. Substantial changes in onsite or nearby offsite pumping rates of ground water.

B. Ground Water Monitoring

System/component leak detection samples, monitoring wells, sentinel wells, and/or site boundary wells are used for timely detection to ensure a timely and effective response to inadvertent releases to the ground water. Monitoring locations should be selected to define both the horizontal and vertical ground water flow and concentrations.

1. The GWPP Monitoring Plan shall include the following constituents as a minimum:

   a. Monitoring locations

   b. Sampling frequencies

   c. Sampling protocols and/or procedures (See Appendix B) [1.3.c]

   d. Analytical protocols and/or procedures including sensitivity limits controlled by the Environmental Radiological Monitoring and Instrumentation (ERMI) Laboratory [1.3.c]

2. Each site shall establish an inspection and maintenance program for wells. Appendix A provides guidance for inspection and maintenance of ground water wells. [1.3.f]

3. A sampling schedule shall be established including periodic sampling for the following hard-to-detect radionuclides performed at least on an annual basis:

   a. Strontium-89

   b. Strontium-90

   c. Iron-55

   d. Nickel-63

   e. Gross alphas

The sampling for these radionuclides should be performed only on the highest activity wells, if new activity has been discovered, or activity of the well has increased by 50%. If the sampling is performed on the highest activity well on site and is within normal trending, the performance of the analysis should be performed at a minimum on an annual basis.

3.2.3 Early Detection and Remediation (continued)

C. Selection of Ground Water Monitoring Locations (See Appendix A)

Each site shall identify sampling locations for ground water and surface water monitoring. Sampling locations shall consider the following as a minimum: [1.3.a]

1. Use of the Site Conceptual Model to determine monitoring locations down gradient from the plant but within the site boundary. This would include:

   a. One or more wells down gradient of either SSCs that have the highest potential for offsite migration and impact to offsite ground water pathways. [1.3.b]

   b. One or more wells down gradient of existing plumes from historical radioactive spills or leaks.

2. Use of the ground water risk assessments to determine monitoring locations close to SSCs that have the highest potential for inadvertent releases that could reach ground water or where leak detection capability is limited. [1.3.b]

D. Site Chemistry shall assign a program manager to maintain a database with current monitoring well activity and monitor data to detect adverse trends which may indicate ground water contamination.

E. Remediation of Inadvertent Radioactive Releases

1. Any inadvertent spill or leak that can potentially affect ground water shall be documented in the Corrective Action Program and evaluated for remediation per corporate procedure RCDP-11. Forms SPP-5.14-1 and RCDP-11 Attachment B and details of any remedial action shall be included in the 10 CFR 50.75(g) report for the incident.

2. RCDP-11 provides the decision making protocol that is to be used to evaluate any remediation that may be required for an inadvertent spill or leak. The procedure includes the following:

   a. Determination of the volume of the spill, leak or release.

   b. Identification of the radioactive constituents and associated concentrations in the spill, leak, or release.

   c. Evaluation and documentation of any decommissioning impacts resulting from remediation activities or the absence thereof. [1.4.c]

   d. Initiation of communication/notification actions, if required, in accordance with SPP-5.14.

3. Each site shall perform an evaluation of the potential for detectible levels of licensed material resulting from planned releases of liquids and/or airborne materials.

3.2.4 Communications/Reports

A. Ground Water Protection Program Briefings

B. Initial and periodic briefings should be conducted of site specific GWPP programs with designated state and local officials. [2.1]

C. Communication of Inadvertent Radiological Spills/Leaks to Outside Agencies

Make informal communication as soon as practicable to appropriate officials as prescribed in SPP-5.14, Guide for Communicating Inadvertent Radiological Spills/Leaks to Outside Agencies. [2.2]

D. Reports

1. Thirty-Day Reports

a. Thirty-day reports to the NRC shall be submitted for any water sample result for onsite ground water that is or may be used as a source of drinking water that exceeds any of the criteria in the licensee's existing REMP as described in the ODCM. [2.3.a]

b. The 30-day special report should include:

(1) A statement that the report is being submitted in support of the GWPP.

(2) A list of the contaminant(s) and the verified concentrations.

(3) Description of the action(s) taken.

(4) An estimate of the potential or bounding annual dose to a member of the public.

(5) Corrective actions, if necessary, that will be taken to reduce the projected annual dose to a member of the public to less than the limits in 10 CFR 50 Appendix I. [2.3.b]

c. All written 30-day NRC reports shall be concurrently submitted to designated state/local officials. [2.3.c]

2. Annual Reporting

a. Ground water sample results that are taken in support of the GWPP but are not part of the REMP program are reported in the ARERR required by 10 CFR 50.36a(a)(2).

b. A description of all spills or leaks that were communicated per SPP-5.14 criteria shall be included in the ARERR.

3.2.5 Periodic Reviews, Assessments, and Audits

A. Self-Assessments

1. Periodic self-assessments of the Ground Water Protection Program shall be performed at least every five years after the initial self-assessment. [1.3.g, 3.1b]

2. Self-assessments shall be performed and documented per SPP-1.6, NPG Self-Assessment and Benchmarking Program. [3.1e]

B. Periodic Reviews

1. The laboratories providing the analytical services shall be periodically reviewed every 3 to 5 years for its analytical capabilities and turn-around times. [1.3.e]

2. The evaluation of SSCs and work practices shall be periodically reviewed and updated every 3 to 5 years. [1.2.g]

3. A review of the Ground Water Protection Program shall be performed under the auspices of NEI by an independent, knowledgeable individual within one year of the initial self-assessment prescribed in 3.2.5.A.1. [3.2.a]

4. A periodic review of the Ground Water Protection Program shall be performed under the auspices of NEI every 5 years, subsequent to the license's periodic self-assessment performed per 3.2.5.A.2. [3.2.b]

C. Review of Site Hydrogeological Study [1.1.d]

Each site shall periodically (every 5 years) have a qualified hydrogeologist review the site hydrogeological studies for changes which could impact ground water movement. Exceptions to this requiring a more frequent review include:

1. Substantial onsite construction

2. Substantial disturbance of site property

3. Substantial changes in onsite or nearby offsite use of water

4. Substantial changes in onsite or nearby offsite pumping rates for ground water

5. Absent of any of the above activities, a periodic review of the Site Conceptual Model shall be performed every five (5) years.

4.0 RECORDS

4.1 QA Records

4.1.1 NRC Record Keeping Requirements for 10 CFR 50.75(g)

Provide documentation for spills with the potential to release plant-related radionuclides to the environment, and other subsurface contaminating events. An estimate of the date, location, volume, quantity of radioactivity, and any remedial actions shall be included for all documented spills. Such information shall be filed in the site 10 CFR 50.75(g) file in accordance with NPG recordkeeping procedures. [1.5.a]

4.1.2 NPG Sampling Records for GWPP

Ground water monitoring data submitted as part of the Annual Radiological Environmental Operating Report for REMP or Annual Radioactive Effluent Release Report as required by 10 CFR 50.36a (a)(2) for RETS or other monitoring well data that is routinely or especially taken to support the ongoing monitoring of contamination in ground water should be managed to ensure that results are documented, retained, and readily retrievable.

4.1.3 Ground Water Protection Program Compliance

Records demonstrating compliance with the Ground Water Protection Program including:

A. Attachment 1, SPP-5.14-1, Response to Contaminated Spills/Leaks

B. Appendix B, RCDP-11, Risk/Cost Benefit Analysis Worksheet

C. Thirty-day and annual reports

D. Self-Assessments

E. Monitoring well data spreadsheets

F. Inspection reports

4.2 Non-QA Records

None

5.0 DEFINITIONS

AREOR - Annual Radiological Environmental Operating Report - summarizes the results of the Radiological Environmental Monitoring Program. (REMP).

ARERR - Annual Radioactive Effluent Release Report - required by 10 CFR 50.36a (a)(2) - summarizes the releases of liquid, airborne, and solid wastes from the facility and provides the calculated doses attributable to those releases.

Ground water - any subsurface water, whether in the unsaturated or vadose zone, or in the saturated zone of the earth.

5.0 DEFINITIONS (continued)

Licensed Radioactive Material - Source material, special nuclear material, or byproduct material received, possessed, used, transferred or disposed of under a general or specific license issued by the Nuclear Regulatory Commission.

Site Conceptual Model (SCM) - A unifying hypothesis to describe how a contaminant release may be observed and measured currently in the site environment, and to identify the ultimate fate of the contaminant in the future. The model incorporates what is known about a site's hydrology, existing and past site activities that may have resulted in contaminant releases, the contaminants of concern, their fate and transport within the environment, and the receptors of those contaminants.

Spill or Leak - an inadvertent event or perturbation in a system, structure or component's performance resulting in a release of radioactive material. This event threshold is intended to ensure that State/Local stakeholders are made aware that there has been an event of interest at the site and to keep them apprised of the licensee's action to contain and, as needed, remediate the event. Spill or leak events that meet the criteria stated in SPP-5.14 shall be communicated regardless of whether or not the onsite ground water is, or could be used as, a source of drinking water.

Surface Water - Water within streams, rivers, lakes, reservoirs, discharge canals, cooling towers, retention ponds, water from precipitation events, wetlands, estuaries, and oceans.

Vadose Zone - The subsurface zone where earth materials are not saturated.

Wells - A borehole drilled in the earth and lined, either partially or entirely, with a casing to stabilize and isolate one or more sections of the borehole. Types of wells employed in ground water protection include monitoring wells, sentinel wells, investigation wells, intercept wells, remediation wells, and site boundary wells.

A. Investigation Well

A ground water well that is used to perform limited sample collection to support a hydrogeological survey.

B. Monitoring Well

A ground water well that is used to monitor the transport and tritium concentration of a known plume of contaminated ground water.

C. Remediation Well

A ground water well that is used to remove contaminated water to reduce the concentration of tritium or other radionuclides to a predetermined level.

D. Sentinel Well

Ground water wells that are sampled on a frequent basis established by site procedures and designed to monitor SSCs that have been assessed to present an increased risk of inadvertent releases of contaminated substances into the environment.

6.0 REQUIREMENTS AND REFERENCES

NEI 07-07, Industry Ground Water Protection Initiative - Final Guidance Document, Nuclear Energy Institute, Washington, D.C., August 2007

EPRI Report 1015118, Ground Water Protection Guidelines for Nuclear Power Plants, Electric power Research Institute, Palo Alto, CA, November 2007

USNRC Title 10, Code of Federal Regulations Part 50.75 (g), (10 CFR 50.75(g)), United States Nuclear Regulatory Commission, Washington D.C.

USNRC Title 10, Code of Federal Regulations, Part 20, United States Nuclear Regulatory Commission, Washington D.C.

Regulatory Guide 1.21, Measuring, Evaluating, and Reporting Radioactivity in Solid Wastes and Releases of Radioactive materials in Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants, Revision 1

Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through normal Operations to License Termination) - Effluent streams and the Environment, Revision 1

Standard Programs and Processes SPP-5.14, Guide for Communicating Inadvertent Radiological Spills/Leaks to Outside Agencies

ASTM D4448, Standard Guide for Sampling Ground-Water Monitoring Wells

Business Practice 122, Governance System

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Guidance for Ground Water and Surface Water Monitoring Locations

This appendix contains guidance for selecting monitoring locations to be included in the site ground water monitoring plan. Monitoring locations are selected for sample collection and analysis. Monitoring locations can include ground water wells and surface water, as appropriate to each site.

1.0 MONITORING LOCATIONS

The selection of ground water and surface water monitoring locations depends on the specific site hydrogeological characteristics and takes into consideration the location of risk significant systems, structures and components (SSCs) and past radiological releases. The objectives of ground water monitoring include the following:

A. Detecting leakage from high risk SSC as early as practical to allow mitigation and remediation actions

From the system, structures, and component (SSC) and work practice assessments, identification of where ground water impacts may result from leaks, spills, or the existence of an unanalyzed pathway from an SSC. Using the ground water information from the Site Conceptual Model (SCM), wells located near and down gradient from an SSC could provide early indication of a leak, spill, or unmonitored leakage pathway. The quantity and depth of these wells would be dependent on the SSC and the area ground water characteristics.

B. Monitoring the migration of existing and potential plumes

For sites with existing or potential future sub-surface and/or ground water contamination, movement of any plumes should be monitored. Using the ground water characteristics from the SCM, wells located in the predicted flow path could provide confirmation of plume movement and velocity. The quantity and depth of these wells would be dependent on the expected plume size and the ground water characteristics.

For sites with onsite drinking water wells within the predicted flow path of a potential ground water contaminant plume, monitoring wells should be placed up gradient from these drinking water wells to monitor potential impacts.

C. Detecting radioactive constituents in ground water prior to migration offsite

Ground water monitoring wells should be located onsite (e.g., at or near the site boundary) in an up gradient direction between the plume and the site boundary to detect the presence of radioactive constituents in ground water prior to its movement offsite. The quantity and depth of these wells would be dependent on the expected plume size and the ground water characteristics.

For sites with offsite drinking water wells within the projected flow path of a potential ground water contaminant plume, monitoring wells should be placed onsite, up gradient from these drinking water wells to monitor potential impacts.

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Guidance for Ground Water and Surface Water Monitoring Locations

2.0 GROUND WATER MONITORING WELLS

Wells are boreholes drilled in the earth and lined, either partially or entirely, with a casing to stabilize and isolate one or more sections of the borehole providing access to ground water for sampling and analysis. The specific configuration of any well is dependent on its intended use (e.g., monitoring, sentinel, investigatory). Consult a geoscientist to ensure the well design is appropriate for the intended application and to identify the appropriate state or local requirements for installation and documentation.

A. Wells in the Ground Water Monitoring Program

The following criteria should be considered in the selection of wells in the ground water monitoring program. The process should include determination and documentation of the following for each well in the monitoring program:

1. Purpose of the well
2. Design objectives for the well
3. Rationale for the well's location and depth
4. Types of ground water samples that will be colleted from the well
5. Types of analyses to be performed on the well samples
6. Intended use of the resulting investigative data

B. The following guidance is provided for the installation of wells

1. Wells should be installed and constructed under the supervision of a qualified hydrogeologist in accordance with applicable standards.
2. Wells should be installed with the appropriate size and depth to allow proper sampling.
3. Well construction details should be documented and retained. Details should contain the following as a minimum:
    a. Drilling method
    b. Total well depth
    c. Depth interval over which the well is open to the aquifer (screen zone)
    d. Approximate depth to ground water to the well. (Following installation, the top of casing elevation should be measured and recorded.)
    e. Type and thickness of any filter material adjacent to the screen zone

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Guidance for Ground Water and Surface Water Monitoring Locations

2.0 GROUND WATER MONITORING WELLS (continued)

f. Method of well development

g. Identify geological materials penetrated by wells

4. The design and construction of wells that were installed during previous hydrogeological studies and are to be used in the ground water monitoring plan should be reviewed for adequacy by a geoscientist.

C. Well Inspection and Maintenance

A program should be developed to maintain wells utilized in ground water monitoring. This program should address the following:

1. Physical inspections of wells annually including:

   a. Well pad

   b. Riser casing

   c. Grout seal

   d. Well cap, bolting, or locking mechanism

   e. Labeling

2. Periodically check for water turbidity and sediment buildup

   a. Water turbidity should be checked during sample extraction or annually as a minimum to confirm acceptability for analysis.

   b. Sediment buildup should be checked every three (3) years to confirm viability of well (i.e., check interference with screen area).

   c. Well re-development may be used to resolve turbidity and sediment buildup issues.

3. Perform maintenance on wells to restore to operating conditions

   a. Consult with qualified hydro-geologist for specific guidance for resolving well issues.

   b. Well maintenance and repairs should be performed by qualified or knowledgeable personnel in accordance with industry and EPA standards.

4. Wells which are no longer useful for their intended purpose shall be decommissioned or abandoned in accordance with state and local regulations.

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Guidance for Ground Water and Surface Water Monitoring Locations

2.0 GROUND WATER MONITORING WELLS (continued)

5. Inspection results and maintenance records should be maintained.

3.0 SURFACE WATER MONITORING

In addition to wells, surface water monitoring can be utilized to detect inadvertent leakage of radioactive materials. Surface water monitoring includes onsite surface water bodies (e.g., retention ponds, canals, wetlands), storm drains, berms, leak detection points, and other water collection / movement processes.

As with wells, the following criteria should be considered in the selection of surface water sampling locations. The process should include determination and documentation of the following for each location in the monitoring program:

A. Purpose of the surface water sample

B. Design objectives for the surface water sample

C. Rationale for the surface sample location

D. Constituents in the surface water that will be collected

E. Types of analyses to be performed on the surface water samples

F. Intended use of the resulting investigative data

Appendix B
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Guidance for Ground Water Sampling

The Ground Water Protection Monitoring Plan requires that periodic water samples be taken from monitoring wells and surface water for analysis. This appendix contains guidance for the sampling of ground water and surface water including sampling frequency, protocols / procedures for sampling, and control of samples.

The site procedures for ground water sampling shall comply with ASTM D 4448-01, Standard Guide for Sampling Ground-Water Monitoring Wells.

1.0 PURPOSE AND OBJECTIVES OF WELL SAMPLING:

The purpose and design objective should be documented for each monitoring, investigation, and sentinel well. For other sampling locations, such as surface water bodies, tell-tale points, berms, storm drains, and other onsite water collection / movement processes, the location's design objective and purpose should also be documented.

2.0 ANALYTE LIST

A. For each planned sample, identify the list of radionuclides targeted for identification and quantification in the analysis. The list should consider the following:

B. Radionuclides (past and present) contained in the system, structures, and components (SSCs) that are potential sources for ground water contamination.

C. Tritium should always be included.

D. Gamma emitting radionuclides should be considered on sentinel wells.

E. Radionuclides from historical onsite spills or leaks.

The analyte list should be periodically reviewed for the following:

- Changes in plant processes and/or source terms.
- Detection of contaminants at locations with no historical baseline.
- Deletion of radionuclides which historically have not been detected.

3.0 BACKGROUND AND BASELINE CONDITIONS

A. Monitoring locations should be evaluated for the potential of analytical complications due to pre-existing background concentrations of radionuclides. This would minimize the impact of false-positive indications near environmental minimum detectable concentrations (MDC). The results of this evaluation should be documented.

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Guidance for Ground Water Sampling

3.0 BACKGROUND AND BASELINE CONDITIONS (continued)

B. The presence of radionuclides in onsite ground water due to historical spills or leaks should be evaluated to establish a baseline for radionuclides and their expected concentrations at each monitoring location or area. The baseline is defined as the statistical mean of a minimum of 10 sample results. The threshold for action for future inadvertent leaks or spills and/or unplanned releases is defined as a sample result exceeding twice the standard deviation. The basis for establishing a baseline should be documented and include the following:

1. Documented evidence of previous spills or leaks.
2. Identification of radionuclides and their respective concentrations from both the original spill or leak and as currently projected.
3. An understanding of the ground water hydrology with respect to its direction and velocity of migration.
4. Documented sampling results over a 12 to 24 month period demonstrating continuity with projected or expected levels of radionuclides.

C. Sample frequency

NOTE

Sampling frequencies resulting from this protocol should not override existing "required" sampling frequencies; those sampling frequencies specified in Technical Specifications, Land Use Permits, NPDES Permits, etc. For those sampling locations, the following protocol would be a 'request an additional sample volume' for the GWPP.

1. All monitoring locations are sampled at least annually.
2. Increasing sampling frequency to quarterly if:
   a. The result is statistically greater than baseline and,
   b. No previous sample history nor expectation of results above baseline
3. Increase sampling frequency to monthly if:
   a. The quarterly result is statistically greater than baseline and, either
   b. The result indicate an unexplained, adverse (increasing) trend in three or more consecutive samples or

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Guidance for Ground Water Sampling

3.0 BACKGROUND AND BASELINE CONDITIONS (continued)

c. The result increased by a factor of three or more from the most recent sample result.

4. The result exceeds 20,000 pCi/l.

   Specific sampling frequency would be based on circumstances and should be determined by the plant conditions and understanding of the plume.

5. Sampling frequency in monitoring wells may be reduced to annual if two consecutive quarterly results are below minimum detection limits. This excludes sentinel wells.

6. "For Cause" sampling may be requested for the following:

   a. In response to a spill or system leakage.

   b. In response to an unexplained increase in activity.

7. The minimum sampling frequency for any sentinel well should not exceed one quarter.

D. Surface Water Sampling

1. Surface water sampling methods should be similar to those used in REMP sampling.

2. A dedicated grab sample may also be used for surface water sampling.

E. The site procedure shall prescribe the minimum sample volumes, container type, preservation, and handling requirements are based on the minimum detectible concentrations (MDCs) and laboratory protocols for a chosen analytical method.

10919

WR2005-1-36-132

EVALUATION OF THE 316(B) CLASSIFICATION OF THE SOURCE WATERBODY FOR THE KINGSTON FOSSIL PLANT

TVA

RIVER SYSTEM OPERATIONS & ENVIRONMENT
KNOXVILLE, TENNESSEE

TENNESSEE VALLEY AUTHORITY
River System Operations & Environment
River Scheduling

EVALUATION OF THE 316(b) CLASSIFICATION OF THE SOURCE WATERBODY FOR THE KINGSTON FOSSIL PLANT

WR2005-1-36-132

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July 2005

TVA

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EXECUTIVE SUMMARY

The purpose of this study is to determine the classification of the source waterbody for the Kingston Fossil Plant (KIF). This classification is required under Section 316(b) of the Clean Water Act to determine the required performance standard for the plant cooling water intake structure. That is, the waterbody type determines whether both impingement mortality and entrainment, or impingement mortality alone, must be considered. Depending on the waterbody classification, the standard for entrainment may or may not be applicable for the plant.

Maps of the TVA river system show that the KIF is located on Watts Bar Reservoir. However, the physical characteristics of the reservoir in the immediate vicinity of the plant appear to be riverine in nature. This includes the Emory River embayment, which is relatively narrow, much like a river. In this study, the appropriate classification of the source waterbody was determined by evaluating the hydrothermal and biological characteristics of the Emory River embayment and by seeing if they are river-like or reservoir-like in behavior.

For the hydrothermal characteristics, the behavior of stage, flow, and water temperature were evaluated. For stage, data and hydraulic modeling show that the lower 15 miles of the Emory River embayment is inundated and controlled by the impoundment created by Watts Bar Dam. In contrast, if the embayment existed as a river, the stage would be controlled almost exclusively by the magnitude of flow in the Emory River, as determined by runoff in the Emory River watershed. For flow, modeling results show that the Emory River embayment interacts with other parts of Watts Bar Reservoir by exchanging water with the Clinch River embayment and the main stem of the reservoir, which includes the Tennessee River and other small tributaries. If the embayment existed as a river, the flow would move consistently in the downstream direction with little or no exchange with other parts of Watts Bar Reservoir, and all of the KIF flow would be derived from the Emory River. For water temperature, the occurrence of stratification and other complex temperature-related density currents and mixing patterns suggest reservoir-like behavior. If the embayment existed as a river, the flow would tend to be well-mixed and uniform in temperature.

The biological characteristics of the KIF source waterbody were examined by comparing existing historical data for fish entrainment at KIF with the aquatic habitat found upstream in the free-flowing portion of the Emory River and with that found downstream in the main stem of Watts Bar Reservoir. The results show that fish species in the KIF intake flow were primarily of the type found in Watts Bar Reservoir, not the free-flowing portion of the Emory River. Only about 7 percent of the species occurring in the Emory River were found to be common to species entrained in the KIF intake flow (5 of 64 species). However, all fish entrained at the KIF intake were common Watts Bar Reservoir species. The aquatic biology, therefore, also supports a finding that the Emory River embayment is reservoir-like in behavior.

Altogether, therefore, based on the hydrothermal and biological characteristics of the Emory River embayment, TVA believes it is appropriate to classify the source waterbody for the KIF as a reservoir.

Determination of the 316(b) Classification of the Source Waterbody for Kingston Fossil Plant

INTRODUCTION

Maps of the TVA river system show that the Kingston Fossil Plant (KIF) is located on Watts Bar Reservoir. A diagram of Watts Bar Reservoir is shown in Figure 1. Given in Figure 2 is an aerial photo showing details of the reservoir in the immediate vicinity of the plant. The KIF intake is located on the Emory River embayment of the reservoir, about 1.9 miles upstream of the Clinch River embayment and about 6.3 miles upstream of the main stem of the reservoir on the Tennessee River. In terms of the overall extent of the reservoir, the intake is about 20.4 miles downstream from Melton Hill Dam, located on the upper end of the Clinch River embayment; 41.1 miles downstream of Fort Loudoun Dam, located on the upper end of the reservoir main stem; and 44.0 miles upstream of Watts Bar Dam, which is located on the Tennessee River and creates the impoundment.

The purpose of this study is to determine the classification of the source waterbody for KIF. Although KIF is located on Watts Bar Reservoir, the source waterbody does not appear at first glance to be a reservoir. This is because the geomorphology of the Emory River embayment upstream of KIF appears to be riverine in character. For example, the embayment is relatively narrow, much like a river. Also, since the intake is located on the Emory River embayment, one might think that the withdrawal is primarily from the Emory River and not other parts of Watts Bar Reservoir. The classification of the source waterbody is needed to establish the applicability of the performance standard for entrainment under Section 316(b) of the Clean Water Act. Specifically, the source waterbody needs to be classified either as a river or as a reservoir. Under the 316(b) rule, standards for entrainment must be applied for power plants on freshwater rivers, if these river intakes withdraw more than 5 percent of the mean annual flow of the river. In contrast, for reservoirs with a hydraulic retention time greater than 7 days, the entrainment standard does not apply. The hydraulic retention time for Watts Bar Reservoir is about 18 days; thus, if the KIF source waterbody is classified as a reservoir, the plant would not be subject to the entrainment performance standard.

In this study, the classification of the source waterbody is determined by examining the hydrothermal and biological characteristics of the Emory River embayment. The determination is based on whether these characteristics support river-like or reservoir-like behavior. To assess the hydrothermal characteristics, the properties of the stage, flow, and water temperature at KIF are examined. To assess the biological characteristics, the properties of the aquatic habitat and species are examined.

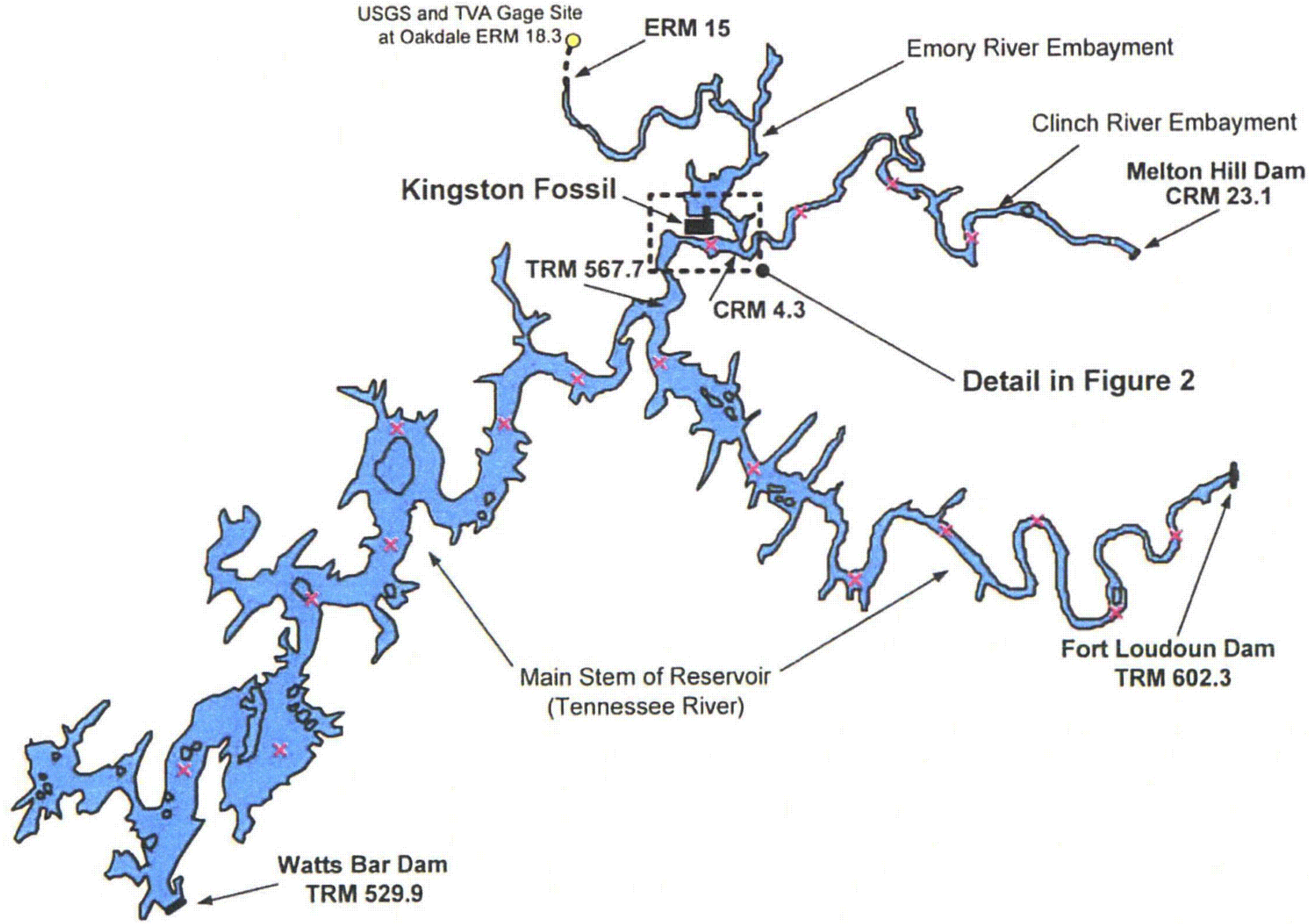

Figure 1. Watts Bar Reservoir

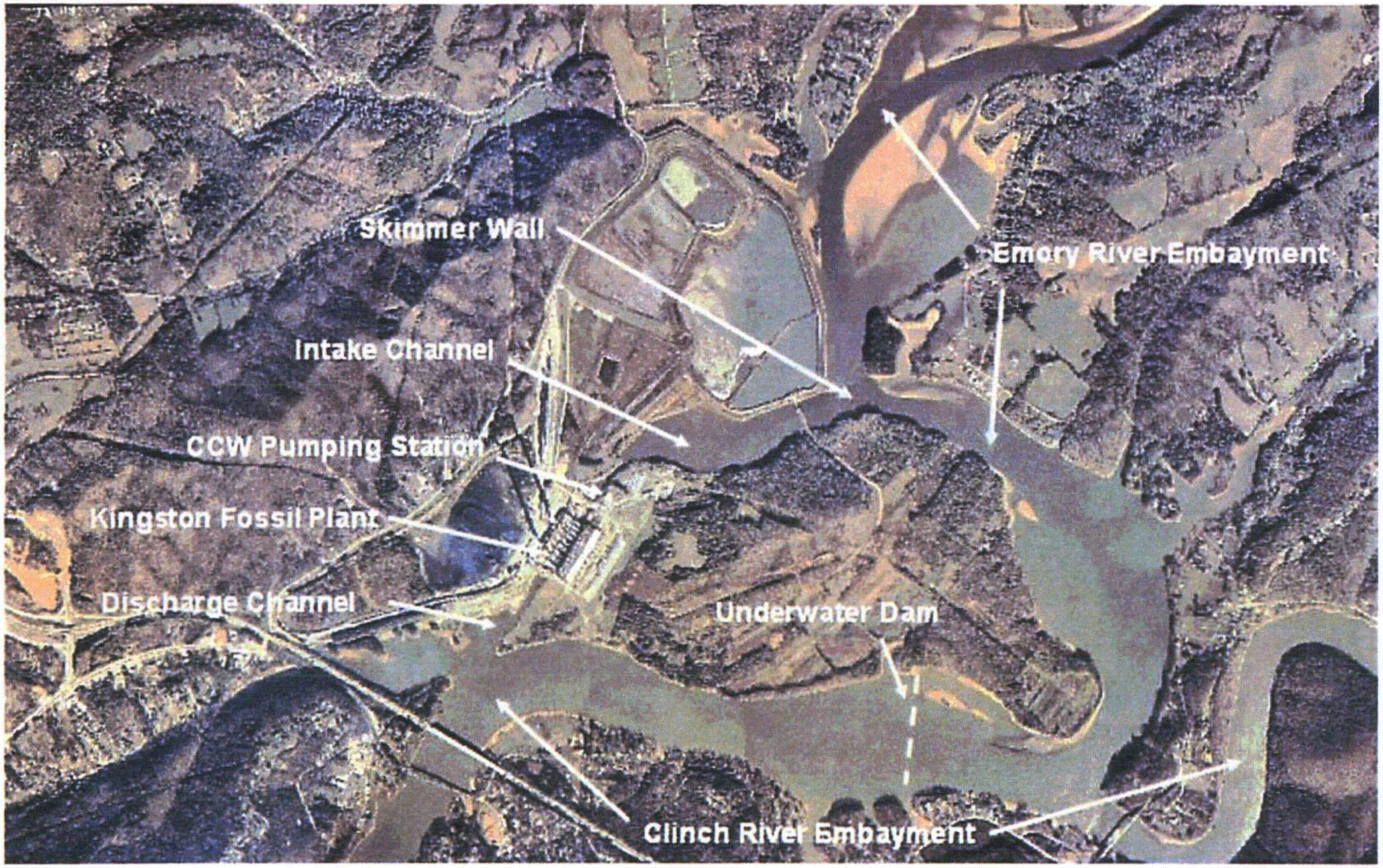

Figure 2. Source Waterbody at Kingston Fossil Plant

HYDROTHERMAL CHARACTERISTICS

Stage

The basic configuration of flow for KIF's cooling water is shown in Figure 2 (previously introduced). Condenser Cooling Water (CCW) is pumped into the plant through an intake channel connected to the source waterboby. After passing through the plant, the CCW effluent enters a discharge channel that returns the flow to the source waterbody about 4.0 miles downstream of the intake skimmer wall. Figure 3 is a schematic profile of the Emory River embayment and the lower portion of the Clinch River embayment. At the entrance to the plant intake channel, a concrete skimmer wall with a deep opening is provided to promote the withdrawal of cooler bottom water from the source waterbody. The elevation of the top of the skimmer wall opening is 715 feet mean sea level (msl). Furthermore, to help maintain a pool of cooler bottom water, an underwater dam with a crest at elevation 722 feet msl is provided about 2.4 miles downstream of the plant intake in the Clinch River embayment. The normal maximum and minimum pool elevations for Watts Bar Reservoir are 741 feet msl and 735 feet msl, respectively. Based on the TVA Reservoir Operation Study of 2004, except in extreme drought conditions, the pool elevation in Watts Bar Reservoir is not expected to fall below 735 feet msl. Under these conditions, the Emory River embayment at the KIF intake should almost always contain a pool that is at least 35 feet deep (see Figure 3).

Water surface elevation, or stage, is a good parameter for distinguishing between areas dominated by reservoir behavior, areas dominated by river behavior, and areas of transition between these two extremes. In flow-through waterways, areas dominated by reservoir behavior tend to have a stage that is strongly correlated with the stage at the control structure creating the impoundment. These areas reside within the "flat pool" region of the reservoir and tend to have a large depth compared to the tributaries that supply water to the impoundment. Beyond the limits of the flat pool, the hydraulic characteristics of the river start to become significant. This creates a transition between reservoir behavior and river behavior, usually characterized by a backwater profile that depends on both the reservoir conditions and the river conditions. In this region the water velocities are reduced from a momentum-dominated river flow to a slower, stage-dominated reservoir flow. Upstream, beyond the backwater region, river behavior dominates, wherein the stage depends primarily on local flow conditions and is independent of conditions further downstream (e.g., reservoir stage).

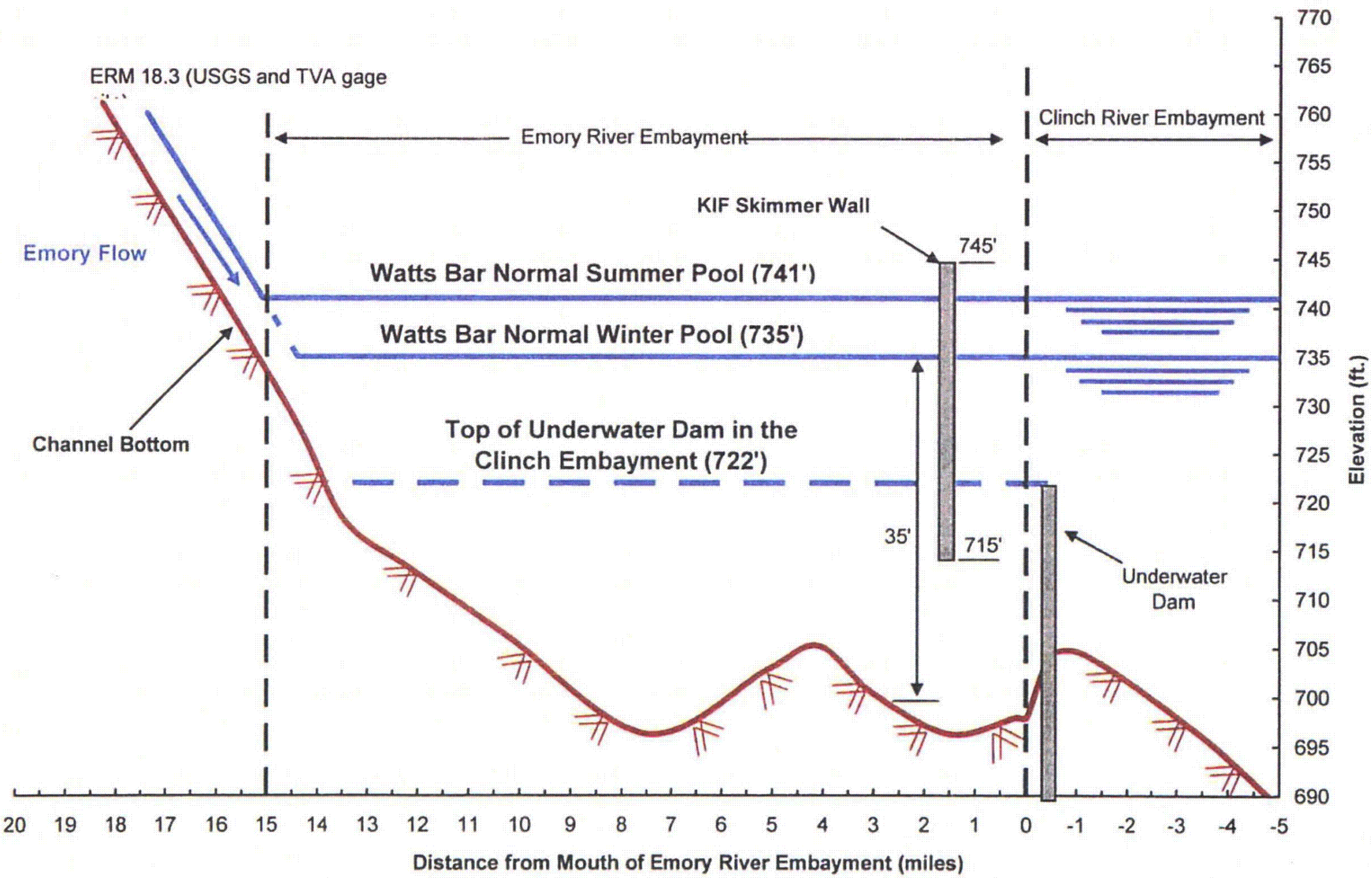

Figure 3. Profile of Source Waterbody at Kingston Fossil Plant

To determine the extent of flat pool behavior in the Clinch River embayment, stage data below Melton Hill Dam were compared to data for the water surface elevation in the forebay at Watts Bar Dam. To eliminate bias caused by local surge created by operation of the hydroturbines at Melton Hill Dam, stage data were examined for periods wherein generation at Melton Hill was not occurring for at least 12 hours (the stage below Melton Hill Dam is measured at the exit of the hydroturbines). Results for years 2000 through 2004 are given in Figure 4. As shown, the stage in the Clinch River below Melton Hill Dam closely follows the stage at Watts Bar Dam. Thus, the pool of Watts Bar Reservoir inundates the Clinch River embayment all the way to Melton Hill Dam.

Since it resides 20 miles downstream of Melton Hill Dam, the Emory River embayment also would be inundated as part of Watts Bar Reservoir. Based on the flat pool elevations in Watts Bar Reservoir, the Emory River embayment extends about 15 miles up the Emory River, well upstream of the confluence with the Clinch River embayment and KIF intake skimmer wall. To confirm this behavior, stage measurements were made at KIF during the period of reservoir filling for this year (i.e., 2005). The results are given in the top part of Figure 5. As shown, the KIF stage closely follows the stage at Watts Bar Dam. It also is noted that in contrast to Figure 4, the stage data given in the top part of Figure 5 are not filtered for periods of no flow in the Clinch River embayment or Emory River embayment (e.g., note Emory River inflow in the bottom part of Figure 5). This highlights the fact that the stage at KIF is controlled primarily by the stage at Watts Bar Dam, regardless of the flow entering from Melton Hill Dam or the Emory River watershed. It is also important to note in Figure 4 that throughout the sample period, 2000 through 2004, the minimum pool never dropped below 735 feet msl, ensuring a water depth of at least 35 feet at KIF, even after long periods of no flow from Melton Hill Dam. Maintaining such a depth in a consistent manner is characteristic of reservoir behavior.

To better visualize the dramatic impact of Watts Bar Dam on the stage in the lower part of the Emory River, simulations were made using a one-dimensional flow model (Hauser, 1995) of the portion of the TVA river system including Chickamauga Reservoir, Watts Bar Reservoir, and the Clinch River and Emory River embayment. The difference in stage between reservoir and riverine conditions on the Emory River embayment can be examined by running the model with and without Watts Bar Dam. Example results are shown in Figure 6. Water surface profiles with Watts Bar Dam are given on the right-hand side of the figure, and those without Watts Bar Dam on the left-hand side. In both cases the inflow and outflow from the model are the same. It is emphasized that for model boundaries consisting of dams, releases are made only during the hours of peak power demand. For projects such as Melton Hill Dam, periods of no releases can persist for perhaps several days (e.g., weekends). Results in Figure 6 are given at three points in time—day 10, day 17, and day 20 after the beginning of the simulation. The following features are emphasized.

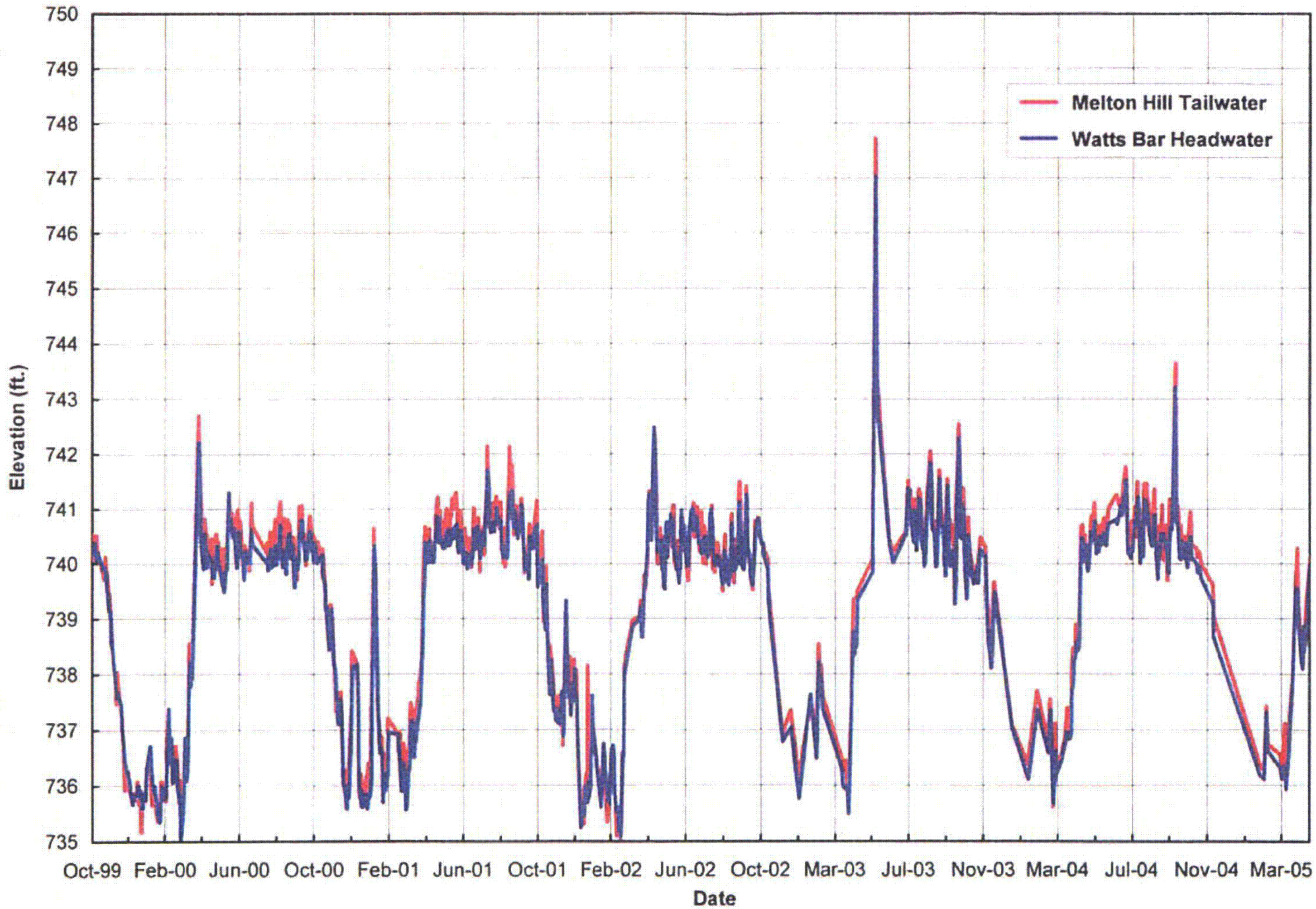

Figure 4. Pool Elevations When Melton Hill Releases were Zero for More Than 12 Hours

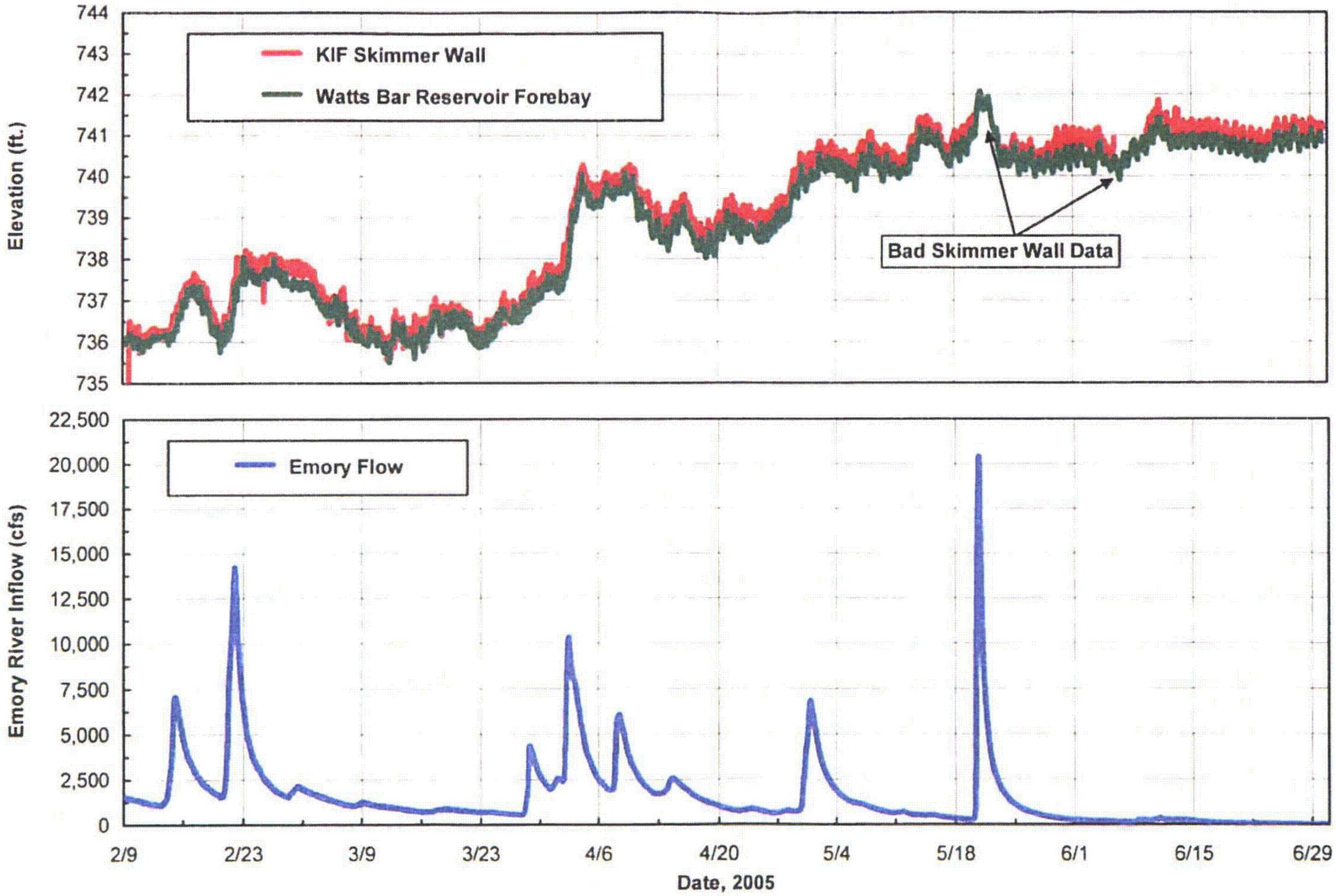

Figure 5. Measured Elevation and Inflow In Emory River Embayment

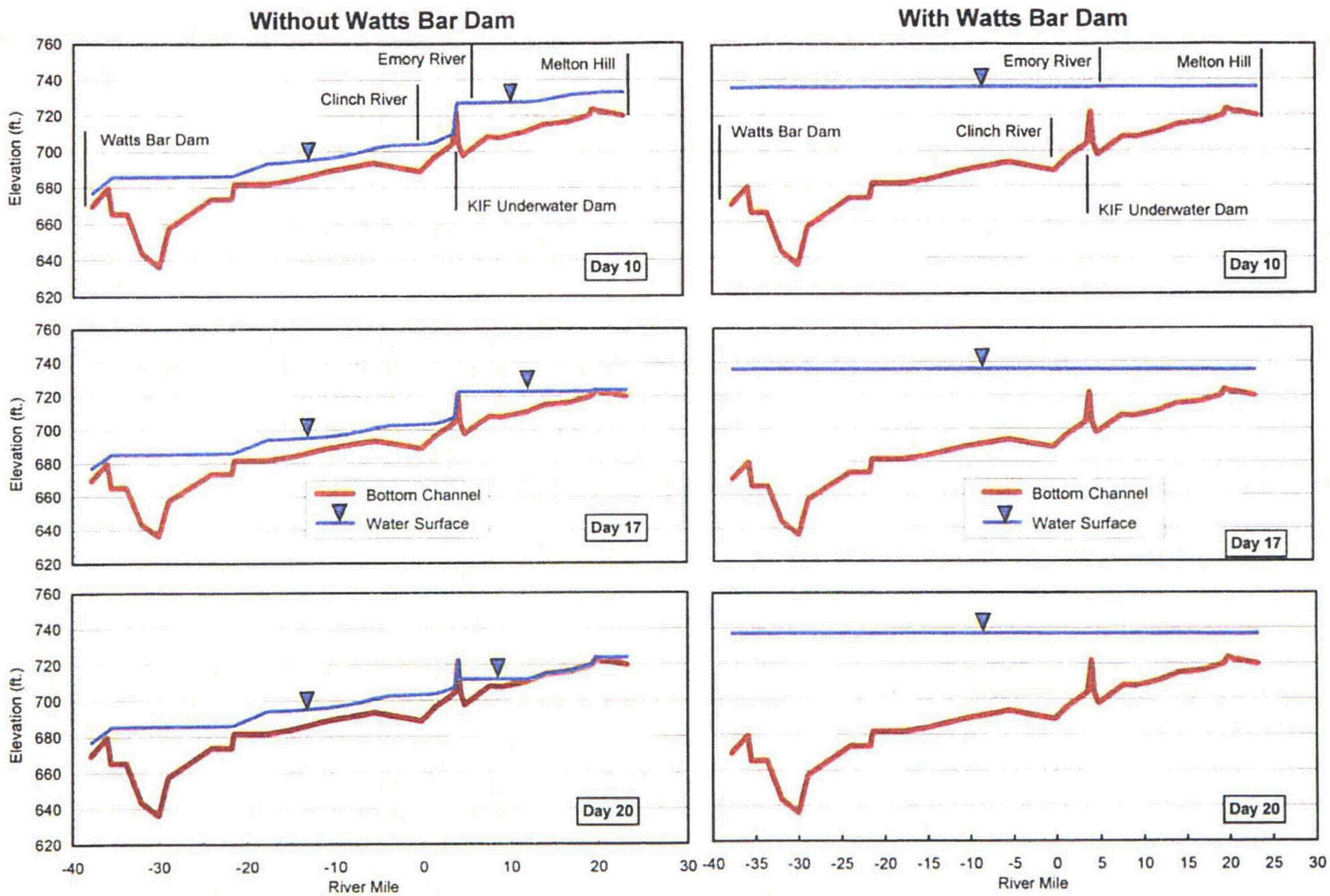

Figure 6. Computed Water Surface Profiles With and Without Watts Bar Dam

- Without Watts Bar Dam (hypothetical condition), the water surface in the upper part of the Watts Bar Reservoir and the Clinch River is much shallower than that with Watts Bar Dam. At a shallower depth, the underwater dam near KIF controls the depth of flow in the Clinch River and Emory River immediately upstream. If flow from Melton Hill Dam and the Emory River are sufficiently large (e.g., day 10), the underwater dam provides a depth of approximately 20 feet in the reaches immediately upstream. However, if Melton Hill Dam and the Emory River enter a period of low flow (e.g., between day 17 and day 20), the pool behind the underwater dam is dewatered by the intake flow at KIF, and ultimately is emptied.

- With Watts Bar Dam (existing conditions), a pool is maintained throughout the lower part of the Clinch and Emory Rivers, as previously emphasized in Figures 4 and 5. Regardless of the inflows from the Clinch River and Emory River, the water surface profile remains "flat".

In effect, the results in Figure 6 indicate that without Watts Bar Dam, KIF could not be adequately supplied by the flow in the Clinch and Emory Rivers. Thus, in the absence of Watts Bar Dam, and in the absence of special releases from Melton Hill Dam, KIF could not operate as it currently does. It also is interesting to note that if Watts Bar Dam, KIF, and the underwater dam did not exist, water depths in the lower parts of the Clinch River and Emory River would be substantially less than current conditions. In the summer and fall, when natural inflows are low, parts of the rivers could potentially experience near dry-bed conditions, especially if continuous releases were not provided at Melton Hill Dam.

Flow

In general, water in the Emory River embayment, and ultimately the water withdrawn by KIF, is supplied by three sources—the Emory River, the Clinch River, and the Tennessee River (main stem of Watts Bar Reservoir). Overall, flow from the Emory River contributes only about 0.4 percent of the total volume of Watts Bar Reservoir and the Clinch River only about 1.2 percent. The remaining 98.4 percent of the volume is provided by the Tennessee River and other tributaries. The focus here is on the behavior of the flow in the Emory River embayment.

On a daily basis, the inflow into Watts Bar Reservoir from the Emory River is variable. A good example of this behavior is given in Figure 7, which shows the inflow from the Emory River for two years, 2002 and 2003. These years represent potential extremes in seasonal flows. Year 2002 was dry, with natural summertime flows about 55 percent below normal. In contrast, 2003 was wet, with natural summertime flows about 88 percent above normal. As shown, each year is characterized by between six and ten rainfall events providing enough runoff to match or exceed the KIF intake flow. Some events are very short, lasting only a few days. The remainder of the year, there is relatively little inflow from the Emory River.

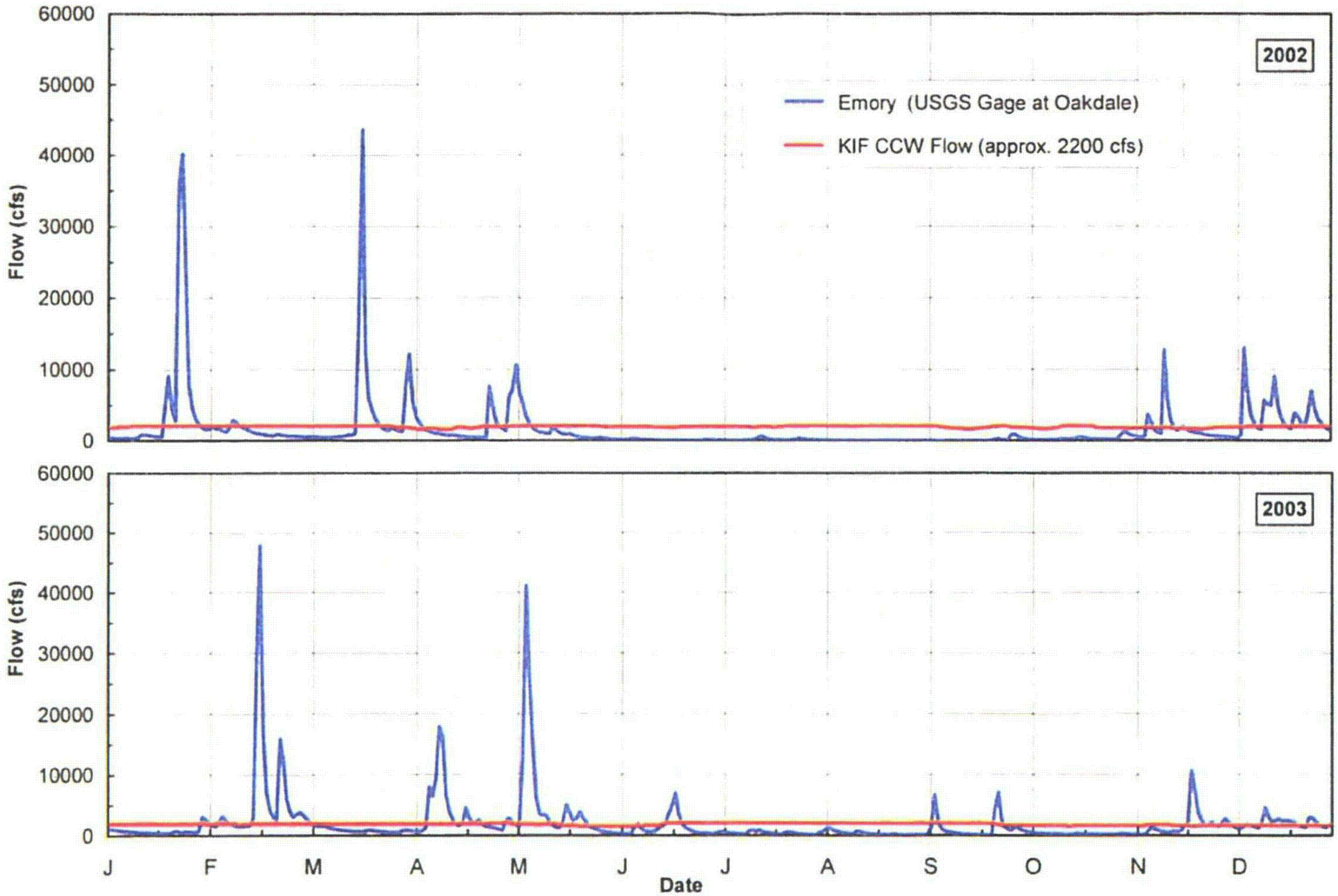

Figure 7. Daily Flow in Emory River, 2002 and 2003

The overall conclusion from Figure 7 is that for significant periods of time, the Emory River cannot supply the flow needed by KIF. The flow must come from sources other than the Emory River. To better understand the behavior of the flow in the source waterbody and approximate contribution by the Emory River, simulations of Watts Bar Reservoir were made with CE-QUAL-W2, a two-dimensional, laterally averaged hydrodynamic and water quality model (USCOE, 1995). A pre-existing version of the model calibrated to predict the KIF intake temperature was used in the analysis (Shiao and Proctor, 2003). To visualize the behavior of the flow, a conservative tracer was numerically released in the flow entering Watts Bar Reservoir from the Emory River (e.g., C_E=10 mg/L for the Emory River boundary condition). Simulations were made for 2002 and 2003. In general, the model shows that the only time the Emory River embayment is filled solely by flow from the Emory River is during large storm events when the runoff from the Emory River watershed is large enough to flush out the water from the other sources. An example of this situation is given in Figure 8(a), which shows the computed tracer concentration along the length of the Emory River embayment for a storm event on March 18, 2002. In this case, the tracer concentration is 10 mg/L throughout most of the embayment. As the Emory River runoff subsides, flow reenters the embayment from the other sources. Figure 8(b) shows Emory River tracer concentration during the recession of the storm event, where the embayment is being refilled by water from the Clinch River and also perhaps from the main stem of Watts Bar Reservoir. Figure 8(c) shows the tracer concentration after the Emory River inflow has dropped to base flow conditions. In this case, due to the low Emory River inflow, the tracer concentration is negligible throughout a large portion of the embayment.

Overall, the data in Figures 7 and 8 depict flow behavior in the Emory River embayment that is reservoir-like in character, with flows moving upstream and downstream depending on the overall hydrodynamic conditions of the reservoir. When the discharge entering from the Emory River is high, the flow moves primarily downstream. When the discharge is low, the flow moves upstream into the Emory River embayment from the Clinch River embayment. If the discharge in the Clinch River embayment also is low, the flow moves upstream from the main stem of the reservoir. Flows moving upstream (i.e., reverse flows) occur not only during periods of low Emory River discharge, but also during reservoir filling and periods of reservoir "sloshing", created by peaking operations at the upstream and downstream dams. In contrast, source waterbodies comprised of rivers are dominated by flows that consistently move in the downstream direction, and in a manner that is independent of the magnitude of flow in the waterbody.

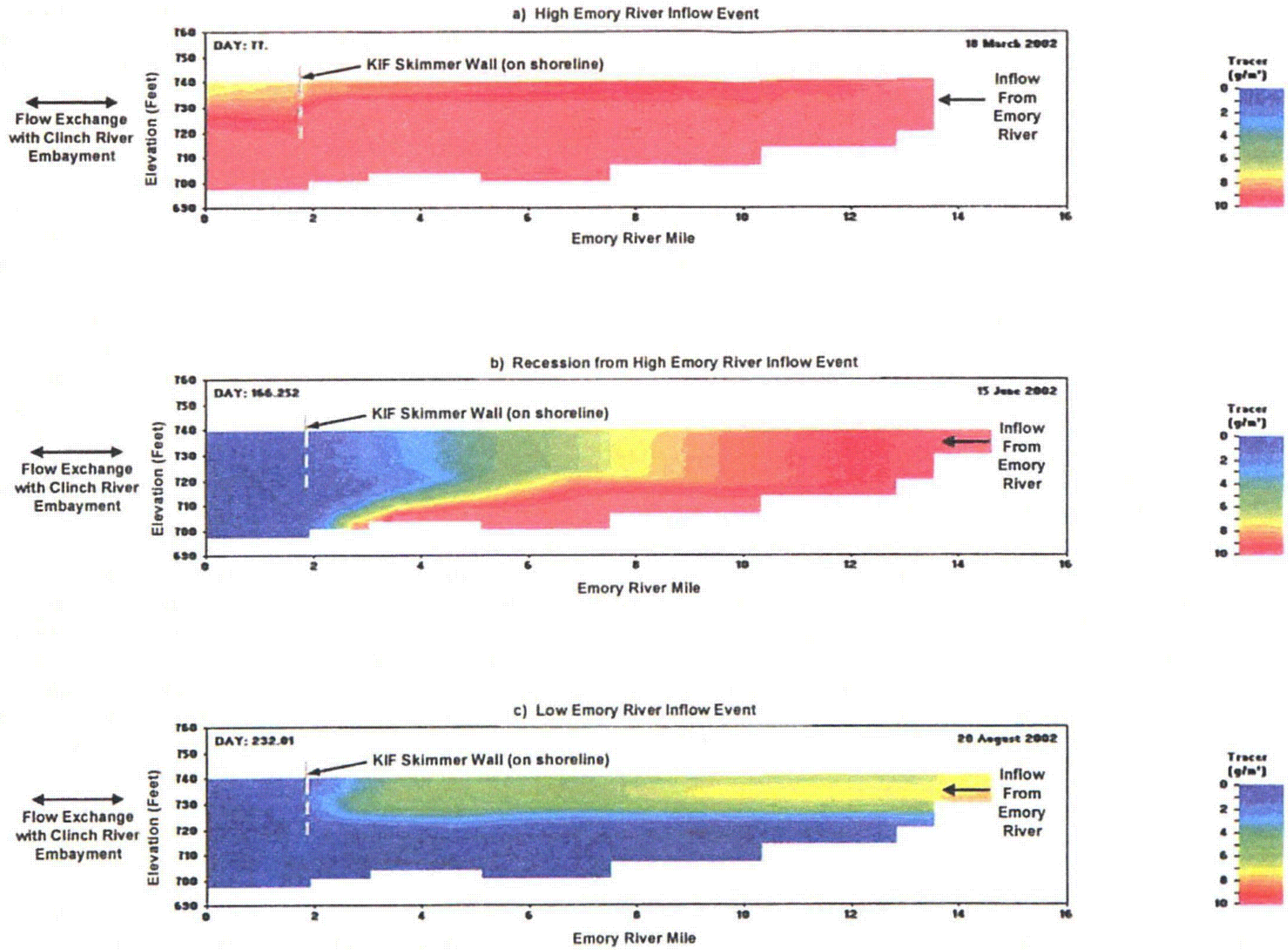

Figure 8. Profile of Computed Concentration of Tracer along Centerline of Emory River Embayment

Water Temperature

Water temperature provides a measure of river-like versus reservoir-like behavior based on the character of stratification. In general, the temperature in rivers tends to be uniform throughout the depth of flow. In contrast, depending on the time of year and flow conditions, the temperature in reservoirs develops characteristics of stratification. In reservoirs, the variation of water temperature also provides evidence of the potential source of the flow entering the KIF intake.

Water temperatures measured at several key locations in Watts Bar Reservoir are shown in Figure 9 for 2002 and Figure 10 for 2003. The locations include: the hydro release from Melton Hill Dam (MHH), the hydro release from Fort Loudoun Dam (FLH), the inflow from the Emory River as measured at Oakdale, and the intake at KIF (see Figure 1). For 2002, only grab samples are available for the release from MHH (rather than continuous measurements). Also, measurements from MHH and FLH are made only after March, when issues with water quality are a greater concern. The flow in the Emory River also is given for each year. The following features are noted.

- During high flow events on the Emory River, the KIF intake temperature is usually of the same magnitude as the temperature of the Emory River (e.g., February 2003). During such events, the Emory River embayment is flushed by the natural inflow from the Emory River and provides the main source of flow for KIF. However, as previously emphasized this occurs infrequently.

- At other times, the KIF intake temperature deviates from the temperature of the Emory River, suggesting that water from other sources is mixed in the embayment. Depending on the temperature of the water, the flow from the Emory River may altogether bypass the KIF intake, as suggested in the next point concerning stratification.

- Evidence of stratification is seen in the warmer months of the year, from mid-May through mid-September, when there is a significant difference between the cool water from MHH and warmer water from the Emory River. In this period, the temperature of the intake flow at KIF usually falls between these two extremes. Also, because it is warmer (more buoyant), the flow from the Emory River, what little there is during the summer, will tend to reside in the upper part of the water column and bypass the deep opening of the KIF skimmer wall. This bypass condition prevails during peak spawning and potential entrainment periods of eggs and juveniles.

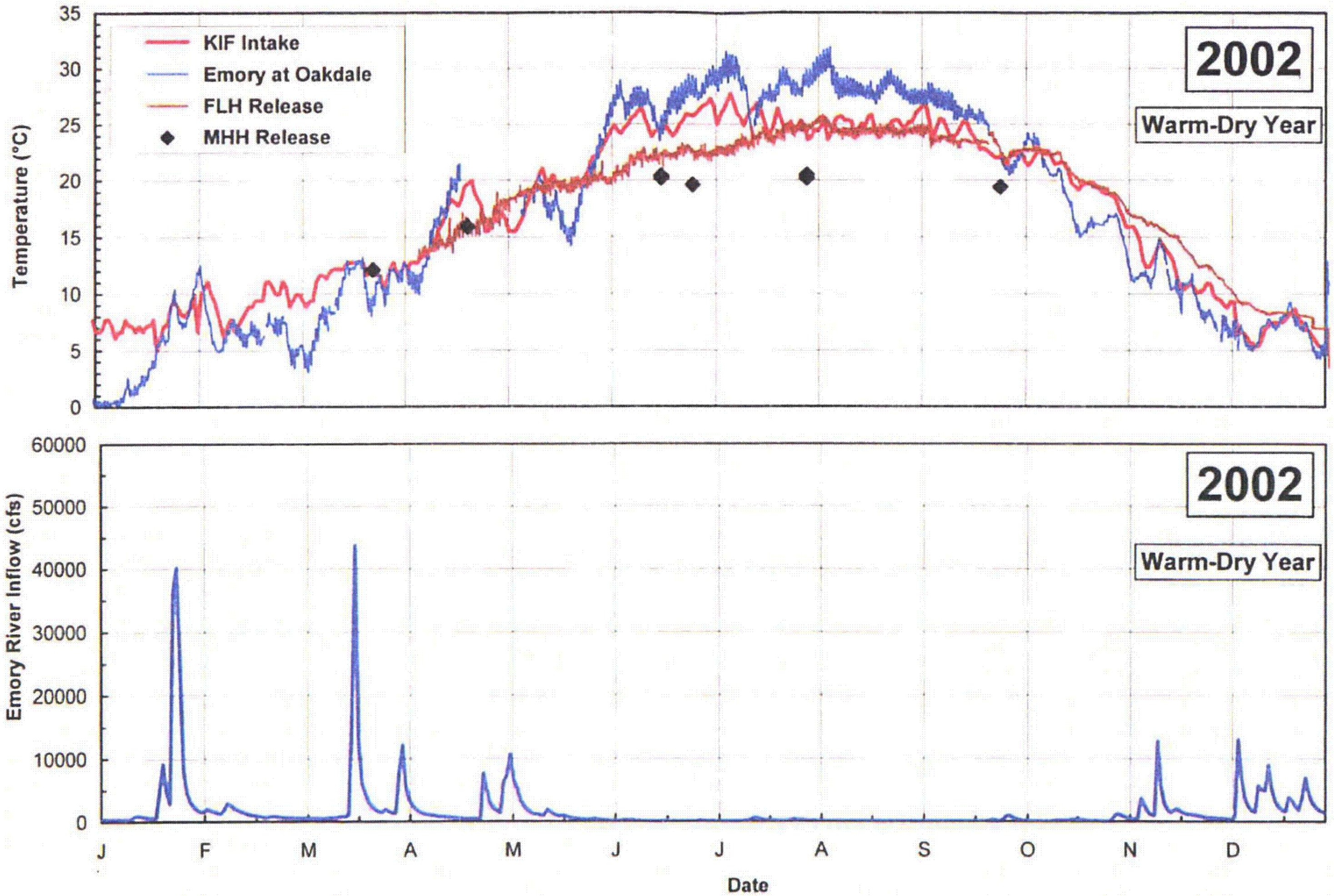

Figure 9. Measured Water Temperature for 2002

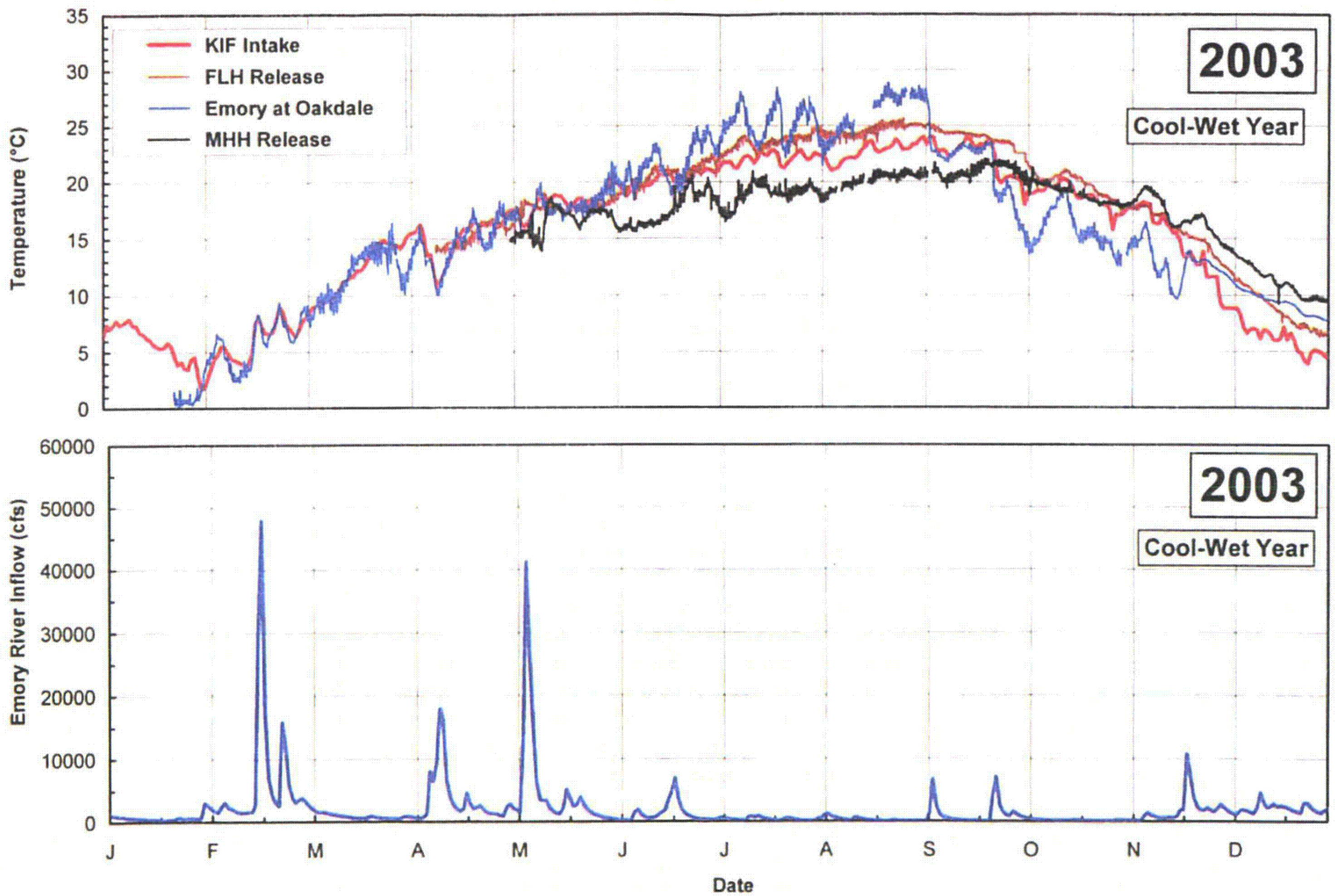

Figure 10. Measured Water Temperature for 2003

- In the summer of 2002 (July and August), when the inflow from the Emory River was low for an extended period of time (as was also true for the Clinch River), the temperature of the KIF intake was of the same magnitude as the release from FLH. This suggests that during this period, a significant portion of the KIF intake flow was likely supplied from the main stem of the reservoir, which is fed by releases from FLH.

- In the fall of 2003 (mid-September to mid-November), when the inflow from the Emory River again was low, the temperature of the KIF intake was of the same magnitude as the release from MHH. This occurred during the drawdown of the Norris Reservoir, yielding larger flows from MHH, which likely supplied a significant portion of the KIF intake flow. In this case, however, the KIF intake probably also captured a significant portion of the Emory River. This is because the temperature of the Emory River was cooler (less buoyant), causing it to reside as a density current on the bottom of the embayment, where it could enter through the opening of the KIF skimmer wall. However, even though the water from the Emory River was cooler, its volume was so small compared to that supplied by MHH that the KIF intake temperature continued to be dominated by the MHH release. Additionally, this thermal pattern does not coincide with expected peak spawning and potential entrainment periods.

To confirm the hydrothermal behavior of the Emory River embayment, and in particular the occurrence of stratification, simulations were made using the two-dimensional model CE-QUAL-W2. The simulations were made for 2002 and 2003. Example results showing longitudinal profiles of water temperature along the length of the Emory River embayment are given in Figure 11. Three extreme conditions are highlighted—high winter inflow from the Emory River, low summer inflow from the Emory River, and low autumn inflow from the Emory River. The following features are emphasized for each.

- High winter inflow from the Emory River (January 15, 2002)—The embayment is flushed by the high Emory River flow, creating a situation wherein the water temperature is essentially uniform throughout the embayment and equivalent to that of the Emory River. Obviously, in the winter, the temperature will be cool.

- Low summer inflow from the Emory River (July 29, 2002)—Due to strong solar heating and the inflow of cool water from MHH, the embayment is well-stratified with warm water residing in the surface region of the embayment. The KIF intake withdraws cooler water from the bottom. In this particular case, the inflow from the Emory River is warm and thus moves in the surface region of the embayment.

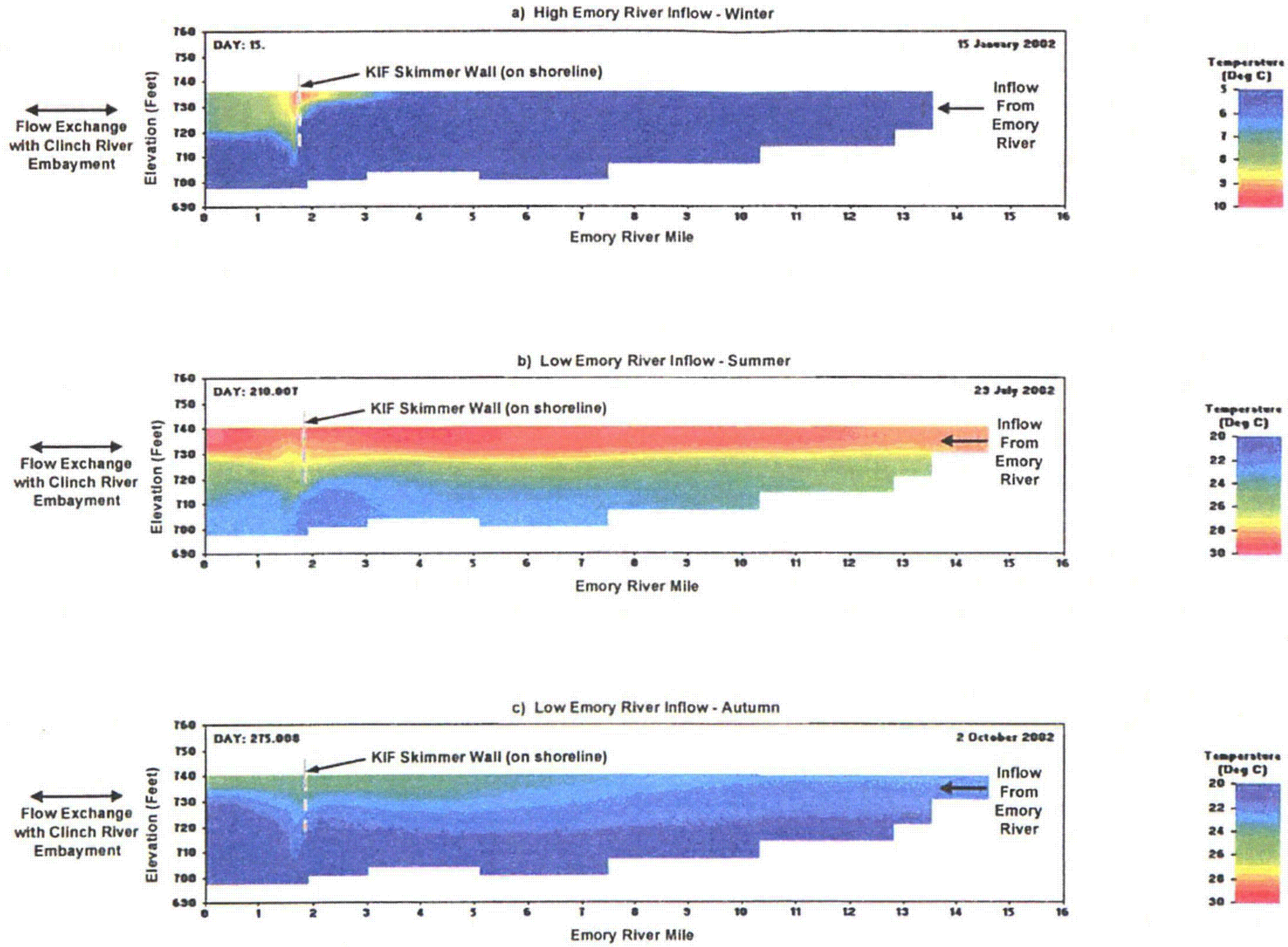

Figure 11. Profile of Computed Temperature along Centerline of Emory River Embayment

- Low autumn inflow from the Emory River (October 2, 2002)—Due to low flow conditions from the Emory, the embayment is filled mostly with water from MHH. With cooler autumn temperatures and higher flows in the Clinch River embayment, very little stratification exists in the embayment. In the particular case shown, the inflow from the Emory River is cool and thus moves in the bottom region of the embayment where it can be entrained into the KIF intake flow. Overall, in terms of water temperature, data from measurements and model simulations suggest that the Emory River embayment displays a reservoir-type behavior. In the fall and winter, water temperatures tend to be uniform. In late spring, with the onset of warmer meteorology and lower flows, stratification emerges and persists through the summer. The inflow from the Emory River moves in the embayment at a depth that depends on the temperature of the Emory River relative to that of the water in the embayment. If the Emory River is warmer, the inflow will tend to move in the surface region of the embayment; if cooler, the inflow will tend to move in the bottom region. If the temperature is roughly the same, the inflow will move throughout the entire water column. Any inflow moving in the bottom region of the embayment, of course, can be entrained by the KIF intake flow.

BIOLOGICAL CHARACTERISTICS

The examination of the biological characteristics is made by a comparison of ichthyofauna in different regions of Watts Bar Reservoir. In the Emory River embayment, lentic conditions (standing water habitats) prevail; while in the Clinch River embayment, lotic conditions (running water habitats) prevail (TVA, 1976). In general, after hatching, ichthyofaunas drift downstream into nursery habitats and are found throughout the water column in both lentic and lotic conditions.

The Emory River embayment of Watts Bar Reservoir extends about 15 miles upstream of KIF. This lentic habitat is further enhanced by the rising reservoir levels during the spring fill to summer levels. During this time frame, water travels upstream (reverse flow) from the mouth of the Clinch River embayment and into the Emory River embayment. As the Emory River flows enter the impoundment, it slows and creates a lentic habitat. This habitat allows ichthyofauna to settle, forming a nursery for larval and juvenile fish.

In the Clinch River embayment, ichthyofaunas are exposed to a lotic habitat and also drift downstream after hatching. The production of fish larvae is closely associated with productive shallow water (overbank) and sheltered habitat areas such as coves or embayments (TVA, 1976). The Clinch River embayment has little shallow water or sheltered habitats. The majority of the ichthyoplankton drifts past the plant and settle out downstream into the main stem of Watts Bar Reservoir where productive overbank areas are found (TVA, 1976).

To obtain an estimate of ichthyoplankton abundance at KIF, historical entrainment data collected at five sampling locations in the vicinity of the plant were examined. The samples were taken in 1974 and 1975 and include larval fish and egg densities (TVA, 1976). The results are summarized in Table 1. Samples collected from the KIF intake channel show that clupeids (shad) are predominantly entrained by the plant. Altogether, only six families of fish were collected in the intake channel: Clupeidae (73.33 percent), Centrarchidae (8.57 percent), Cyprindidae (7.62 percent), Catostomidae (3.81 percent), Ictaluridae (3.81 percent), and Sciaenidae (1.90 percent). Furthermore, the species entrained at KIF, as well as those collected nearby in the Clinch River and Emory River embayments, are primarily characteristic of species found in the main stem of Watts Bar Reservoir (e.g., Tennessee River at TRM 566.4 in Table 2). The peak occurrence of ichthyoplankton production in the Emory and Clinch embayments followed a regular pattern, with peak historical larval density occurring June 4, 1975 (TVA, 1976). Peak historical entrainment at KIF occurred July 16, 1975.

As for the Emory River, TVA currently has biological information from five monitoring stations upstream in the free-flowing portion of the river. These are located at Emory River Mile (ERM) 18.3, 21.4, 27.7, 29.2, and 41.4. The fish species found at these locations, a total of 64, are summarized in Table 2. Of these, five species, or about 7 percent, were common to species entrained at KIF, all of which are common species to the main stem reservoir. These were spotfin shiner, freshwater drum, largemouth bass, channel catfish and common carp. Thus, the majority of the Emory River species, about 93 percent, do not represent species entrained at KIF.

Overall, since the species collected in the intake at KIF are primarily of the type found in the main stem of Watts Bar Reservoir rather than those found in the free-flowing portion of the Emory River, the biological characterization suggests that the source waterbody for the plant is more reservoir-like in behavior. Therefore, no significant impacts to riverine species from entrainment are believed to occur at KIF. Further, the impact to reservoir species is not believed to be significant.

Table 1. Fish Eggs and Larvae Collected in the Vicinity of Kingston Steam Plant, Watts Bar Reservoir, 1975.

Species	Common Name	KIF Intake Channel	Emory River Embayment (ERM 1.9)	Clinch River Embayment Upstream (CRM 5.4)	Clinch River Embayment Downstream (CRM 1.1)	Tennessee River Downstream (TRM 566.4)
Unspecified Eggs	Unspecified Eggs	110	0	1	0	1
Unidentified Larvae	Unidentified Larvae	1	0	3	4	2
Clupeidae *Unspecified clupeids*	**Shads and Herrings**	76	15,673	3,674	7,078	7,495
Alosa chrysochloris	Skipjack Herring	0	0	0	3	8
Dorosoma spp.	Threadfin or Gizzard Shads	1	83	57	93	27
Dorosoma cepedianum	Gizzard Shad	0	5	0	4	3
Dorosoma petenense	Threadfin Shad	0	218	10	30	30
Hiodontidae *Hiodon tergisus*	Mooneye	0	0	0	1	4
Cyprindidae *Unspecified cyprinids*	Minnows	7	80	25	49	30
Cyprinus carpio	Common Carp	1	150	30	29	4
Notropis atherinoides	Emerald shiner	0	1	0	4	0
Notropis spilopterus	Spotfin shiner	0	3	0	0	0
Catostomidae *Unspecified catostomids*	Suckers	4	22	17	18	68
Ictaluridae *Ictalurus punctatus*	Channel catfish	4	17	0	5	1
Moronidae *Morone spp.*	True Basses	0	7	1	5	3
Centrarchidae *Unspecified centrarchids*	Sunfishes	0	0	1	1	3
Lepomis spp.	Sunfish	5	660	47	215	88
Micropterus spp.	Black Basses	1	3	3	1	1
Micropterus salmodes	Largemouth bass	1	0	0	0	0
Pomoxis spp.	Crappies	2	16	4	16	17
Percidae *Unspecified percids*	Perches	0	0	0	0	2
Percina carrodes	Logperch	0	0	1	0	5
Stizostedion spp.	Walleye or Sauger	0	0	0	0	2
Sciaenidae *Aplodinotus grunniens(eggs)*	Freshwater Drum Eggs	30	12	157	362	346
Aplodinotus grunniens	Freshwater Drum	2	0	1	1	56

Table 2. Emory River Species and Composition from Five Sampling Locations 1986-2003.

Common Name	Scientific name	Number of Individuals	% Composition
Redline darter	Etheostoma rufilineatum	1037	10.67
Whitetail shiner	Cyprinella galactura	925	9.52
Tangerine darter	Percina aurantiaca	899	9.25
Mimic shiner	Notropis volucellus	774	7.97
Largescale stoneroller	Campostoma oligolepis	689	7.07
Tennessee shiner	Notropis leuciodus	516	5.31
Silver shiner	Notropis photogenis	426	4.38
Rock bass	Ambloplites rupestris	414	4.26
Greenside darter	Etheostoma blennioides	399	4.10
Redbreast sunfish	Lepomis auritus	345	3.55
Spotfin chub	Cyprinella monacha	304	3.13
Longear sunfish	Lepomis megalotis	272	2.80
Telescope shiner	Notropis telescopus	261	2.68
Gizzard shad	Dorosoma cepedianum	252	2.59
Striped shiner	Luxilus chrysocephalus	229	2.36
Spotfin shiner	Cyprinella spiloptera	225	2.31
Warpaint shiner	Luxilus coccogenis	210	2.30
Northern hog sucker	Hypentelium nigricans	174	1.79
Bluegill	Lepomis macrochirus	152	1.56
Logperch	Percina caprodes	139	1.43
Rosefin shiner	Lythrurus ardens	137	1.41
Bluntnose minnow	Pimephales notatus	96	0.99
Smallmouth bass	Micropterus dolomieu	84	0.86
Bluebreast darter	Etheostoma camurum	81	0.83
Black redhorse	Moxostoma duquesnei	81	0.83
Spotted bass	Micropterus punctulatus	75	0.77
Snubnose darter	Etheostoma simoterum	65	0.67
Flathead catfish	Pylodictis olivaris	60	0.62
Channel catfish	Ictalurus punctatus	43	0.44
Stripetail darter	Etheostoma kennicotti	39	0.40
Golden redhorse	Moxostoma erythrurum	38	0.39
Freshwater drum	Aplodinotus grunniens	34	0.35
River chub	Nocomis micropogon	32	0.33
Brook silverside	Labidesthes sicculus	27	0.28
Gilt darter	Percina evides	26	0.27
Common carp	Cyprinus carpio	24	0.25
Sand shiner	Notropis stramineus	22	0.23
Redear sunfish	Lepomis microlophus	16	0.16
Largemouth bass	Micropterus salmoides	12	0.12
River redhorse	Moxostoma carinatum	12	0.12
Green sunfish	Lepomis cyanellus	8	0.08
Longnose gar	Lepisosteus osseus	7	0.07
Hybrid darter	Hybrid etheostoma	6	0.06
Hybrid sunfish	Hybrid lepomis spp.	6	0.06
Wounded darter	Etheostoma vulnerum	5	0.05
Rosyface shiner	Notropis rubellus	5	0.05
Olive darter	Percina squamata	5	0.05
Creek chub	Semotilus atromaculatus	5	0.05
Blueside darter	Etheostoma jessiae	4	0.04
Northern studfish	Fundulus catenatus	4	0.04
Black buffalo	Ictiobus niger	4	0.04
Yellow bullhead	Ameiurus natalis	3	0.03
Smallmouth buffalo	Ictiobus bubalus	2	0.02
Ashy darter	Etheostoma cinereum	1	0.01
Black darter	Etheostoma duryi	1	0.01
Hybrid bass	Hybrid micropterus sp.	1	0.01
Hybrid shiner	Hybrid notropis sp.	1	0.01
Hybrid darter	Hybrid percina	1	0.01
Unidentified lamprey (1)	Ichthyomyzon sp.	1	0.01
Spotted sucker	Minytrema melanops	1	0.01
Striped bass	Morone saxatilis	1	0.01
Golden shiner	Notemigonus crysoleucas	1	0.01
White crappie	Pomoxis annularis	1	0.01
Blacknose dace	Rhinichthys atratulus	1	0.01
	Total	9721	100.10

CONCLUSIONS AND RECOMMENDATIONS

For the various hydrothermal and biological characteristics examined for the source waterbody for Kingston Fossil Plant, the following conclusions emerge.

- Stage—The Emory River embayment is inundated by Watts Bar Reservoir and resides within the flat-pool region of the impoundment. In this manner, under normal conditions, the stage in the embayment is controlled primarily by the stage at Watts Bar Dam, and for the most part is independent of the magnitude of flow in the Emory River and Clinch River. The TVA operating guide for Watts Bar Reservoir ensures a water depth of at least 35 feet in the lower portion of the Emory River embayment. In general, these characteristics of stage are reservoir-like in behavior. In contrast, if the source waterbody included the Emory River as a free-flowing stream, the stage and water depth would be significantly lower than current conditions and would vary significantly depending on the magnitude of river flow. Based on the historical runoff from the Clinch and Emory watersheds, model simulations show that seasonal low flow conditions would not allow KIF to operate as it currently does if the Emory River embayment and Clinch River embayment occurred as free-flowing rivers.

- Flow—The flow in the Emory River embayment moves upstream and downstream as water is exchanged with other portions of the source waterbody. This movement is in response to the hydro-thermodynamic conditions of the ambient water in the embayment and the inflows from the Emory River, Clinch River, and main stem of Watts Bar Reservoir. In general, these motions are more characteristic of reservoir-like behavior. In contrast, waterbodies exhibiting river-like behavior are characterized by momentum-dominated flows that move consistently in the downstream direction.

- Water Temperature—Field data and model simulations show that the Emory River embayment seasonally stratifies due to warm meteorology and cool water from Melton Hill Dam. The temperature of the ambient water in the embayment relative to the temperature of the water in the Emory River, Clinch River, and main stem of Watts Bar Reservoir has a profound effect on how the inflow from these sources is dispersed in the embayment, and ultimately on what water is withdrawn by the KIF intake. The occurrence of stratification and the occurrence of complex temperature–related density currents and mixing patterns are characteristics of reservoir-like behavior. In contrast, the flow in rivers tends to be well-mixed and uniform in temperature.

- Aquatic Biology—Historical entrainment data from the KIF intake channel and data from biological sampling stations located in the Emory, Clinch, and Tennessee embayments show that fish species occurring in the KIF intake flow are primarily of the type found in Watts Bar Reservoir, not the free-flowing portion of the Emory River. In fact, only about 7 percent of the species occurring in the free-flowing Emory River were found to be common to species entrained in the KIF intake flow. However, all fish entrained at the KIF intake are common Watts Bar Reservoir species. The aquatic biology, therefore, supports characteristics in the Emory River embayment that are reservoir-like in behavior. TVA has concluded that the reservoir entrainment, historically estimated at 0.13 percent, is judged to be an insignificant impact on the fishery resources of Watts Bar Reservoir.

Altogether, even though the Emory River embayment appears riverine, based on the characteristics in the embayment for the stage, flow, water temperature, and aquatic biology, TVA recommends for the purpose of Section 316(b) of the Clean Water Act, that the source waterbody for the Kingston Fossil Plant be allied with Watts Bar Reservoir. That is, the source waterbody should be classified as a reservoir.

REFERENCES

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TVA

Watts Bar Nuclear Plant

Unit 0

Environmental Compliance Manual

Chapter 4

Erosion/Storm Water Pollution Prevention Controls

Revision 0031

Non-Quality Related

Level of Use: Information Use

Effective Date: 07-13-2009

Responsible Organization: ENV, Environmental

Prepared By: Jerri L. Phillips

Approved By: Todd E. Rose

Revision Log

Revision or Change Number	Effective Date	Affected Page Numbers	Description of Revision/Change
20	01/27/2005	19, 38	Intent change. Clarified Section 8.3 and Appendix E
21	04/05/2005	27-34, 36, 49	Modified Appendix B to reduce opportunities for human error. Update Appendix D for sample preservation expectations. Update Appendix H.
22	05/20/2005	9, 12, 15, 44, 47, 48, 52	Removed date field from permit; clerical changes; identify Isco sampler as a registered trademark; clarify concrete chute rinse out; added transformer storage locations to Appendix G.
23	8/30/05	14, 47, 48	Require independent verification of data entry into regulatory reports; corrective action to PER 83437. Clarify runoff coefficients for areas 11, 12, 13.
24	10/10/06	8, 42, 43, 47, 50, 51	Clarify storage location of weekly inspection records. Update land-use changes and SW-8 location due to SGRP. Clarify the location of Trench A and BMP's for concrete truck chute rinse out area. Update SWPPT members.
25	04/01/2007	7, 8, 11, 12, 17, 39, 40, 44, 51, 52	Add language and spill containment to address EPCRA Section 313 requirements. Update TVA organization, ECM-11 revisions, and the following Appendices: E (Non-Storm Water Site Assessment), F (Storm Water Sample Points), G (Storm Water Drainage Areas), H (SWPPT members).
26	12/12/2007	ALL	Update. This procedure has been converted from Word 95 to Word XP using rev 25, by The Conversion. Team. Update sections 2.1, 4.1 and 4.3 to ensure consistency with ECM-8. Update Appendix G to reflect site changes in support of Unit 2 construction.

Revision Log

Revision or Change Number	Effective Date	Affected Page Numbers	Description of Revision/Change
27	04/01/2008	20, 29, 32-40, 43, 48, 53, 54, 62, 63, 65	Add reference CM-6.73, ISCO® Sampler Programming Instructions. Format changes. Add requirement to re-certify SWPPP when ECM-4 is revised, PER # 139754. Update Appendix E to indicate observed non-storm water discharges. Update Appendix G to reflect site changes in support of Unit 2 and WBN Tie-in to Spring City Wastewater Treatment System construction. Update Appendix H.
28	07/03/2008	37, 41, 42, 47, 48, 54, 55	Update Appendices E, F, and G to delete monitoring at SW-7 as non-industrial land use and change SW-8 monitoring location. Update Appendix H.
29	02/06/2009	11, 33-39	Add language to describe any solids observed in the visual samples and add a description line to Appendix B for solids observations (PER 159343).
30	04/01/2009	8, 10, 11, 40, 50, 52-64, 67	Clarify language to reduce human error. Add detail as required for the revised NOI regarding termination of OSN 112 to begin TMSP monitoring as SW-11 and for Division submittal of the minor modification to the NPDES permit. OSN 112 monitoring to continue until receipt of Division approval for NPDES minor modification. Add SW-11 to Appendices B, F, and G. Add pond acreage and additional Unit 2 construction information to Appendix G. Update Appendix H.
31	07/13/2009	8, 11, 18, 21, 23, 25, 29, 35, 36, 39, 40, 42, 51, 54, 56, 61, 62	Add TDEC clarification of the waiver of the 72 hour interval. Corrected cited NEPA procedure. Corrected SW-11 weir head height. Update TVA organizations and Appendix B to reflect TMSP TSS benchmark monitoring requirements & certification effective 06/01/2009. Relocate SW-8. Add U2 laydown areas to drainage areas 2, 9 and11.

Table of Contents

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1.0 INTRODUCTION

1.1 *Purpose*

Identify the actions required to satisfy the regulatory requirements applicable to storm water discharges from the Watts Bar Nuclear Plant (WBN) facility and the organizations responsible for performing key activities.

1.2 *Applicability*

This procedure applies to all TVA and contracted workers involved in any industrial or maintenance activity that may contaminate storm water discharges from the WBN facility with pollutants that can harm lakes and streams. Examples include: sediment; floating, suspended, or settled solids; foam; turbidity; color; odor; oil sheens; iron or other metals.

1.3 *Compliance Approach*

Several documents and procedures in addition to Environmental Compliance Manual Chapter 4 (ECM-4) ensure compliance with Storm Water regulations. The most important document is the Storm Water Pollution Prevention Plan (SWPPP). The SWPPP is a living document that is described in more detail below. Procedures that were written primarily to support other activities are referenced in ECM-4 and the SWPPP where appropriate rather than duplicate their content.

The SWPPP is a working notebook or set of notebooks prepared and maintained in accordance with regulatory requirements and must be available for regulatory review by EPA and State regulators. The SWPPP contains the documentation and expectations for the monitoring and remediation of operational activities that may generate storm water pollution at WBN. At a minimum, the SWPPP shall contain:

1. Notice of Intent including topographic site map
2. A current copy of ECM-4
3. Storm Water Representative Site Certifications
4. Annual reports submitted to the state (for the last three years)
5. Storm Water Analytical Laboratory Results (for the last three years)
6. Storm Water Visual Observation Sheets (for the last three years)
7. Storm Water Event Guidelines
8. Non-Storm Water Site Assessment Report
9. Erosion and Sediment Control Inspections (for the last three years)

1.3 *Compliance Approach* (continued)

10. Construction Storm Water Pollution Prevention Plan, Construction Storm Water Permit and Monitoring Records (if needed for projects >1 acre)

11. Incidental Construction Project Monitoring Records (if needed for projects <1 acre)

12. Current SWPPP team members and training rosters

13. Aerial photograph Site Map

14. Copies of required inspections or instructions on how to retrieve them.

15. Documentation of rainfall events.

1.4 *Storm Water Permits*

Storm water runoff is typically regulated by the State through the use of a general storm water permit associated with industrial activity referred to as the Tennessee Multi-Sector Permit (TMSP). Storm water runoff that is routed to retention ponds and treatment works at WBN are addressed under the site's National Pollutant Discharge and Elimination System (NPDES) permit. Additionally, storm water runoff from WBN construction/excavation activities which will disturb one (1) or more acres per drainage area must be permitted under a separate construction storm water permit associated with the specific construction activities. Certain non-storm water discharges are allowed to discharge through outfalls authorized under the TMSP. These include fire protection flushes, groundwater, irrigation drainage, etc. A complete list of allowable non-storm water discharges is located in the TMSP.

To be authorized to discharge storm water under the TMSP, industrial facilities must first submit a Notice of Intent (NOI). A NOI is submitted to the Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control whenever changes have been made to the site that alters the information previously submitted or when the TMSP is renewed. When inspections or scheduled construction activities indicate a new NOI must be submitted, consult the current TMSP available on-line from TDEC to ensure the most current NOI form is submitted with all the required information. It is important to note that the SWPPP must be prepared and implemented prior to submitting the NOI.

In addition to meeting the general requirements found in the TMSP, WBN must meet the requirements for facilities subject to EPCRA Section 313 reporting and two industry specific sectors of the TMSP. WBN is subject to reporting for naphthalene, a constituent of diesel fuel oil, which is classified as a' Section 313 priority chemical'. WBN stores diesel fuel in the diesel storage tanks located east of the Auxiliary Building in Drainage Area 2. A discussion of containment and drainage control for the diesel storage tanks is provided in Section 4.1 and Section 4.3. Sector L addresses storm water discharges associated with industrial activity from waste disposal at landfills and land application sites that receive or have received industrial wastes. WBN has one closed and one active demolition landfill, and sector L requirements apply to the runoff from these areas. Sector O of the TMSP applies to power generating facilities and as such these requirements apply to all drainage areas at WBN.

Excavation/grading/disturbance of one (1) or more acres in a given drainage area requires WBN to apply for a Construction Storm Water Permit. Once permitted (i.e. receipt of Notice of Coverage or Notice of Coverage number), strict adherence to the designated inspections, prompt repairs to the controls required in the plan, and meticulous attention to the record keeping requirements described in the application are necessary. The Construction Storm Water permit and all its associated documentation shall be maintained as part of the site's SWPPP. Additional information and the Construction Storm Water Permit application are available from the TDEC website. Work schedules should allow a minimum 90 day approval process before excavation may begin under a Construction Storm Water Permit.

2.0 STORM WATER INSPECTIONS

Storm water sampling point locations were selected to take advantage of discrete drainage channels available for runoff collection down-gradient of a site specific industrial activity. Appendices E, F and G along with the aerial site map provide a detailed characterization of each of these storm water outfalls and drainage areas [1].

Personnel trained in the requirements of the SWPPP (typically members of the Storm Water Pollution Prevention Team or SWPPT) shall inspect designated equipment and areas of the facility at appropriate intervals. The inspection reports are stored in working notebooks or a set of notebooks prepared and maintained in accordance with site procedures. Copies of these documents are available in the Chemistry/Environmental area. In addition, these inspections shall be recorded and sent to EDMS for record keeping and copies or instructions on how to retrieve copies from EDMS will be maintained in the SWPPP.

2.1 Tanks/Equipment/Secondary Confinement Inspections

Inspections of above ground storage tanks, pipelines, pumps and secondary confinements for leaks and structural integrity are performed by Operations and Environmental staff and documented per instructions in WBN ECM-8 and 1-PI-OPS-1.

2.2 Monthly SWPPP Inspections

Inspections for erosion control or BMP issues with the open demolition landfill are addressed by a minimum of monthly inspections described in ECM-11.

SWPPT members document a monthly inspection of all drainage areas using Appendix A. Measures to reduce pollutant loading shall be evaluated to determine whether they are adequate and properly implemented or whether additional controls are needed. Structural storm water management measures, sediment and erosion control measures, and other structural pollution prevention measures shall be observed to ensure they are operating correctly. These monthly inspections identify:

A. Areas which, due to topography, industrial activities, or other factors, have a high potential for soil erosion and any needed structural, vegetative, and/or stabilization measures to limit erosion.

B. The adequacy of spill controls in the area including, but not limited to, the physical integrity of drums, storage tanks, pumps and hose connections, and berms/dikes.

C. Stabilization or structural erosion control issues with the closed demolition landfill.

2.2 *Monthly SWPPP Inspections* (continued)

Responsible SWPPT members discuss the necessary erosion/storm water corrective actions and agree on the final remediation completion date. Completion dates are based on the potential impact to runoff. Actions with a high risk for pollution will generally be completed in shorter periods of time. However, extenuating circumstances such as safety or unfavorable weather conditions are factored into the due date and extensions to the due date. A Problem Evaluation Report (PER) shall be issued for action items that exceed the remediation completion dates without reasonable justification for extension. PERs are issued in accordance with Standard Programs and Processes, SPP-3.1. Copies of these inspections or a reference on how to retrieve them electronically shall be maintained in the SWPPP.

2.3 *Comprehensive Site Compliance Evaluation*

An annual evaluation of drainage areas associated with industrial activity shall be conducted by SWPPT members during a rainfall event. This evaluation may be substituted for a quarterly visual examination that is scheduled for the same quarter. In addition to visually inspecting for pollutants entering the drainage system, structural measures used to reduce pollutant loading are evaluated for effectiveness with additional controls identified as needed. Ineffective measures and controls shall be identified and the SWPPP appropriately revised within 2 weeks of this evaluation. Physical changes to correct deficiencies shall be documented using the site's Corrective Action Program and are to be implemented within 12 weeks of the evaluation.

2.4 *Non Storm Water Discharge Assessment*

The SWPPP shall contain a non-storm water discharge assessment that certifies the storm water discharges from the facility have been tested or evaluated for the presence of non storm water discharges. The assessment shall be conducted during dry weather as needed. Such an assessment was conducted site wide for WBN when the site was initially covered under the TMSP. These assessments are documented using Appendix E. Additional site assessments driven by regulatory or site/facility changes are conducted as needed to ensure the drainage area descriptions continue to reflect actual site conditions. While the most recent assessment performed is provided in Appendix E for this revision as an example, it is not necessary to revise ECM-4 each time an Appendix E is completed. File the completed Appendix E in EDMS. Copies of these inspections or instructions on how to retrieve them electronically shall be maintained in the SWPPP.

3.0 MONITORING AND SAMPLING REQUIREMENTS

There are two basic types of monitoring: visual observations and analytical monitoring. Storm water monitoring and sampling are documented using Appendix B of ECM-4 and maintained in the SWPPP [2]. Storm water monitoring is initiated by a qualifying storm event. A qualifying storm event is characterized as a storm event generating 0.1 inches or greater of rainfall or snowfall which occurs a minimum of 72 hours after the last 0.1 inch storm event. The TMSP allows certain exceptions for a qualifying event. Also refer to TDECs' email clarification dated July 7, 2009 that the waiver of the 72 hour interval also extends to individual outfalls which require a large amount of precipitation for measurable runoff, even if the rest of the facility had a discharge.

Storm water sampling is conducted when the qualifying storm event produces a measurable runoff at the sample point(s). Grab samples representative of the monitored activity may be collected during the first 30 minutes of discharge from an outfall, or if not practicable, within the first hour. Samples for monitored sites may be collected: (1) manually during daylight business hours or (2) automatically by an Isco® Sampler (or equivalent) equipped with a liquid activated switch. Refer to appendix D for Isco® sampling collection methods. Samples collected by an Isco® Sampler will be individually evaluated prior to analysis to ensure the samples have been adequately preserved and are therefore representative of the runoff.

Some drainage areas are not sampled due to a lack of industrial activity or coverage under the WBN NPDES permit. Other drainage areas may not require sampling if they are considered to be represented by samples collected at another outfall. Representative storm water sites are not monitored and certification statements to that effect are maintained in the SWPPP. Likewise, former storm water monitoring sites located in an area in which the land use has been changed from industrial to non-industrial are not monitored and certification statements to that effect are maintained in the SWPPP. Refer to Appendix F for a summary of storm water sample points.

TMSP sampling for SW-11 commenced when the revised NOI was submitted to the Division on April 8, 2009. The maximum amount of flow that may be measured at OSN 112/SW-11 is 0.65ft head per weir (discharging over the dam versus through the discharge weirs only). Because six streams flow into the RHP, the pond may flow during non-storm water periods. Therefore, visual observations and analytical samples will be collected only during or immediately following a qualifying storm event when the water exceeds the 0.65ft head per weir. Until receipt of Division Notification of NPDES Minor Modification, NPDES parameters for OSN 112 will continue to be monitored.

On June 24, 2009 WBN submitted a NOI for Sector L and O for the TDEC TMSP revision effective June 1, 2009. The WBN Notice Of Coverage (NOC) is pending.

3.1 *Quarterly Visual Observations*

Visual observations will be performed once per quarter beginning the First Quarter (January-March) in 2002 through the permit duration on all monitored Storm Water Outfalls. Visual observations are documented using Appendix B of ECM-4 and maintained in the SWPPP [2]. Reasons for not performing visual examinations (e.g., adverse weather conditions, event not during daylight hours, no flow (state reason), Isco® failure or sample not retrievable in a timely manner) are documented and retained with records documenting the rainfall event. No additional sampling is required for missed Quarterly Visual Observations; however, collecting a make-up sample is a preferred TVA practice. Anytime there is a negative mark on Appendix B of ECM-4, the inspector is to document the reason or probable cause of the issue. For example if the discharge is turbid, the inspector needs to walk around the area upstream of the discharge to determine why (i.e. exposed soil, etc.) Observation of solids requires documenting what they were (i.e. bark, leaves), documenting the source (i.e. detritus), documenting if the amount of these solids was significant or not, and finally, documenting if the solids are impacting the quality of the discharge.

3.2 *Annual Analytical Monitoring*

Sample collection and analyses is outfall specific, documented using Appendix B, and maintained in the SWPPP [2]. WBN samples are analyzed for total iron and total suspended solids depending on the TMSP sector requirements for the outfall. Appendix C contains a summary of specific storm water outfall sampling requirements. Iron is analyzed for all outfalls; total suspended solids are analyzed for those outfalls that receive storm water runoff from landfills. WBN is required to document an estimate of the volume discharged (in gallons) for the event in addition to date, duration of event, rainfall amount (inches), and duration in hours since the last qualifying storm event. Makeup sampling the following calendar year is required for missed Annual Analytical Monitoring samples. Documentation as to why collecting a sample was not possible during the year must be maintained in the SWPPP. Copies of Appendix B are filed in EDMS and a copy retained in the SWPPP for a minimum of 3 years.

4.0 BEST MANAGEMENT PRACTICES

Storm water runoff management is accomplished utilizing a variety of Best Management Practices (BMPs). In accordance with the storm water permit, all areas of the facility shall be inspected at specific intervals to maintain good housekeeping and material management. Based upon inspection results, inadequate control measures shall be replaced, modified or repaired before the next rain event if possible. The allowable time shall be determined by the CEM or designee, and may include extensions due to safety concerns or other extenuating circumstances. Such extensions will be documented in the monthly report using Appendix A of ECM-4.

4.1 Spill Prevention and Response

Loading and unloading areas, long term and short term material storage areas, switchyards, bulk storage tanks, areas adjacent to disposal ponds and landfills, maintenance areas, and liquid storage tanks are inspected for integrity and leaks in accordance with a variety of WBN procedures. Inspections are required by the monthly Erosion Control Inspection in ECM-4; the Landfill Inspection in ECM-11; by Operator Rounds in 1-PI-OPS-1; by material receipt inspectors in SPP-4.2 and by ECM-8, Spill Prevention Controls and Countermeasures Plan (SPCC).

ECM-8 is appropriately updated to describe all reportable spills and to reflect pertinent site changes in inventory and storage location. Response teams are on duty continuously. Annual SPCC training is provided to Fire Operations, Environmental, and Operations personnel.

4.2 Preventative Maintenance

A preventative maintenance program has been implemented to ensure permit compliance. This program encompasses timely inspections and maintenance of storm water management devices and inspection and testing of facility equipment and systems. Operations staff conducts daily rounds using several Periodic Instructions (PIs) and completes electronic checklists documenting the evaluation of facility equipment. The inspections are specific for leaks and spills as well as unusual noises, vibrations, or other abnormal operating characteristics that could lead to equipment failure and spills to the environment.

4.3 *Measures and Controls*

Measures to reduce potential storm water contamination from industrial activity are implemented by several WBN procedures and practices. To prevent or minimize spillage, spill and overflow protection (drip pans, drip diapers, drain covers, etc.), secondary containment (berms, curbing, etc.), and alternative BMPs (storm water drain protection, maintenance activities away from storm water drains, etc.) are utilized as required in the site SPCC. Spill huts and clean-up kits are readily accessible throughout the industrial area as well as in close proximity to construction sites and delivery areas. All site personnel are trained through General Employee Training to activate the site's emergency response system by dialing extension 3911 and notifying Operations staff of spills requiring emergency response to prevent runoff and leakage to storm drains. A description of the storm water management controls used at this facility includes the following.

A. **Good Housekeeping.** The maintenance of areas which may contribute pollutants to storm water discharges shall be kept in a clean and orderly manner. These practices are fully addressed in the SPCC, and off fueling procedures are covered in Ops-SOI-18.01 and CM-6.03

4.3 *Measures and Controls* **(continued)**

B. **Delivery Vehicle Inspections.** All vehicles arriving at the warehouses are visually inspected by receipt personnel. No delivery vehicles with leakage or spillage will be allowed on site.

C. **Covered Storage Areas -** Materials that pose a potential negative impact for contamination of storm water runoff are stored indoors or undercover as required by the site SPCC. Appropriate BMPs shall be placed in service on a case by case basis for temporary construction laydown materials. Loading/unloading areas will be covered as required in the site SPCC and all dry, bulk chemicals shall be stored undercover.

D. **Loading and Unloading Activities**. The loading and unloading of chemicals is conducted away from storm water drains when possible or with storm water drain protection in place.

E. **Fuel or Chemical Transfers.** Fueling operations and the transfer of bulk chemicals in general require the use of spill and overflow protection (drip pans, drip diapers, secondary containment devices, etc.) in accordance with ECM-8. Diesel fuel transfers take place inside a diked secondary containment constructed of concrete. Any diesel fuel spilled outside of the confinement will flow to the yard drainage system and then into the Yard Holding Pond (YHP) where it would be contained for cleanup.

F. **Vehicle Maintenance -** General vehicle maintenance is conducted off-site. However, instances of minor emergency repairs on site shall be performed utilizing appropriate spill control measures (drip pans, drip diapers, etc.). The repairs shall be performed away from storm water drains if possible, or with storm water drain protection in place.

G. **Above Ground Storage Tank Requirements.** Tanks containing liquids will minimize contamination of storm water runoff from by employing the following:

1. Containment Curbs

2. Spill and Overflow Protection Devices - i.e. drip pans, etc.

3. Large Bulk Fuel Storage Tanks - Comply with SPCC Plan. Specifically, the diesel fuel tanks are located within a concrete dike containing closed valves. These valves are securely locked in the closed position when in nonoperating status. This secondary containment has the capacity to retain the entire contents of the tank in addition to six inches of freeboard in the event of a storm event. With the loss of the secondary containment, diesel fuel would flow to the nearby yard drainage system and then into the Yard Holding Pond (YHP) where it would be contained for cleanup.

4.3 *Measures and Controls* (continued)

4. Oil Bearing Equipment in Switchyards - All leaks and spills shall be cleaned up immediately from gravel areas surrounding the equipment. Containment measures shall be applied to faulty equipment until the leak has been repaired.

4.4 *Runoff Management*

WBN endorses a proactive approach to erosion control and spill prevention. Contamination of site runoff shall be minimized by: (1) erosion/sedimentation controls; (2) holding ponds engineered to provide neutralization, oil skimming, and sedimentation for industrial storm water runoff; and (3) procedures and practices to reduce or minimize spills. Descriptions of such erosion and spill control measures in each site area are found in Appendix G of this document.

Prior to the start of any construction at WBN, earthwork activities shall be coordinated with Chemistry/Environmental per Sections 1.4 and Section 7.6. to ensure appropriate planning and runoff controls are carried out. Erosion and/or sediment runoff control can be achieved through implementation of the following generic measures on a case-by-case basis.

4.4.1 Erosion Controls

Erosion control is the "front-end" mechanism for reducing the amount of contaminants in storm water runoff. Examples of erosion control include:

A. Planning construction activities to reduce the extent and duration of exposure is an effective tool in controlling site runoff. Planning should include site selection and layout to reduce effects of runoff and sediment loss. STAGING OF GRADING, REESTABLISHING VEGETATION, SEASONAL WORK, etc. can reduce exposure of potential contamination sources to erosion and/or sediment transport.

B. Vegetation and ground cover are effective methods of preventing erosion when properly implemented in a timely fashion. Vegetation should be chosen for suitability to the particular area. Good site preparation involving soil preparation and proper planning is required.

C. Where practicable, runoff should be intercepted and diverted before coming into contact with contamination sources (exposed soil, material storage, etc.). Diversion structures, including dikes, ditches, and terraces, can be used up-gradient of a contamination source to prevent contact by runoff or to intercept contaminated runoff and divert it to a safe disposal area, such as a basin, trap, or filter. Temporary holding ponds should be constructed, if necessary, to allow settling. The contents (water) should then be conveyed to the yard drainage pond or other approved drainage course.

4.4.1 Erosion Controls (continued)

D. Shielding, using various types of mulch, protects the soil from rainfall impact.

E. Commercial binding agents can be applied as a liquid to bind surface soil particles into a mass more resistant to rainfall impact and runoff. This is particularly applicable to soil exposed for short periods or when prompt reestablishment of vegetation is impractical.

F. Steep slopes increase runoff velocity. Shallow slopes tend to be longer slopes and may require division into a series of short slopes by trenching, terracing or use of ditches and dikes. Vegetation is better achieved on a three to one slope.

G. Scarification, such as tracking with a bulldozer horizontal to the slope, will increase slope roughness and decrease runoff volume and velocity.

4.4.2 Sediment Controls

Sediment control is a second line of defense as eroded material in runoff is trapped. Sediment control can be achieved using the following generic controls on a case-by-case basis.

A. Vegetative Controls. Vegetative controls, consisting of vegetation or sod, are used to filter and reduce overland flow to allow sediment to deposit over a broader area. These controls include filter strips and inlet filters.

B. Structural Controls. Structural controls reduce runoff velocity by diverting it from unvegetated areas and filter/retain sediment where runoff flow becomes concentrated. Controls include filters, traps, check dams, basins, and diversion structures.

   Runoff filters may consist of coarse CRUSHED STONE DIKES or SILT FENCES. Stone filters are used around or in front of storm water drains or across drainage areas where runoff concentrates. Silt fences are more effective in instances where runoff is not concentrated and where sheet flow prevails. Periodic sediment removal or filter cleaning or replacement preserves structure effectiveness.

   Traps temporarily detain runoff and promote sedimentation and consist of SANDBAGS, SOIL/STONE BERMS, STRAW BALES or ANY COMBINATION of these materials. Some amount of filtration will initially be provided until media clogging occurs. Traps placed at regular intervals along flow paths provide a high degree of removal efficiency.

4.4.2 Sediment Controls (continued)

Basins are essentially impoundments (e.g., retention swale, yard drainage pond) typically located near the site boundary. Basins are used on larger drain ways and are constructed by damming, excavating a depression, or a combination of both. Properly designed and maintained basins are effective for both coarse and fine textured sediment removal.

5.0 REPORTING REQUIREMENTS

5.1 *Storm Water Analytical Report*

Annually, one grab sample per outfall shall be analyzed for iron and/or total suspended solids (refer to Appendix C). Analytical results shall be reported on the TMSP Storm Water Monitoring Report Form CN-1115 and submitted to TDEC by March 31st of the following year. All data input into regulatory reports shall be independently verified prior to submittal to the regulatory agency.

5.2 *Comprehensive Site Compliance Evaluation*

An annual report based on the inspections described in Section 2.2 and 2.3 of this procedure. In addition to describing the inspection results, the report will identify incidents of noncompliance (incidents where waters of the US were adversely impacted). In cases of a report without a noncompliance, a certification of compliance shall be included and signed by the CEM or designee in accordance with TMSP Signatory Requirements. Current reports are to be filed in EDMS and maintained in the SWPPP for a minimum of 3 years. These reports are not submitted to TDEC.

5.3 *Exceedance Reports*

If analytical results are above the benchmark monitoring requirements, the permittee must inform TDEC within 30 days as to the likely cause of the exceedance(s), and modifications or additions need to be made to the plan. A summary of the proposed plan and timetable for implementation must be submitted to the Division's Chattanooga Environmental Assistance Center (EAC) within 60 days.

5.4 *Notice Of Intent*

A NOI shall be submitted to TDEC with: (1) a permit renewal; (2) an application for a Construction Storm Water Permit; and (3) when a significant change in industrial activity warrants a change in the number or types of sampling required at storm water outfalls or merits additional storm water outfalls.

5.5 *Non-Storm Water Assessment*

A Non Storm Water Assessment is performed periodically in accordance with Section 2.4 to support changes in the SWPPP or NOIs. The SWPPP shall include a certification that all outfalls have been tested or evaluated for the presence of non-storm water discharges. Should non-storm water discharges be observed during dry weather from an unidentified source, site Environmental shall be immediately notified. Chemistry/Environmental Staff shall evaluate the discharge and (1) obtain the necessary NPDES discharge permit for process or cooling water, or (2) implement the appropriate changes to the storm water plan.

5.6 *Plan Modification*

The SWPPP must be reviewed and possibly updated under the following conditions:

Within 60 days of notification by the Director (or designee) that the SWPPP is inadequate; If change to design, construction, operation, etc. has the potential to significantly impact discharges to waters of the U.S.; In the event WBN exceeds a cut off concentration for an analytical parameter (as shown in Appendix C, the SWPPP must be reviewed and modified as appropriate, and TDEC shall be provided with a brief summary of the revisions.

6.0 TRAINING

The Environmental Management System (EMS) Environmental Training Process ensures all TVA Environmental Training requirements are met.

Annual training is provided to SWPPT members responsible for ensuring Storm Water permit compliance and as needed to other WBN organizations. Training ensures site personnel are knowledgeable of their ECM-4 and SWPPP responsibilities. Documentation of the actual date of training is be maintained in the ATIS database and in the SWPPP.

Additionally, the "Nuclear Power Environmental Awareness Handbook" and General Employee Training provide all badged site employees a basic understanding of spill control and awareness of storm water runoff issues.

7.0 RESPONSIBILITIES

7.1 *Storm Water Pollution Prevention Team (SWPPT)*

Responsible for developing the SWPPP and assists the facility or plant manager in its implementation, maintenance, and revision.

Participate in annual SWPP training and BMP usage.

NOTE
Refer to the example of the SWPPT in Appendix H. Personnel changes are documented and maintained in the Storm Water Notebook and submitted to EDMS.

7.2 *WBN Site Vice President*

Manages WBN's power generation and maintenance programs in a manner that ensures material storage and handling activities are consistent with environmental regulations and all applicable permits to maintain compliance with erosion and sedimentation control requirements.

7.3 *Plant Manager*

A. Ensures day-to-day management of activities related to plant operation, and that all materials are stored and handled in a manner which prevents their release into the environment.

B. Ensures a member of WBN senior management is designated for the coordination and implementation of requirements identified in this plan.

7.4 *Chemistry/Environmental Manager (CEM) or Designee*

A. Participates as the team leader for the SWPPT.

B. Provides erosion and sediment control training for personnel reasonably expected to perform duties identified in the SWPPP.

C. Establishes and maintains the SWPPP as a working document in compliance with TMSP requirements. Re-certifies SWPPP with each revision of the ECM. Ensures the SWPPP is reviewed and initiate amendments whenever there is a change in design, construction, or maintenance which significantly affects storm water discharge of pollutants; and when the SWPPP proves to be ineffective at significantly minimizing pollutants.

D. Reviews all proposed actions that will result in erosion: Approves or revises the initiating organization's written erosion control plan to specify additional BMP requirements as needed.

E. Directs the monthly erosion and sediment control inspections and other site inspections required to maintain TMSP compliance.

F. Ensures performance of monthly erosion and sediment control inspections by coordinating corrective actions with Facilities Services personnel.

G. Approves and signs the Annual Comprehensive Compliance Evaluation as the responsible corporate official.

H. Directs the required quarterly storm water visual examinations and the annual analytical storm water monitoring.

I. Submits annual analytical monitoring results in accordance with TMSP.

J. Submits storm water benchmark monitoring requirement exceedances (See Parameter Reporting Levels for Storm Water Discharges, Appendix C) and monitoring results in writing to the State as required by TMSP.

K. Ensures the Non-Storm Water Discharge Assessment is updated as needed.

L. Submits a NOI to the appropriate EAC upon expiration of the current permit or when there is a change in the design or operation of the facility that impacts storm water discharges.

M. Submits a Construction NOI to the appropriate EAC to obtain a Construction Storm Water Permit if an area of one or more acres per drainage area will be disturbed.

N. Escorts regulatory agencies, Environmental Assessment and Performance (EA&P), and other personnel performing site inspections.

7.5 *Chemistry/Environmental Section*

A. Participate as SWPPT members.

B. Maintain the SWPPP Notebook(s) containing all pertinent storm water information and data. The Notebook(s) shall be located in the Environmental Section or be readily available electronically.

C. Maintain a current list of SWPPT members and their duties in the SWPPP using Appendix G or its equivalent.

D. Provide storm water training to the SWPPT and maintain rosters in the SWPPP.

E. Maintain rainfall information documenting daily rainfall activity from the WBN meteorological tower along with the ECS response to rainfall events as part of the SWPPP.

F. Perform Quarterly Storm Water Visual Observations and collect Annual Analytical Monitoring samples in accordance with permit regulations and guidelines. Document storm water sampling results in the SWPPP using Appendix B (Refer to Appendices C and E for sampling parameters and site locations, respectively).

G. Inspect the site monthly and document the status of erosion/storm water control measures using Appendix A.

H. Recommend to the CEM preventative maintenance activities, BMP measures, and coordinate corrective actions with Facilities Services or the responsible Organizations.

I. Complete or assist with National Environmental Policy Act (NEPA) reviews for excavation/construction activities.

J. Submit to the CEM or designee an NOI and SWPPP at least 90 days prior to construction commencement if the excavation will disturb an area of one acre or greater. A Construction Storm Water Permit must be submitted to the state for excavations of this magnitude.

K. Manage WBN's SWPPP to ensure adequate erosion and sediment control for disturbances less than 1 acre; for disturbances >1 acre, ensure construction storm water permit is obtained.

L. Inspect the New Inert Landfill and the Old Demolition Landfill monthly and quarterly, respectively.

M. Conduct the Non-Storm Water Assessment as needed due to regulatory or facility changes.

7.6 ***Project Management, Site Engineering, Modifications and Maintenance, Facilities Services, Transmission and Power Supply, and Other Responsible Organizations***

A. Participate as team members on the SWPPT as needed.

B. Obtain excavation permits in accordance with TI-215, Work Permits that identify appropriate BMPs.

C. Maintain copies of all written erosion control plans and attach the erosion control plan to the work authorizing document.

D. Notify the CEM or designee prior to removing any vegetation that will produce an eroded area.

NOTE
No work may be performed until the CEM or their designee has approved the mitigation plan for erosion/storm water control.

E. Initiate and comply with NEPA requirements as required by SPP-5.13.

F. Notify the CEM at least 24 hours in advance if the proposed action will disturb **less than** one acre.

G. Notify the CEM prior to construction commencement if the excavation will disturb an area of **one acre or greater**. The CEM must be provided with detailed drawings or maps that include calculations of disturbed surface area acreage, the number of cubic feet of soil that will be excavated, and the BMPs that will be implemented to ensure erosion/sediment control. A Construction Storm Water Permit must be submitted to the state for excavations of this magnitude at least 90 days prior to work starting.

H. Implement appropriate erosion control measures/BMPs as specified in the SWPPP and/or as needed and/or directed by the CEM or designee.

I. Take appropriate and timely actions to upgrade or maintain erosion control devices as directed by the CEM or designee.

J. Furnish personnel and materials to perform any upgrading or maintenance of erosion control devices as directed by the CEM or designee.

7.6 *Project Management, Site Engineering, Modifications and Maintenance, Facilities Services, Transmission and Power Supply, and Other Responsible Organizations* (continued)

K. Supervise the application of fertilizers and herbicides around the plant.

L. Ensure concrete trucks return to the Concrete Facility to do washout operations of the concrete barrel on the truck in compliance with the Ready Mixed Concrete Facilities General Permit Number TNG110000.

M. Supervise the rinsing of concrete truck chute to comply with the WBN TMSP and avoid adverse impacts on storm water total suspended solids and pH parameters. The "chute rinse out" is restricted to the designated location in Drainage Area 13.

8.0 RECORDS AND CERTIFICATION

8.1 *QA Records*

Records are to be managed according to the Environmental Management System (EMS) Records Management Process and Standard Programs and Processes (SPP) Chapter 2.4, Records Management.

The following documents are Quality Assurance (QA) records when completed and submitted to EDMS. They should be verified and then transmitted for retention in accordance with the DCRM program.

A. Erosion/Storm Water Control Monthly Inspection Record (Appendix A)

B. Annual Analytical Monitoring and Quarterly Visual Observation Log (Appendix B)

C. Non-Storm Water Discharge Assessment (Appendix E)

D. Storm Water Pollution Prevention Plan Team (Appendix H)

8.2 *Non-QA Records*

Records are to be managed according to the Environmental Management System (EMS) Records Management Process and Standard Programs and Processes (SPP) Chapter 2.4, Records Management.

8.3 *Certification*

The following certification is provided for the SWPPP

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the site, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations. I also certify that these Outfalls have been tested or evaluated for the presence of non-storm water discharges.

I further certify that storm water discharges from Watts Bar Nuclear Plant are not *likely to adversely impact species listed in Addendum F of the Tennessee Storm Water Multi Sector General Permit for Industrial Activities.*

____

Signed:

Name:	Official Title:
Signatory Authority for:	Official Title:

Date Signed:________________________________

9.0 ACRONYMS AND DEFINITIONS

9.1 *Acronyms*

BMP - Best Management Practices

CEM - Chemistry/Environmental Manager

CFR - Code of Federal Regulations

DCRM - Document Control and Records Management

EAC - Environmental Assistance Center

ECM - Environmental Compliance Manual

EDMS - Environmental Document Management System

EMS - Environmental Management System

EP&P - Environmental Policy and Planning Staff

IPS - Intake pumping station

NEPA - National Environmental Policy Act

NOI - Notice of Intent (submitted to TDEC)

NOC - Notice of Coverage (form provided by TDEC)

NPDES - National Pollutant Discharge Elimination System

PER - Problem Evaluation Report

SPCC - Spill Prevention Control and Countermeasure

SPP - Standard Programs and Processes

SWPPP - Storm Water Pollution Prevention Plan

SWPPT - Storm Water Pollution Prevention Team

TDEC - Tennessee Department of Environment and Conservation

9.1 ***Acronyms* (continued)**

TDUST - Tennessee Department of Underground Storage Tanks

TMSP - Tennessee Storm Water Multi-Sector General Permit for Industrial Activities

WBN - Watts Bar Nuclear Plant

YHP - Yard Holding Pond

9.2 ***Definitions***

BEST MANAGEMENT PRACTICE (BMP) - Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the State. BMPs also include treatment requirements, operating procedures, and practices to control facility site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

BUFFER - An area composed of natural strips of preserved vegetation or installed vegetation through the staging of site grading and revegetation before grading of upland areas.

COLLECTION DITCHES - Ditches to collect storm water runoff and transport runoff in a controlled fashion to holding ponds or other containment structures.

COLOR - Results from the presence of natural metallic ions, humus and peat materials, plankton, weeds, and industrial wastes.

DIVERSION DIKES - Used to route storm water runoff away from exposed areas.

FILTER STRIPS - Strips of vegetation, usually sod, placed at intervals along the contour of a graded slope to control sedimentation.

FOAM - Froth on the water surface, an indicator of contamination.

FLOATING SOLIDS - Oils, greases, and other materials floating on the water surface that results in an undesirable appearance and obstructs the passage of light necessary for plant growth.

GRAB SAMPLE - A single storm water sample of at least 100 milliliters collected at a randomly selected time over a period not exceeding 15 minutes, collected within the first 30 minutes (or as soon as practical, but not to exceed one hour) of when the runoff begins discharging. Sample shall be representative of the total discharge, recognizing that a “first flush” sample is the most accurate representation for various pollutants in the storm water runoff.

9.2 *Definitions* (continued)

GROUND COVER - Cloth-like covering, made from natural materials, used to hold grass and seeds in place until vegetation can take hold. Ground cover is usually left in place, since it will decompose. Ground cover may also be considered to be gravel, rip rap, or natural vegetative cover employed to prevent bare ground from eroding.

INLET FILTERS - Vegetation or sod placed around or immediately up gradient of a storm drain inlet to control sediment. This vegetative control method may be used with other up gradient control practices.

LANDFILL - An area of land or an excavation in which wastes are placed for permanent disposal.

OIL SHEEN - A thin, glistening layer of oil on water that causes a rainbow effect on the water surface.

POLLUTION - The presence of any foreign substance (organic, inorganic, radioactive, or hazardous) which tends to degrade the water quality and constitutes a hazard or impairs the uses of the water.

QUALIFYING STORM EVENT - A storm event of a magnitude greater than 0.1 inch and that occurs a minimum of 72 hours after the last 0.1 inch rainfall. The TMSP allows certain exceptions for a qualifying event.

REPRESENTATIVE SITE - Two or more outfalls that the permittee reasonably believes to have substantially identical effluents. These sites are not monitored for reports sent to the State.

RETENTION SWALES - Hollows or depressions where sediment is allowed to settle.

ROCK CHECK DAMS - Sediment control dams constructed of rocks used to reduce or prevent excessive erosion by reduction of flow velocities.

SEDIMENT TRAPS - Small holding ponds where sediment is allowed to settle out as water evaporates or percolates into the soil.

SILT FENCING - Man-made materials erected across an exposed area which filters out sediment, allowing water to pass through.

STRAW BALE SEDIMENT BARRIERS - Temporary berms, diversions, or other barriers constructed of straw bales that retain sediment on site by retarding and filtering storm water runoff.

STORM WATER - The flow of water or surface runoff resulting from rainfall or snowmelt.

9.2 *Definitions* (continued)

STORM WATER NOTEBOOK(s) - A working document representing the WBN SWPPP. This documentation for permit compliance is maintained by Chemistry/Environmental and is located in the Environmental Section.

STORM WATER POLLUTION PREVENTION TEAM - Specific individuals responsible for developing the SWPPP and assisting senior management in the implementation, maintenance and revision of the SWPPP. The activities and responsibilities of the team shall address all aspects of the SWPPP.

SUSPENDED SOLIDS - Decomposing organic solids that cause odors/unsightly conditions or inorganic suspended solids that blanket the stream bed, adversely affecting benthos organisms.

SPILL AND OVERFLOW PROTECTION - Use of drip pans, drip diapers and/or other containment devices placed under chemical connectors for containment of spillage that might occur during vehicle repair, deliveries, or connector leaks. Required BMP for maintenance and repair areas.

VISUAL OBSERVATION - A visual inspection made of the runoff from a storm water area to determine quality of runoff. Includes color, turbidity, odor, and other visual characteristics.

10.0 REFERENCES

10.1 *Source Documents*

A. 40 CFR 112.5, Amendment of Spill Prevention Control and Countermeasure Plan by Owners or Operators

B. 40 CFR 122.26, Storm Water Discharges

C. EPA, Guidelines for Erosion and Sediment Control Planning and Implementation, EPA-R2-72-015. August 1972

D. EPA, Processes, Procedures, and Methods to Control Pollution resulting from All Construction Activities, EPA-430/9-73-007. October 1973

E. EPA, Storm Water Management for Industrial Activities Developing Pollution Prevention Plant and Best Management Practices, EPA-832-R-92-006. September 1992

F. Erosion and Sediment Control Plan, submitted to EPA Region 4, July 1984. Letter from M. R. Rivers, TVA to P. J. Traina, EPA Region 4, Atlanta, Georgia, July 1983

G. Evaporation/Percolation Pond Reclamation. Letter from TDEC, A. A. Holt, State Remediation Program, Division of Solid Waste Management. August 18, 1999.

H. General Tennessee Multi-Sector Permit for Storm Water Associated with Industrial Activities Permit No. TNR050000; WBNs' Coverage number is TNR051343, (effective June 1, 2009 through May 14, 2014).

I. NPDES Permit TN0020168, Part IV

J. SSP-13.03, Environmental Compliance

K. SWPPP (Storm Water Notebooks)

L. Storm Water in Tennessee, A Training Manual for Manufacturers, The University of Tennessee Center for Industrial Services. 1992.

M. Validity of an automatic sampler for visual observations and analytical sampling. Email from Vojin Janjic, TDEC. November 9, 2004.

N. Clarification that the waiver of the 72 hour interval also extends to individual outfalls, even if the rest of the facility had a discharge. Email from Vojin Janjic, TDEC. July 7, 2009.

10.2 *Interface Documents*

A. 1-PI-OPS-1-..., A Variety of Operator Rounds for Specific Areas

B. CM 6.03, Diesel Fuel control

C. CM-6.73, ISCO® Sampler Programming Instructions.

D. ECM Chapter 8, Spill Prevention Control and Countermeasures (SPCC) Plan

E. ECM Chapter 11; Solid Waste and Demolition Waste Landfill

F. Good Practice, OP-206, Generic Round Sheets and Shift Operating Practices

G. SOI-18.01 Fueling and Fuel Transfers

H. SPP Chapter 2.4, Records Management

I. SPP 3.1, Corrective Action Program

J. SPP-4.2, Material Receipt and Inspection

K. TI-215, Work Permits

Appendix A
(Page 1 of 2)

EROSION/STORM WATER CONTROL & SPCC INSPECTION RECORD

Date: ____________ Time: ____________ Inspected By: ____________

Drainage Area(s)	Primary Industrial Activity	Erosion/Storm Water Control Measures **REFER TO** page 2 for detailed descriptions of issues.
# 1, 2:	Main Plant Area	☐ Adequate ☐ Inadequate: Comment:
# 3:	Construction Switchyard, Lay down, & Outage Parking	☐ Adequate ☐ Inadequate: Comment:
# 4 & 15:	Non-Industrial Area	☐ Adequate ☐ Inadequate: Comment:
# 5 & 7:	Yard Ponds	☐ Adequate ☐ Inadequate: Comment:
# 6 & 8:	Special Waste Storage, Scrap Metal Bin	☐ Adequate ☐ Inadequate: Comment:
# 9 & 10:	Yard 2 & Old Landfill	☐ Adequate ☐ Inadequate: Comment: Date of last Old Landfill quarterly inspection________
# 11:	Yard 2	☐ Adequate ☐ Inadequate: Comment:
# 12:	Demolition Landfill	☐ Adequate ☐ Inadequate: Comment:
# 13:	RHP, Firing Range, & Borrow Area	☐ Adequate ☐ Inadequate: Comment:
# 14:	Warehouses, OSGSF	☐ Adequate ☐ Inadequate: Comment:
# 16:	IPS, Chemical Loading/Unloading	☐ Adequate ☐ Inadequate: Comment:
# 17:	WBF Ash Pond	Comment: Monitored by WBF NPDES permit

Inspect all Drainage Areas for the following	
Storm Drain Protection & BMP's	Corroded or damaged storage tanks
Broken or cracked dikes or berms	Torn bags or bags exposed to rain water
Corroded drums or drums without plugs or covers	Leaking pumps and/or hose connections

List new items from page 2: ____________

List closed items from page 2: ____________

Erosion/Storm Water Pollution Prevention Plan Requires Revision? ☐ Yes ☐ No

Inspector's Signature: ____________ Reviewed By: ____________

Appendix A
(Page 2 of 2)

EROSION/STORM WATER CONTROL & SPCC INSPECTION RECORD

________/________
(MONTH, YEAR)

NUMBER	LOCATION	DESCRIPTION	INSPECTION REPORTED DATE	PROJECTED CLOSURE DATE/INITIALS Responsible Section & ESC	COMPLETED INSPECTION DATE/INITIALS Of RESPONSIBLE SECTION & ENV.

Appendix B
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Analytical and Visual Monitoring

SW-1: ANNUAL ANALYTICAL MONITORING

Examiner:______________________________If collected by Grab sample; enter Date/time:____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________ Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) Was sample collection made within first 30 minutes of storm water discharge? ☐ Yes ☐ No
If no, why was collection within the first 30 minutes impracticable?________Was sample collection made w/in first hour of discharge? ☐ Yes ☐ No
Comments____

SW-1: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:___________________________Grab date/time:_____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe__________________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:____
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

Second Quarter (April - June) Examiner:_________________________Grab date/time:______________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe__________________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:____
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

Third Quarter (July - Sept.) Examiner:__________________________Grab date/time:______________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe__________________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:____
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

Fourth Quarter (Oct.-Dec.) Examiner:_________________________Grab date/time:_______________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe__________________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:____
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

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Analytical and Visual Monitoring

SW-2: ANNUAL ANALYTICAL MONITORING

Examiner:_______________ If collected by Grab sample; enter Date/time:__________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________ Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) Was sample collection made within first 30 minutes of storm water discharge? ☐ Yes ☐ No
If no, why was collection within the first 30 minutes impracticable?________Was sample collection made w/in first hour of discharge? ☐ Yes ☐ No
Comments__________________

SW-2: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:__________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________

Second Quarter (April - June) Examiner:__________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________

Third Quarter (July - Sept.) Examiner:__________________Grab date/time:__________________
If sampled by Isco ®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________

Fourth Quarter (Oct.-Dec.) Examiner:__________________Grab date/time:__________________
If sampled by Isco ®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________

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Analytical and Visual Monitoring

SW-3: ANNUAL ANALYTICAL MONITORING

Examiner:________________________________If collected by Grab sample; enter Date/time:______________
If sampled by Isco ®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________
Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) TSS (mg/L): ________ (If > 150 mg/L reported to State within 30 days); Date Reported________
3) Was sample collection made within first 30 minutes of storm water discharge? Yes No
If no, why was collection within the first 30 minutes impracticable?______________________________
Was sample collection made w/in first hour of discharge? Yes No Comments__________________________

SW-3: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:______________________________Grab date/time:______________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____________________________________

Second Quarter (April - June) Examiner:______________________________Grab date/time:______________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____________________________________

Third Quarter (July - Sept.) Examiner:________________________________Grab date/time:____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____________________________________

Fourth Quarter (Oct.-Dec.) Examiner:________________________________Grab date/time:____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____________________________________

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Analytical and Visual Monitoring

SW-4: ANNUAL ANALYTICAL MONITORING

Examiner:________________________________If collected by Grab sample; enter Date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________
Date of last qualifying storm event________Duration in hours since last event ≥0.10 in______ 1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) TSS (mg/L): ________ (If > 150 mg/L reported to State within 30 days); Date Reported________
3) Was sample collection made within first 30 minutes of storm water discharge? Yes No
If no, why was collection within the first 30 minutes impracticable?________________________________
Was sample collection made w/in first hour of discharge? Yes No Comments________________________________

SW-4: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:______________________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ________________________________

Second Quarter (April - June) Examiner:______________________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ________________________________

Third Quarter (July - Sept.) Examiner:______________________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches) 72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ________________________________

Fourth Quarter (Oct.-Dec.) Examiner:______________________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ________________________________

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Analytical and Visual Monitoring

SW-8: ANNUAL ANALYTICAL MONITORING

Examiner:______________________________If collected by Grab sample; enter Date/time:____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________ Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) Was sample collection made within first 30 minutes of storm water discharge? ☐ Yes ☐ No
If no, why was collection within the first 30 minutes impracticable?________Was sample collection made w/in first hour of discharge? ☐ Yes ☐ No
Comments____

SW-8: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:______________________________Grab date/time:__________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________

Second Quarter (April - June) Examiner:____________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________

Third Quarter (July - Sept.) Examiner:____________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________

Fourth Quarter (Oct.-Dec.) Examiner:____________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________

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Analytical and Visual Monitoring

SW-9: ANNUAL ANALYTICAL MONITORING

Examiner:________________________________If collected by Grab sample; enter Date/time:____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________ Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) Was sample collection made within first 30 minutes of storm water discharge? ☐ Yes ☐ No
If no, why was collection within the first 30 minutes impracticable?________Was sample collection made w/in first hour of discharge? ☐ Yes ☐ No
Comments____

SW-9: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:__________________________Grab date/time:__________________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe_______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:_______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

Second Quarter (April - June) Examiner:__________________________Grab date/time:______________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe_______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:_______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

Third Quarter (July - Sept.) Examiner:___________________________Grab date/time:______________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe_______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:_______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

Fourth Quarter (Oct.-Dec.) Examiner:___________________________Grab date/time:______________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe_______________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:_______________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ____

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Analytical and Visual Monitoring

SW-10: ANNUAL ANALYTICAL MONITORING

Examiner:________________________________If collected by Grab sample; enter Date/time:________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________
Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) TSS (mg/L): ________ (If > 150 mg/L reported to State within 30 days); Date Reported________
3) Was sample collection made within first 30 minutes of storm water discharge? Yes No
If no, why was collection within the first 30 minutes impracticable?________________________________
Was sample collection made w/in first hour of discharge? Yes No Comments______________________________

SW-10: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:__________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Second Quarter (April - June) Examiner:__________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Third Quarter (July - Sept.) Examiner:____________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches?☐ Yes☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Fourth Quarter (Oct.-Dec.) Examiner:____________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
72 Hours Since Last Event Greater than 0.10 inches?☐ Yes☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Appendix B
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Analytical and Visual Monitoring

SW-11: ANNUAL ANALYTICAL MONITORING

Examiner:______________________________If collected by Grab sample; enter Date/time:____________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________
Storm Event Duration (hours):________Estimate of Total Discharge Volume (gallons):________ Date of last qualifying storm event________Duration in hours since last event ≥ 0.10 in______
1) Iron (mg/L): ________ (If > 5.0 mg/L reported to State within 30 days); Date Reported________
2) Was sample collection made within first 30 minutes of storm water discharge? ☐ Yes ☐ No
If no, why was collection within the first 30 minutes impracticable?________Was sample collection made w/in first hour of discharge? ☐ Yes ☐ No
Comments____

SW-11: QUARTERLY STORM WATER VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:__________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________ RHP flow >454 gpm ☐ Yes ☐ No
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Second Quarter (April - June) Examiner:_________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________ RHP flow >454 gpm ☐ Yes ☐ No
72 Hours Since Last Event Greater than 0.10 inches? ☐ Yes ☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Third Quarter (July - Sept.) Examiner:___________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________ RHP flow >454 gpm ☐ Yes ☐ No
72 Hours Since Last Event Greater than 0.10 inches?☐ Yes☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Fourth Quarter (Oct.-Dec.) Examiner:___________________________Grab date/time:____________________
If sampled by Isco®, complete last page of Appendix B and attach to this form
Circle One: Snow/ice melt or Rainfall event Total Rainfall Amount (inches)________ RHP flow >454 gpm ☐ Yes ☐ No
72 Hours Since Last Event Greater than 0.10 inches?☐ Yes☐ No
1) Color: ☐ Colorless ☐ Amber/Brown Tint ☐ Gray Tint ☐ Other
2) Clarity: ☐ Clear ☐ Mild Turbidity ☐ Turbid
3) Floating Solids ☐ Yes ☐ No 4) Settled Solids ☐ Yes ☐ No 5) Suspended Solids ☐ Yes ☐ No If Yes, describe________________
6) Foam ☐ Yes ☐ No 7) Oil Sheen ☐ Yes ☐ No 8) Odor ☐ Yes ☐ No If Yes, describe:________________________________
Was sample collection made within first one hour of storm water discharge? ☐ ☐ Yes ☐ No
Describe potential pollutant source if contamination observed: ______________________________________

Appendix B
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Analytical and Visual Monitoring

SW-____: REPRESENTATIVE SAMPLE DETERMINATION: ANNUAL ANALYTICAL MONITORING

Examiner:______________________________
Isco®: Initiated date/time____________________Terminated date/time____________
Sample collected date/time:____________________ No. Of samples collected____________
Date/time ice added____________________ Date/time acid added (Fe only)____________
Comments:______________________________
Total amount of time between Isco® initiation and sample removal (hours) ________
(If sample held >12 hrs. or exposed to temperatures >40 °F; then Chem./Env. Staff must evaluate)
Isco® sampling corresponds to qualifying rainfall event: ☐ Yes ☐ No
Sample Representative: ☐ Yes ☐ No Initials________

SW-____: REPRESENTATIVE SAMPLE DETERMINATION: QUARTERLY VISUAL OBSERVATION LOG

First Quarter (Jan. - March) Examiner:____________________
Isco®: Initiated date/time____________Terminated date/time____________
Sample collected date/time:____________________ No. Of samples collected____________
Date/time ice added____________________ Date/time acid added (Fe only)____________
Comments:______________________________
Total amount of time between Isco® initiation and sample removal (hours) ________
(If sample held >12 hrs. or exposed to temperatures >40 °F; then Chem./Env. Staff must evaluate)
Isco® sampling corresponds to qualifying rainfall event: ☐ Yes ☐ No
Sample Representative: ☐ Yes ☐ No Initials________

Second Quarter (April - June) Examiner:____________________
Isco®: Initiated date/time____________Terminated date/time____________
Sample collected date/time:____________________ No. Of samples collected____________
Date/time ice added____________________ Date/time acid added (Fe only)____________
Comments:______________________________
Total amount of time between Isco® initiation and sample removal (hours) ________
(If sample held >12 hrs. or exposed to temperatures >40 °F; then Chem./Env. Staff must evaluate)
Isco® sampling corresponds to qualifying rainfall event: ☐ Yes ☐ No
Sample Representative: ☐ Yes ☐ No Initials________

Third Quarter (July - Sept.) Examiner:____________________
Isco®: Initiated date/time____________Terminated date/time____________
Sample collected date/time:____________________ No. Of samples collected____________
Date/time ice added____________________ Date/time acid added (Fe only)____________
Comments:______________________________
Total amount of time between Isco® initiation and sample removal (hours) ________
(If sample held >12 hrs. or exposed to temperatures >40 °F; then Chem./Env. Staff must evaluate)
Isco® sampling corresponds to qualifying rainfall event: ☐ Yes ☐ No
Sample Representative: ☐ Yes ☐ No Initials________

Fourth Quarter (Oct.-Dec.) Examiner:____________________
Isco®: Initiated date/time____________Terminated date/time____________
Sample collected date/time:____________________ No. Of samples collected____________
Date/time ice added____________________ Date/time acid added (Fe only)____________
Comments:______________________________
Total amount of time between Isco® initiation and sample removal (hours) ________
(If sample held >12 hrs. or exposed to temperatures >40 °F; then Chem./Env. Staff must evaluate)
Isco® sampling corresponds to qualifying rainfall event: ☐ Yes ☐ No
Sample Representative: ☐ Yes ☐ No Initials________

Appendix C
(Page 1 of 2)

Parameter Reporting Levels Of Storm Water Discharges

1.0 PARAMETER REPORTING LEVELS

EFFLUENT PARAMETER	CUT-OFF CONCENTRATION (mg/l)	MINIMUM MEASUREMENT FREQUENCY [1]	SAMPLE TYPE [2]
Total Iron [A]	5.0	Once / Calendar Year	Grab(Analytical)
Total Suspended Solids (TSS) [B]	150	Once / Calendar Year	Grab(Analytical)
Color [C, D]	**N/A**	Calendar Quarters	Grab (Observation)
Odor [C]	**N/A**	Calendar Quarters	Grab (Observation)
Clarity [C]	**N/A**	Calendar Quarters	Grab (Observation)
Floating Solids [C]	**N/A**	Calendar Quarters	Grab (Observation)
Settled Solids [C]	**N/A**	Calendar Quarters	Grab (Observation)
Suspended Solids [C]	**N/A**	Calendar Quarters	Grab (Observation)
Foam [C]	**N/A**	Calendar Quarters	Grab (Observation)
Oil Sheen [C, D]	**N/A**	Calendar Quarters	Grab (Observation)

Due to a 15 minute delay for the posting of Meteorological Tower Data Station (Met Tower) information for rainfall events, manual sample discharge collection may be conducted within one hour of flow before rainfall data is electronically available. After samples are collected, verification of the qualifying storm event will be conducted utilizing the Met Tower database. Samples collected from a non-qualifying event will be discarded.

Analytical Monitoring and Visual Observations collected with an Isco® Sampler equipped with a liquid activated switch (15 minute delay) may be substituted for manually collected samples. Appropriate comments for the collection method and initiation time will be made in the document log.

On page 9 of Sector O (part 5.1.2), the TMSP states that "The required 72-hour storm event interval is waived where the preceding measurable storm event did not result in a measurable discharge from the facility." TDEC has clarified that the waiver of the 72 hour interval also extends to individual outfalls which require substantial precipitation for a measurable runoff (even if the rest of the facility had a measurable runoff).

A. Iron analysis is required for all monitored storm water sampling sites (SW-1, SW-2, SW-3, SW-4, SW-8, SW-9, SW-10, and SW-11).

B. Total Suspended Solids analysis is required for downstream of the old demolition landfill (SW-3 and SW-10), and the new demolition landfill (SW-4).

Appendix C
(Page 2 of 2)

Parameter Reporting Levels Of Storm Water Discharges

1.0 PARAMETER REPORTING LEVELS (continued)

NOTES
1) Representative sites are not monitored: SW-1 represents SW-6.
2) Non-industrial sites, SW-5, SW-7, are not monitored.
3) Additional sampling the following year is required for missed Annual Analytical Monitoring samples.

C. Visual observations are to be performed quarterly. Sampling will be conducted either (1) manually, during daylight hours, within 1-hour and preferably within the first thirty (30) minutes of the rainfall event or (2) with an Isco® sampler within 15 minutes of flow and observed at the beginning of the next business day. Quarterly visual observations must be performed beginning the First Quarter in 2002 through the permit duration. Reasons for not performing visual examinations (e.g., adverse weather conditions) must be documented and retained with records of visual observations.

NOTE
No additional sampling is required for required for missed Quarterly Visual Observations; however, collecting a make-up sample is a preferred TVA practice.

D. Storm water discharge must not cause an oil sheen or objectionable color contrast in the receiving stream and must not result in release of materials in concentrations sufficient to be hazardous or otherwise detrimental to humans, livestock, wildlife, plant life, or fish and aquatic life in the receiving stream.

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Methods For Collecting Samples With An ISCO® Sampler

1.0 ISCO SAMPLER OPERATION

Storm water samples may be collected from monitored storm water sampling points using automated samplers such as the model 3700 Standard Isco® Sampler equipped with a liquid activator switch. See reference in Section 10.1M for TDEC authorization.

NOTE
Refer to CM-6.73, ISCO® Sampler Programming Instructions.

GENERAL ISCO® SAMPLER OPERATION INSTRUCTION

[1] **ENSURE** you have a fully charged battery installed and have a fully charged backup battery available if needed

[2] **PLACE** cleaned or new bottles in the base, **AND**

REPLACE the retaining ring so that it rests on top of the slanted portion of the bottles.

[3] **RECONNECT** the draw cords to the retaining ring to secure bottles

[4] **REMOVE** the bottle caps and store in a clean container.

[5] **ADD** sufficient nitric acid to the bottles collecting iron (Fe) samples to ensure preservation.

[6] **ATTACH** the strainer with tygon tubing leading from the sample pump suction to the back of the weir at the bottom of the "V" notch (or to other locations as appropriate to ensure a representative sample is collected).

[7] **ATTACH** liquid activator switch to the Isco® sampler with the contact end just above the bottom of the V notch.

[8] **REVIEW** the programming and configuration **AND**

ENSURE the sampler is programmed to collect two three (3) liter samples during the first 30 minutes of flow:

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Methods For Collecting Samples With An ISCO® Sampler

1.0 ISCO SAMPLER OPERATION (continued)

A. The first flush i.e. when the sampler is activated by flow

B. 15 minutes after the first flush

[9] **RECORD** in Appendix B the requested Isco® sampler information, **AND**

REQUEST an engineering evaluation of the TSS samples for potential holding time and temperature impacts to analytical results as per Standard Methods to determine if the sample may be analyzed as representative of the outfall.

NOTE
Icing the Isco® sampler during ambient temperatures greater than 40 F for an expected rainfall event is a preferred TVA practice.

[10] **COLLECT** storm water samples as soon as possible after the rainfall event **AND**

ENSURE delays are minimized in observing visual samples due to adverse conditions as listed in TMSP or for samples collected after normal business hours.

2.0 VISUAL OBSERVATION INSTRUCTIONS

[1] **DOCUMENT** the time the sampler initiated and the time of sample collection in Appendix B.

[2] **OBSERVE** the sample in the Isco® bottle for settled solids in a well lit area.

[3] **TRANSFER** the sample into a clean glass jar and secure with a lid, **AND**

INVERT the glass jar containing the sample three (3) times, allowing the air bubbles to rise to the surface each time.

[4] **OBSERVE** the sample for:

A. Color

Appendix D
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Methods For Collecting Samples With An ISCO® Sampler

2.0 VISUAL OBSERVATION INSTRUCTIONS (continued)

B. Clarity

C. Floating Solids

D. Settled Solids

E. Suspended Solids

F. Foam

G. Oil Sheen

H. Odor

I. Other Indicators of Storm Water Pollution

[5] **CHECK** the tygon tubing and Isco® bottle for signs of oil residue.

[6] **DOCUMENT** visual observations and sample collection by an Isco® sampler on forms similar to those found in Appendix B as required (refer to Appendix C, note 3) If negative observations are made, be sure to observe and document the potential sources for contamination.

3.0 ANALYTICAL SAMPLE INSTRUCTIONS

IF laboratory analysis is required per Appendices B and C:

[1] **TRANSFER** the sample into the appropriate analytical container(s).

[2] **PRESERVE** sample(s) not to be analyzed immediately as follows:

A. **TSS:** Cool to four (4) degrees Celsius and analyze within seven (7) days.

B. **Total Iron:** Acidify to a pH of <2 with nitric acid and analyze within six (6) months.

[3] **STORE** samples between 1 and 4 degrees Celsius without freezing.

[4] **VERIFY** a qualifying rainfall event has occurred.

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Methods For Collecting Samples With An ISCO® Sampler

3.0 ANALYTICAL SAMPLE INSTRUCTIONS (continued)

[5] **EVALUATE** representative status of the runoff sample based upon the time and temperature the Isco® sampler initiated and the time and temperature collection preservation techniques were applied.

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Non-Storm Water Site Assessment

SW OUTFALL	OBSERVATION DATE & OBSERVOR INITIALS	METHOD OF DETERMINA-TION	POTENTIAL SOURCES	RESULTS OF OBSERVATIONS DURING DRY WEATHER
SW 1 (AREA 4)	9/30/2002 DEC	VISUAL OBSERVATION	CHEM STORAGE (MIC Skid)	No flows observed from concrete swale to river intake.
SW 2 (AREA 8)	9/30/2002 DEC	VISUAL OBSERVATION	ASBESTOS & SPECIAL WASTE	No flows observed from industrial areas to perennial drain.
SW 3 (AREA 9)	9/30/2002 DEC	VISUAL OBSERVATION	YARD 2 AND OLD LANDFILL	No flows observed from warehouse to intermittent drain.
SW 4 (AREA 12)	9/30/2002 DEC	VISUAL OBSERVATION	NEW INERT LANDFILL	No flows observed.
SW 5 (AREA 6)	9/30/2002 DEC	VISUAL OBSERVATION	E/P POND, MET STATION	No flows observed from closed evaporation pond.
SW 6 (AREA 3)	5/20/2004 JLP	VISUAL OBSERVATION	CHEMICAL LIQUID (MIC) UNLOADING	No flows observed from concrete swale to river intake.
SW 8 (formerly SW 7) (AREA 3)	5/20/2004 JLP	VISUAL OBSERVATION	CONSTRUCTION SWITCHYARD DRAINAGE	No flows observed from Transformer Switchyard to drainage to Trench A.
SW 9 (formerly SW 8) (AREA 11)	5/20/2004 JLP	VISUAL OBSERVATION	YARD 2 CONSTRUCTION WAREHOUSE	No flows observed from Laydown Areas upstream of Horseshoe Pond.
SW 10 (formerly SW 9) (AREA 10)	5/20/2004 JLP	VISUAL OBSERVATION	RUN OFF FROM OLD DEMOLITION LANDFILL	No flows observed from the drainage ditch under the road from storm water drainage ditchline to the river.
SW 1 (AREA 4)	02/22/2007 JLP	VISUAL OBSERVATION	CHEM STORAGE (MIC Skid)	No flows observed from concrete swale to river intake.
SW 2 (AREA 8)	02/22/2007 JLP	VISUAL OBSERVATION	ASBESTOS & SPECIAL WASTE	No flows observed from industrial areas to perennial drain.
SW-3 (AREA 9)	02/22/2007 JLP	VISUAL OBSERVATION	YARD 2 AND OLD LANDFILL	No flows observed from warehouse to intermittent drain.
SW-4 (AREA 12)	02/22/2007 JLP	VISUAL OBSERVATION	NEW INERT LANDFILL	No flows observed.

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Non-Storm Water Site Assessment

SW OUTFALL	OBSERVATION DATE & OBSERVOR INITIALS	METHOD OF DETERMINA-TION	POTENTIAL SOURCES	RESULTS OF OBSERVATIONS DURING DRY WEATHER
SW-7 (AREA 3)	02/22/2007 JLP	VISUAL OBSERVATION	POTENTIAL LAYDOWN AREA	Flow observed, potential fire protection leak. PER # 121854 initiated to investigate and WO # 07-813954 to repair the leak.
SW-8 (AREA 3)	02/22/2007 JLP	VISUAL OBSERVATION	CONSTRUCTION SWITCHYARD DRAINAGE	No flows observed from Transformer Switchyard to drainage to Trench A.
SW-9 (AREA 11)	02/22/2007 JLP	VISUAL OBSERVATION	YARD 2 CONSTRUCTION WAREHOUSE	No flows observed from Laydown Areas upstream of Horseshoe Pond.
SW-10 (AREA 10)	02/22/2007 JLP	VISUAL OBSERVATION	RUN OFF FROM OLD DEMOLITION LANDFILL	No flows observed from the drainage ditch under the road from storm water drainage ditchline to the river.
(AREA 2)	12/18/2007 THL	VISUAL OBSERVATION	MAIN PLANT AREA	Water accumulation observed in front of the Fire House. PER # 135439 initiated to investigate and WO # 08-812029-000 to repair the potable water leak.
SW-7 (AREA 3)	04/22/2008 JLP	VISUAL OBSERVATION	LAYDOWN AREA	Walkdown following a qualifying rainfall event revealed two discrete water sources emanating from the stream bank.

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Non-Storm Water Site Assessment

SW OUTFALL	OBSERVATION DATE & OBSERVOR INITIALS	METHOD OF DETERMINA-TION	POTENTIAL SOURCES	RESULTS OF OBSERVATIONS DURING DRY WEATHER
SW-7 (AREA 3)	04/25/2008 JLP	VISUAL OBSERVATION	NON-INDUSTRIAL AREA	Beginning November 2007 trailers providing office space have been installed on the former concrete laydown pad. WBN removed all laydown materials from the old Interim Office Building site (IOB pad) on April 25, 2008. Modified NOI submitted to TDEC June 30, 2008 eliminating monitoring point.

Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the site, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signed: ________________________ Signatory Authority for: ________________________

Name: ________________________ Official Title: ________________________

Official Title: ________________________ Date Signed: ________________________

Appendix F
(Page 1 of 1)

Storm Water Sample Points

Sample Point	Location	Analytical Monitoring	Drainage Area	Representative Site
SW-1	In the concrete channel southwest of the Intake Pumping Station (IPS).	Iron	16	
SW-2	300 yards north of the Tennessee River and 75 yards east of SW-3, at the southern end of the drainage area.	Iron	8	
SW-3	300 yards north of the Tennessee River and 75 yards west of SW-2, at the southern end of the drainage area.	Iron, Total Suspended Solids	9	
SW-4	In the gravel channel northwest of the demolition landfill.	Iron, Total Suspended Solids	12	
SW-5	Down gradient of the closed evaporation/percolation pond area.	NA [A]	6	
SW-6	In the concrete channel northeast of the Intake Pumping Station (IPS).	NA	16	Represented by SW-1 [B]
SW-7	In the wet weather conveyance south if the east U2 office trailer site.	NA [C]	3	
SW-8	In storm water drain downstream from the construction switchyard.	Iron	3	
SW-9	Outside the culvert downstream and across the street from yard 2.	Iron	11	
SW-10	300 yards north of the Tennessee River at the drainage end of the horseshoe pond.	Iron, Total Suspended Solids	10	
SW-11	Discharge point at the south end of the Runoff Holding Pond (RHP)	Iron	13, 14	

A. Former monitoring site. **REFER TO** TDEC letter dated August 18, 1999 cited in references.

B. Representative Site Certification is located in the SWPPP.

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Narrative Description of Storm Water Drainage Areas

Detailed information regarding quantities, characteristics, storage, and handling of oils and chemicals at WBN is provided in the Spill Prevention Control and Countermeasure (SPCC) Plan. Specifically:

1. Inventories
2. Oil Storage
3. Chemicals and Characteristics
4. Transfer Operations
5. Temporary Waste Storage Operation
6. Emergency Actions and Response
7. Emergency Contacts
8. Spill History

Additionally, site waste disposal practices are described in ECM-5, Handling, Storage, and Disposal of Used Oil and Hazardous Waste, and ECM-11, Solid Waste and Demolition Waste Landfill.

Area 1
(NPDES Outfalls 101, 102):

The total surface area drained is 42 acres with approximately 34 acres of impervious surfaces. Ground cover consists of crushed stone, gravel, pavement, and some grass. The runoff coefficient is estimated to be high, above 0.65, and the overall Risk Assessment for this area is also high. This area along with Areas 2 and 16 has the largest potential for oil and chemical spills.

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Narrative Description of Storm Water Drainage Areas

Area 1 includes a parking lot and roof drainage from portions of the Turbine, Auxiliary, and Control Buildings; the Unit One Reactor Building; the Additional Diesel Generator Building; the Service Building; the Power Stores Building; the Makeup Water Treatment Plant, and temporary Unit 2 construction staff offices in the form of trailers. Buildings in this area have internal sumps for collection and containment of spills. If a spill occurs, the flow is into the yard drainage system which drains into the 22 acre YHP. The YHP provides treatment for NPDES permitted discharges and storm water runoff. It can also provide temporary retention for chemical spills and is equipped with an oil skimmer to prevent oil spills from leaving the pond 1. In addition, a portion of the switchyard is located in this area. Spills occurring outside of buildings or in the switchyard are minimized/controlled by the WBN SPCC and flow is to the YHP. Mineral oil spilled from a transformer will flow through the limestone underlayment before entering the drainage ducts which are part of the yard drainage system that drains to the YHP. There have been no spills experienced in this area which would expose residual materials to storm water.

Area 1 also contains the loading dock located off the Service Building and the Chemical Storage Building which houses the acid and caustic tanks. Various materials/supplies including lubricating oils, silicon oils, and various chemicals are off-loaded under cover at the dock. The quantities under roofs of several buildings change daily depending on plant use. The vicinity storm water drain shall be covered when unloading potential storm water contaminates. The Chemical Storage Building is equipped with secondary containment. Chemical off-loading procedures shall adhere to the site SPPC to minimize storm water contamination. The gasoline storage tank was removed from the area next to the loading dock on December 12, 1991.

Herbicides and fertilizers are applied approximately twice per year during the growing season in this area to control vegetative growth in yard areas and fence rows, and enhance the growth of grass in lawn areas.

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Narrative Description of Storm Water Drainage Areas

Area 2 (NPDES Outfalls 101, 102):

The total surface area drained is 49 acres which includes approximately 47 acres of impervious surfaces. The runoff coefficient is estimated to be high, above 0.65, and the overall Risk Assessment for this area is also high. This area, along with Areas 1 and 16, has the largest potential for oil and chemical spills.

This area includes the other halves of the Turbine, Auxiliary, and Control Room Buildings; the Unit Two Reactor Building; the Diesel Generator Buildings; the Lube Oil Tanks; Diesel Fuel Tanks; Cooling Towers (Nos. 1 & 2); the Power Stores Yard; the Corrosion Monitoring Laboratory; the Condenser Cooling Water Building, the Switchyard, additional temporary Unit 2 construction staff offices in the form of trailers, and Unit 2 laydown areas which include various sealands used to store construction materials. Buildings in this area have internal sumps for collection and containment of spills. If a spill occurs, the flow is into the yard drainage system which drains into the 22 acre YHP, an NPDES outfall with neutralizing, oil skimming, and sedimentation capabilities. Spills occurring outside of buildings are minimized and controlled by the WBN SPCC. Furthermore, drainage from this area is via drainage basin and subsurface piping to the YHP. Transformer mineral oil spillage will initially flow through the limestone underlayment before entering the yard drainage system that drains to the YHP. Primary spills can occur from the chemical storage areas and from the other sources of oil and hazardous chemicals. Diesel fuel off-loading is performed in the area adjacent to the two diesel fuel tanks. Control measures include secondary containment and berms for the chemical storage areas and fuel off-loading areas as specified in the WBN SPCC and 1-PI-OPS-1....[1]

On May 2, 2000, estimated less than twenty-five gallons of diesel fuel were released from piping associated with an underground storage tank. A suspected release was reported to state authorities followed by confirmation of the release after extensive piping integrity tests. Assessment results indicated minimal impact due to the geological isolation of the spill location and the apparent intercept of the release by the storm drainage system. This issue was closed on July 23, 2004, with the Tennessee Department of Underground Storage Tanks (TDUST).

Herbicides and fertilizers are applied approximately twice per year during the growing season in this area to control vegetative growth and enhance the growth of grass in lawn areas.

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Narrative Description of Storm Water Drainage Areas

Area 3
(TMSP Outfall SW-8):

The total surface area drained is 132 acres. This area is primarily non-industrial and consists mainly of trees and grass, a wetland, a Construction Switchyard, the North Portal, gravel parking lots, Unit 1 and 2 Cooling Towers, and a Desilting Basin. Ground cover consists primarily of natural vegetation. The non-industrial runoff coefficient is estimated to be low to medium, less than 0.40; and the industrial runoff coefficient is estimated to be high, greater than 0.65. The Risk Assessment for the non-industrial area is low, increasing to high for the industrial portion land-use changes as described below. As shown in the site map, this area is monitored for storm water runoff at SW-8 in accordance with TMSP [1].

Post WBN Plant construction, land-use in the northern portion of this drainage area underwent changes from industrial to non-industrial. Around 1994, the northwest yard area was reclaimed to meadow land as part of a site improvement project. In May 2006 as preparation for the September 2006 Steam Generator Replacement Project (SGRP), a portion of meadow east of the Construction Switchyard was reconverted to a gravel parking lot and laydown area. The North Portal was re-opened January 8, 2008 to permit plant access for construction vehicles and workers. As a component of the Unit 2 construction, the former decomissioned construction switchyard was upgraded and placed back into service May 2008. Approximately 5 acres is designated as semi-permeable as the aforementioned land-use changes have been implemented.

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Narrative Description of
Storm Water Drainage Areas

Drainage in the northern portion of Area 3 south of the northwest yard area is ditched and piped to an ephemeral stream which converges with two wet weather conveyances east of the Delta Gate and south of the railroad tracks and three designated wetlands. This portion of the stream, known as Trench A, has been channelized for plant flood control technical specifications. Trench A drains east then southeast into a wetland before discharging into the Tennessee River. SW-8 was formally located in the ephemeral stream downstream from the Construction Switchyard and the outage gravel parking lot [1]. In August 2006, SW-8 was moved downstream below the pedestrian bridge when additional acreage in Area 3 was utilized as parking and material laydown storage areas. After the completion of the SGRP, SW-8 was relocated to its original location downstream of the Construction Switchyard. Due to water pooling in the discharge pipe, SW-8 was moved to the storm water drain downstream of the Construction Switchyard in May 2008. SW-8 was once again relocated to its original location downstream of the Construction Switchyard post maintenance activities in Trench A to restore flow the summer of 2009. Runoff from the second proposed laydown area (east of the North Portal) as well as the North Portal was monitored by SW-7. This former storm water sampling point was located in a wet weather conveyance which drains into the same stream path as identified above for SW-8 [1]. Presently, surplus non-PCB transformers are stored in the Construction Switchyard with secondary containment in compliance with EPA regulations.

In support of WBN Unit 2 construction, additional temporary engineering staff offices in the form of approximately fourteen 70 foot long triplewide trailers, and three doublewide trailers (bathroom, breakroom, power distribution) were located on the concrete laydown pad east of the north portal with construction beginning November 2007. The bathroom and breakroom trailers were connected to the existing WBN sewer system which discharges to the Spring City POTW. WBN removed all laydown materials from the old Interim Office Building site (IOB pad) on April 25, 2008. A modified NOI was submitted to TDEC June 30, 2008 eliminating monitoring point SW-7 due to land changes from industrial to non-industrial and receiving constant flow via an underground spring. In addition, Unit 2 utilizes the same parking/laydown areas previously described to support the SGRP and expanded the parking area into the meadow west of the Construction Switchyard. During the summer of 2009, Unit 2 construction parking areas were expanded north into the ball field. Under ARAP-NRS09.163 a former road to allow access to the ball field parking lot was re-established, a pedestrian footbridge was constructed over Trench A and maintenance activities were performed in the trench to restore proper drainage and to ensure the integrity of the jurisdictional wetland downstream.

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Narrative Description of Storm Water Drainage Areas

For the SGRP and Unit 2 construction industrial land-use, spill control measures as described in the WBN SPCC were implemented to prevent or minimize storm water contamination. There are no fuel off-loading facilities in this area and mobile vehicles were refueled off-site. No spills have been experienced in this area which would expose residual materials to storm water.

Herbicide and fertilizers are applied approximately twice per year during the growing season in this area to control vegetative growth in yard areas and enhance the growth of grass in lawn areas.

Area 4
(No storm water monitoring - no industrial activity; NPDES Outfalls 101, 102):

The total surface area drained is 91 acres. This drainage area contains a small portion of the YHP (OSN 102), is non-industrial and the ground cover consists primarily of trees, shrubs, and grass. The runoff coefficient is estimated to be low, less than 0.40; and the Risk Assessment is also low. Storm water drainage is primarily sheet-flow over vegetated, non-industrial land to a drainway, which collects runoff from other areas and drains into the waters of the U.S. The runoff the diffuser discharge (OSN 101) is located in this area. In accordance with the TMSP, this area does not require storm water monitoring [1].

A broken supply line which fed a temporary pumping system located adjacent to the yard holding pond, spilled diesel fuel into the pond and less than one gallon of fuel (estimated) reached the water of the U.S., on September 28, 1989.

Herbicides and fertilizers are spot-applied approximately twice per year during the growing season in this area to control vegetative growth and enhance the growth of grass in the area.

Area 5
(No storm water monitoring - no industrial activity; NPDES Outfall 101):

The total surface area drained is 37 acres which includes approximately 22 acres of the YHP. The remaining 15 acres adjacent to the YHP are naturally vegetated and considered pervious. The estimated runoff coefficients are 1.0 in the YHP and less than 0.40 in the vegetated area; the Risk Assessment is low for this area. Storm water drainage is directly into the YHP, then routed via a drainage system to the diffusers (OSN 101) into the river [1]. In accordance with the TMSP, this area does not require storm water monitoring [1].

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Narrative Description of Storm Water Drainage Areas

There is no material storage in this area and subsequently no material loading or access areas. There have been no spills experienced in this area.

Herbicides are applied approximately twice per year during the growing season to control vegetative growth along the rip-rap.

Area 6 (No storm water monitoring - no industrial activity):

The total surface area drained is 29 acres and includes approximately 1 acre of gravel parking and dirt road. This drainage area is non-industrial and the ground cover consists primarily of trees, shrubs, and grass. The runoff coefficient is low, less than 0.40 and the Risk Assessment for this area is also low. The Meteorological Data Station, Meteorological Tower, and the closed Evaporation/Percolation pond (E/P pond) are located in this area.

The Meteorological Data Station houses office equipment and related supplies to support data transmitted from the adjacent meteorological tower. Approximately 250 gallons of propane gas are stored in this area.

The E/P pond was formally monitored by SW-5. However, the E/P pond was permanently closed and documented by WBN during the summer of 1999 and reclaimed to meadow land as part of a site improvement project. TDEC authorization of no further action required in regards to the Evaporation/Percolation Pond Reclamation Project is cited in the references. In accordance with the TMSP, this area does not require storm water monitoring [1].

There have been no spills experienced in this area.

Herbicides are spot-applied approximately twice per year during the growing season to control vegetative growth along fence rows.

Area 7 (NPDES Outfall 103, 107, 101):

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Narrative Description of Storm Water Drainage Areas

The total surface area drained is 18 acres which includes approximately 7 acres of impervious surfaces. The estimated runoff coefficient is 1.0 in the ponds, and greater than 0.40 in the surrounding terrestrial area. The overall Risk Assessment is low. This area consists of the 3.72 acre Low Volume Waste Treatment Pond (LVWTP), the 1 acre alum sludge ponds, the metal cleaning waste ponds (1-MG or 1.3 acre lined pond, 5-MG or 0.26 acre unlined pond), and the temporary waste storage area.

The ponds receive pumped plant influents, precipitation, and storm water runoff. The LVWTP (OSN 103) is a NPDES treatment facility that provides neutralization, oil skimming, and sedimentation to waste water [1]. A portion of this waste water is the alum sludge ponds gravity drained supernatant. Both the LVWTP and the metal cleaning waste ponds (OSN 107) are released to the 22 acre YHP, (OSN 101) an NPDES permitted discharge point that can also provide temporary retention for chemical spills and is equipped with an oil skimmer to prevent oil spills from leaving the pond [1]. Storm water drainage flows primarily over land into the aforementioned ponds and ultimately to the YHP.

Unauthorized access to the temporary waste storage area is restricted by a locked gate and a fenced perimeter. All drums are stored as specified in the WBN SPCC. Any spillage or leaks from the temporary waste storage area is contained in the secondary confinement spill pan. Leaks from the secondary confinement spill pan or used oil tanker will be contained by the berm surrounding the areas. The berm area has a valved drain to the LVWTP. Discharge from the LVWTP into the YHP is controlled by two manually operated valves.

Herbicides are applied approximately twice a year during the growing season to control vegetative growth around the treatment ponds.

Area 8
(TMSP Outfall SW-2):

The total surface area drained is 27 acres of which there are approximately 8 acres of impervious surfaces. Runoff coefficient is estimated to be low to medium, approximately 0.44, and the Risk Assessment is moderate. Approximately 30 per cent of this area is associated with industrial activity. The northern section is a flat grassed area that contains the special waste storage area, the scrap-metal storage bin, waste disposal bins, and the heliport. The lower section is non-industrial, predominately a hilly, tree covered, narrow strip of land with a long drainage valley. This area is the site of the dismantled old dairy farm buildings and red barn.

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Narrative Description of Storm Water Drainage Areas

The general direction of surface water drainage is toward the Tennessee River via the drainage valley and the drainway to the river. As shown on the site map, the storm water runoff is via a drainage valley that begins in the industrial area and drains through the non-industrial area. In accordance with TMSP, SW-2 is located near the end of this drainage valley [1].

The special waste storage area is protected from unauthorized access by a locked gate and a fenced perimeter. All drums are stored as specified in the WBN SPCC. Leaks will be contained by the berm surrounding the area. The berm area has a valved drain aligned to the surface and releases ultimately drain to SW-2. Releases of the berm area are in accordance with the site SPCC to prevent or minimize storm water contamination. Oil and chemical storage in this area is minimal. The heliport consists of a concrete pad and has not been used in several years. There have been no spills experienced in this area which would expose residual materials to storm water.

Herbicide is spot-applied to fence rows approximately twice a year during growing season to control vegetative growth.

Area 9
(TMSP Outfall SW-3):

The total surface area drained is 47 acres which includes approximately 15 acres of impervious surfaces. The overall estimated runoff coefficient is low, approximately 0.30. This is coefficient calculated from impervious surfaces with a high, greater than 0.65, coefficient, and low, less than 0.40 in the surrounding terrestrial area. The overall Risk Assessment is moderate. Approximately 35 percent of this area is associated with industrial activity, and the remaining area is natural vegetation. The industrial area contains the eastern section of Yard 2, Unit 2 laydown construction materials (including, but not limited to carbon steel structural shapes, carbon steel pipes and fittings, carbon steel plate), an office building, a shed, a rock and gravel staging area, and a portion of the old demolition landfill. The landfill is closed and has been reclaimed to meadow land. Ground cover consists of crushed stone, gravel around the building and shed, and natural vegetation on top of the landfill and non-industrial areas. Storm water drainage from Yard 2 and the buildings is overland to two drainways that merge into a single channel that also receives runoff from the closed landfill. The site map shows the location of storm water sampling point SW-3 near the end of the drainage area in the intermittent drainage channel [1].

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Narrative Description of Storm Water Drainage Areas

The office building houses office furniture and minimal amounts of heavy equipment lubricant is stored in a locked fireproof cabinet. Various maintenance heavy equipment is staged on a gravel surface in this area and oil pads are located in close proximity. Construction materials and scaffolding are stored in the shed. There have been no spills experienced in this area which would expose residual materials to storm water.

Herbicide is spot-applied to fence rows approximately twice a year during growing season to control vegetative growth.

Area 10
(TMSP Outfall SW-10):

The total surface area drained is 37 acres of vegetated areas. The runoff coefficient is estimated to be low, approximately 0.27, and the Risk Assessment is low. This drainage area is nearly equally divided between a portion of the old, closed demolition landfill; and non-industrial land-use. The ground cover consists primarily of trees, shrubs, and grass.

As depicted in the site map and in accordance with TMSP, landfill storm water runoff is monitored by SW-10 at the end of this drainage valley [1].

Herbicide is spot-applied to fence rows twice a year during growing season to control vegetative growth.

Area 11
(TMSP Outfall SW-9):

The total surface area drained is 77 acres which includes approximately 18 acres of impervious surfaces. The estimated runoff coefficient is high, approximately 0.65 for the impervious surfaces in Yard 2. The overall runoff coefficient is estimated to be low to medium, approximately 0.30, and the Risk Assessment is moderate. This area includes a major part of the warehouses in Yard 2, a laydown area for Unit 2 construction materials (including, but not limited to galvanized steel conduit, stainless steel pipe, painted structural steel shapes, painted pipe and fittings) and transformers. The area around the warehouse building consists of crushed stone, and gravel, while the remainder of the drainage area is naturally vegetated.

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Narrative Description of
Storm Water Drainage Areas

Lawn maintenance equipment and chemicals are stored in a shed with a concrete floor. Pesticides, herbicides, fertilizers, and equipment oil are stored in locked cabinets located inside a warehouse. Access to these materials is restricted as the chemical cabinet is locked and the warehouse doors are locked at night. Plant outage supplies, (i.e. cables, lumber, office furniture), and Plant Services materials and cleaning supplies are stored in separate warehouses equipped with concrete floors.

This drainage area is monitored for storm water runoff at in accordance with TMSP [1]. As shown on the site map, SW-9 is located along the road leading to the site demolition landfill, down gradient of Yard 2 and upstream of the horseshoe pond [1]. General surface water drainage is directed from the high points of land through and around the horseshoe pond to a perennial stream with eventual connection to waters of the U.S.

Herbicides and fertilizers are applied approximately twice per year during the growing season in this area to control the vegetative growth in yard areas and fence rows and enhance the growth of grass in lawn areas.

Area 12
(TMSP Outfall SW-4):

The total surface area drained is 163 acres which includes approximately 1 acre of impervious surfaces. The estimated runoff coefficient is high for SW-4, approximately 0.70, and low, approximately 0.10 in the surrounding vegetated area. The overall Risk Assessment is moderate. Area 12 is almost entirely non-industrial and naturally vegetated. As shown on the site map this area includes the demolition landfill, which is monitored by SW-4 in accordance with the TMSP [1]. In support of general plant operations and the SGRP, a spoils pile, measuring less than one (1) acre, for excavated soil is located in the North West portion of this drainage area.

Oil and chemical storage in this area is nonexistent.

General surface water drainage is sheet-flow directed to an unnamed tributary of Yellow Creek and then into the Tennessee River. Storm water sampling point SW-4 is located in a discrete drainage channel down gradient from the spoils pile and new demolition landfill [1]. This sampling point intercepts approximately 20 acres of drainage area of which 75 percent is associated with industrial activity.

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Narrative Description of
Storm Water Drainage Areas

Herbicides and fertilizers are applied approximately twice per year during the growing season in this area to control the vegetative growth around fence rows and enhance the growth of grass in specified areas.

Area 13
(NPDES Outfall 112 a.k.a. TMSP Outfall SW-11: pending receipt of Division Notification of NPDES Minor Modification):

The total surface area drained is 166 acres containing six incoming streams to the RHP, with approximately 35 acres of impervious surfaces. The estimated runoff coefficient is high, greater than 0.65 for the impervious surfaces, and low, less than 0.40 in the surrounding vegetated area. The overall Risk Assessment is high. This area includes portions of the warehouse Yard 1 with laydown areas and buildings [Unit 2 Receiving Warehouse, 2 Equalization Tanks (inside a building; relics of the former Sewage Treatment Plant), the Environmental Field Laboratory, Huts 4, 5, 6, 7, 8, 20, 22, 23, and 24; laydown pad 9 will be covered in April 2009 in preparation for staging oxygen acetelyn], Concrete Truck Chute Washout area, the Borrow Area, the Firing Range, the 3.1 acre Runoff Holding Pond (RHP), the Training Center, and parking lots. Ground cover consists of crushed stone, gravel around the warehouses, pavement on the parking lots, trees and grass around the Training Center and on the remaining north and south ends.

Transformers and construction materials including, but not limited to, steel beams, water separators, water separator crossover pipes, cables, transformers, electrical wire, and gravel are staged in the laydown area. The huts are utilized for material storage consisting of plant equipment, field supplies, chemical and oil storage, Radiation Protection equipment, and site office supply procurement items. The concrete truck chute washout area is located on a concrete pad surrounded by graveled areas. Residue/runoff from concrete truck chute rinsing conducted in this area is captured/contained by hay bales and/or jersey barriers lining the perimeter and is not permitted to reach a receiving stream. Excavation of clay from the Borrow Area is kept to less than one acre at all times and is reseeded immediately once the clay has been extracted.

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Narrative Description of Storm Water Drainage Areas

Beginning November 2007, in support of WBN Unit 2 construction, additional temporary staff offices in the form of 70 foot long doublewide trailers were located in the grassy area east of the Dynamic Learning Center (DLC) and across the street from the firing range, numbering four and one respectively in addition to one bathroom trailer at each location. The DLC bathroom trailer connects to the WBN sewer system, which discharges to the Spring City Publicly Owned Treatment Plant (POTW), while the firing range improvement includes an additional septic tank and septic field. The area north and east of the DLC was graveled to provide additional temporary parking for training participants. A 12X20X5' pre-fabricated, galvanized steel carport shelter may be erected east of the shooting tower to provide participants shelter from the elements. No significant change to the overall runoff coefficient is expected to occur with these site changes as the impacted area is insignificant relative to the drainage area.

The former STP and the RHP were/are NPDES permitted outfalls, OSN 111 (effluent monitoring point of the STP) and OSN 112 respectively [1]. The WBN STP was connected to the Spring City POTW on August 9, 2008 and the effluent box was completely filled in with gravel on October 3, 2008. A request for NPDES Minor Modification - Termination of Discharges from Internal Monitoring Point (IMP) 111 was sent to the Division on September 10, 2008. General surface water and drainage of the warehouse, Training Center, and parking lots is routed to OSN 112. The runoff is discharged through a drainway, enter the RHP and go through Outfall 112. The RHP provides temporary retention for precipitation runoff from the entire drainage area as well as chemical spills not dissolved in water and is equipped with an oil skimmer. Any spill that may occur in small quantities can be minimized and controlled by the WBN SPCC. The RHP discharges into an unnamed tributary of Yellow Creek and then into the Tennessee River.

Construction of additional Receiving Warehouse Buildings and a loading dock adjacent to the existing Receiving Warehouse and Storage Warehouses in Yard 1 began spring 2008. These buildings were

Following termination of IMP 111, WBN re-routed the remaining industrial effluent to the RHP, the Training Center Cooling Tower Blowdown, to OSN 101. On April 1, 2009, WBN submitted a request for NPDES Minor Modification - Termination of NPDES monitoring for Outfall 112. In addition, a revised NOI, topographical map and a revised Biocide Corrosion Treatment Plan (B/CTP) were also sent to the Division to include SW-11 (former OSN 112) as a TMSP monitoring point.

Herbicide is spot-applied to fence rows approximately twice a year during growing season to control vegetative growth.

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Narrative Description of
Storm Water Drainage Areas

Area 14
(NPDES Outfall 112 a.k.a. TMSP Outfall SW-11: pending receipt of Division Notification of NPDES Minor Modification):

The total surface area drained is 42 acres with approximately 30 acres of impervious surfaces. The runoff coefficient is high, greater than 0.65, and the Risk Assessment is high. This area consists of a warehouse receiving and parking lot, an equipment building, the warehouse building A-D complex, and Huts 4 and 5. In preparation for the SGRP and Unit 2 construction, Huts 4 and 5 will be used to store hazardous materials. While both huts are located on flat areas and contain concrete floors, those housing chemicals, oil, or hazardous material shall also be equipped with appropriate secondary containment as required by the site's SPCC Plan. Post SGRP and Unit 2 construction, WBN will continue to utilize Huts 4 and 5 for hazardous material storage purposes. Also in support of the SGRP, a concrete bunker was constructed west of Warehouse D to store the old stream generators (OSGSF). Ground cover consists of pavement, crushed stone, gravel around the warehouses, and trees and grass at each end of this Drainage Area.

Materials within this area are stored under roof and are not in contact with storm water. Material storage consists of paints, solvents, thinners, blasting material, heavy equipment lubricating oils and other chemicals either in refillable totes, 55-gallon drums, or smaller containers. Warehouses are equipped with concrete floors and berms, and materials are stored within secondary containment as specified in the WBN SPCC. There have been no spills experienced in this area which would expose residual materials to storm water.

General drainage for most of the warehouse area is routed to the RHP (OSN 112/TMSP SW-11), currently an NPDES permitted treatment facility and discharge point [1]. Any spill that may occur in small quantities can be minimized and controlled at the point of origin by the WBN SPCC. Spills of waste oil, hazardous chemicals, or hazardous waste outside the secondary confinement can flow to the RHP where confinement for cleanup is provided for oils and other floating materials only. Water soluble chemicals will not be contained within the pond boundaries.

General surface water drainage is directed into the RHP which discharges into an unnamed tributary of Yellow Creek and then into the Tennessee River.

Herbicide is spot-applied to fence rows twice a year during growing season to control vegetative growth.

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Narrative Description of
Storm Water Drainage Areas

WBN formerly treated all wastewater via the site Sewage Treatment Plant. Effluent was discharged via two NPDES outfalls, OSN 111 and OSN 112. WBN began construction along the Nuclear Plant Road for the Tie-in to Spring City Wastewater Treatment System on December 11, 200. The date of tie-in completion was August 9, 2008 and the effluent box was completely filled in with gravel on October 3, 2008.

Area 15
(No monitoring - no industrial activity):

The total surface area drained is 8 acres with no impervious surfaces. The estimated runoff coefficient is estimated to be low, less than 0.40. This area is non-industrial and wholly wooded. No oils or chemicals are stored in this area. In accordance with the TMSP, this area does **NOT** require storm water monitoring [1].

General surface water drainage is directed from the high points of land down onto non-TVA property before joining the unnamed tributary of Yellow Creek and then into the Tennessee River.

Area 16
(TMSP SW-1, SW-6)

The total surface area drained is 4 acres, ninety (90) percent of which are impervious surfaces. The runoff coefficient is estimated to be high, above 0.65, and the Risk Assessment is also high. This area is associated with industrial activity and includes the Biocide injection area, a chemical loading/unloading area, a small parking lot, the cooling water intake area, and the IPS. The sodium bromide and sodium hypochlorite (BCDMH) injection area, the Biocide injection area, and the microbiological induced corrosion chemical injection area are housed in discrete sheds outside of the IPS structure. The liquid sodium hypochlorite tank is housed in a concrete basin on the east side of the IPS just in front of the BCDMH tank. The secondary containment basin will contain approximately 8900 gallons of liquid to accommodate complete tank leakage plus 1' freeboard for potential storm water in accordance with the WBN ECM-8, Spill Prevention Control and Countermeasure (SPCC) Plan. Storm water releases will be accomplished via a release valve (pad locked) per WBN CM-4.10 and WBN ECM-8 rev 26.

As shown on the site map, this area is monitored for storm water runoff at SW-1 and SW-6 in accordance with TMSP [1]. These sampling points have the potential of receiving an equal mix of chemically impacted effluent and are located on opposite sides of the IPS at the bottom of concrete storm water channels. The former is located on the west side of the IPS and the latter is located on the east side.

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Narrative Description of Storm Water Drainage Areas

A spill resulting from chemical loading/unloading in this area has the potential to flow to either SW-1 or SW-6. While all containers have secondary confinement, spills that escape the secondary confinement dike will flow into the waters of the U.S. Storm water drainage from the IPS is sheet-flow to a drainway, which collects runoff from other areas and drains into the waters of the U.S.

On June 12, 1990, an estimated one hundred and twenty gallons of 12 percent sodium hypochlorite were released from a broken pipe. The spill was contained near the IPS, neutralized with sodium bisulfite, and cleaned up.

Less than one pound of bromine gas was released from the decomposition of bromo-chloro, dimethylhydantoin at the brominator in August 1993. This release was reported to authorities because it was **NOT** immediately apparent that less than the reportable quantity had been released.

Area 17
(No monitoring)

The total surface area drained is 12 acres with no impervious surfaces. The estimated runoff coefficients are 1.0 in the Ash Pond and less than 0.4 in the surrounding vegetated area. This area contains the Watts Bar Fossil (WBF) Ash Pond and is separated from the WBN drainage areas by a topographic divide. This area is not a drainage area for WBN. WBF is no longer in operation and the Ash Pond's discharge is addressed under the WBF NPDES permit.

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Storm Water Pollution Prevention Team

REFER TO the Storm Water Notebook for the most recent team list as required by the TMSP. Personnel changes are to be documented in EDMS as they occur utilizing this appendix or its equivalent.

LEADER: Jerri L. Phillips Office Phone 423.365.3576	TITLE: Environmental Scientist Pager Number 1.800.323.4853 # 91316
Responsibilities: Prepares site specific procedures for SWPPP implementation for controlling erosion and sedimentation. Provides an annual review and updates SWPPP. Provides instructions to assure continuing compliance with the Storm Water Regulations. Performs and documents site Erosion/Storm Water Control Inspections, and coordinates corrective actions with Steam Generator, Facilities Maintenance, and Modifications personnel as needed. Performs semi-annual site inspections. Maintains site records and inspection report forms. Provides SWPPP site training. Ensures SWPPP and Rainfall Notebook are maintained. Generates Storm Water Annual Report submitted to the State.	
MEMBER: Darrin Hutchison Office Phone: 423. 365.8016	Chemistry/Environmental Technical Support Manager Pager Number 1.800.323.4853 # 11262
Responsibilities: Ensures the overall management of activities related to operating the plant such that all materials are stored and handled in a manner preventing their release into the environment. Maintains all procedures for the SPCC Plan and SWPPP. Ensures annual reports, etc. are submitted to the State. Ensures notification of the State and other environmental agencies in event of a spill or environmental accident. Responsible for solid and hazardous waste, chemical traffic control, and SPCC Plan updates.	
MEMBER: Delmas E. Clark Office Phone: 423.365.3574	Environmental Technician Pager Number 1.800.323.4853 # 11182
Responsibilities: Duties encompass implementation of SWPPP and SPCC programmatic elements. Storm water sample collection; maintains SWPPP and Rainfall Notebooks.	
MEMBER: Dawn Booker Office Phone: 423.365.8005	Environmental Scientist Pager Number 1.800.323.4853 # 19018
Responsibilities: Back-up SWPP lead. Reviews and approves the site Erosion/Storm Water Control Inspection Reports. Responsible for site specific SPCC Plan implementation and prepares procedure updates. Maintain Above Ground Storage Tank site record and inspection report forms. Responsible for solid waste, hazardous waste, and chemical traffic control program implementation and procedure updates. Maintain waste and landfill site record and inspection report forms.	
MEMBER: Mike Browman Office Phone: 423-751-7341	Environmental Engineer
Responsibilities: Provides assistance and advice from the Corporate perspective	
MEMBER: Steve Williams Office Phone: 423.365.8157	Environmental Technician Cell Phone Number: 256.349.6617
Responsibilities: Assists with storm water sample collection on an as needed basis.	

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Storm Water Pollution Prevention Team

MEMBER: Mike Blevins Office Phone 423.365.1313	Manager Modifications/Maintenance Cell Phone Number: 423.593.6360
Responsibilities: Overall management of activities related to support of site facilities such that all materials are stored and handled in such a manner as to prevent their release into the environment. Issues instructions for excavation activities to assure continuing compliance with the Storm Water Regulations.	
MEMBER: Darrel Reed Office Phone: 423.365.1205	Manager Modifications/Maintenance Cell Phone Number: 423.315.5233
Responsibilities: Overall management of activities related to support of site facilities such that all materials are stored and handled in such a manner as to prevent their release into the environment. Issues instructions for excavation activities to assure continuing compliance with the Storm Water Regulations.	
MEMBER: James Davis Office Phone: 423.365.1890	Facilities Maintenance Supervisor Cell Phone Number: 423.593.4801
Responsibilities: Provides support for all facilities activities including site construction and repair projects. Provides for property maintenance, such as installing silt fences and straw bales around construction.	
MEMBER: Bill Wilson Office Phone 423.365.3334	Property Maintenance Group Cell Phone Number: 423.593.2326
Responsibilities: Provides support for property maintenance, recovery from site construction and repair projects such as installing silt fences and straw bales around construction areas. Application of fertilizer and herbicides at the plant.	
MEMBER: Brent Paige Office Phone: 423.365.3334	Bechtel Unit 2 Cell Phone Number: 423.593.9136
Responsibilities:.Provides support for recovery from site construction and repair projects, such as installing silt fences and straw bales around construction areas.	
MEMBER: Jennings Dillard Office Phone: 423.365.7995	Bechtel Unit 2 Cell Phone Number: 423.280.1618
Responsibilities:. Provides support for recovery from site construction and repair projects, such as installing silt fences and straw bales around construction areas.	
MEMBER: Donald Simpson Office Phone: 423.365.3103	Plant Services Foreman Pager Number 1.800.323.4853 # 91339
Responsibilities:.Provide information regarding erosion or housekeeping issues. Assist in issue resolution as needed.	

Appendix I
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Tennessee Storm Water Multi-Sector General Permit For Industrial Activities

STATE OF TENNESSEE

NPDES PERMIT

TENNESSEE STORM WATER
MULTI_SECTOR GENERAL PERMIT
FOR INDUSTRIAL ACTIVITIES

PERMIT NO. TNR050000

Under authority of the Tennessee Water Quality Control Act of 1977 (T.C.A. 69-3-101 et seq.) and the delegation of authority from the United States Environmental Protection Agency under the Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 (33 U.S.C. 1251, et seq.) and the water quality Act of 1987, P.L. 100-4, except as provided in section 1.2.3 below of this storm water multi-sector general permit, operators of point source discharges of storm water associated with industrial activity that discharges into waters of the State of Tennessee, represented by the industry sectors identified in part 11 of this permit, are authorized to discharge storm water runoff associated with industrial activity in accordance with the following storm water pollution prevention plan requirements, effluent limitations, monitoring and reporting requirements and other provisions set forth in parts 1 through 11 herein, from the subject facility to waters of the State of Tennessee.:

This permit is issued on:	May 15, 2009
This permit is effective on:	June 1, 2009
This permit expires on	May 14, 2014

Paul E. Davis

Paul E. Davis, Director
Division of Water Pollution Control

Source Notes
(Page 1 of 1)

Requirements Statement	Source Document	Implementing Statement
Identify rationale for selecting storm water sample points.	State Audit Report 06/27/2003	1
WBN implementing procedures do NOT collect all the information required by the storm water permit. Identified during EP&P Audit No: WBN (Water)-04-04-13.	WBN PER 34206	2

TVAN CALCULATION COVERSHEET

Title	Design Releases to Show Compliance with 10CFR20	Plant WBN Unit 1/2	Page 1

Preparing Organization Mechanical Design	Key Nouns (For EDM) Radwaste, Gas Release, Liquid Release

Calculation Identifier WBNTSR-100	Each time these calculations are issued, preparer must ensure that the original (R0) RIMS/EDM accession number is filled in.		
	Rev	(for EDM use)	EDM Accession Number
Applicable Design Document(s) NA	R0		B26 950110 310
	R4		
UNID System(s) 77, 30	R5		
	R6		

	R0	R4	R5	R6			
					Quality Related?	Yes ■	No ☐
DCN, EDC, NA	NA	D-50502-A			Safety related? If yes, mark Quality Related yes	Yes ☐	No ■
Prepared	Marc C. Berg						
Checked	Regis M. Nicoll				These calculations contain unverified assumption(s) that must be verified later?	Yes ☐	No ■
Design Verified	Regis M. Nicoll				These calculations contain special requirements and/or limiting conditions?	Yes ☐	No ■
Approved	Frank A. Koontz, Jr.				These calculations contain a design output attachment?	Yes ☐	No ■
Approval Date	1-9-95				Calculation Classification	Essential	
SAR Affected?	Yes ☐ No ■	Yes ■ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Microfiche generated	Yes ☐	No ■
Revision applicability	Entire calc ■	Entire calc ■ Selected pgs ☐	Entire calc ☐ Selected pgs ☐	Entire calc ☐ Selected pgs ☐	Number		

Statement of Problem: Determine the design liquid and gaseous releases and show that these releases are less than the 10CFR20 App.B Table 2 Effluent Concentration Limits (ECL).

Abstract The Standard Review Plan sections 11.2.III.2.c, 11.2.IV.3, 11.3.III.2.b, and 11.3.IV.3 require that the gaseous and liquid releases based on 1% failed fuel be within 10CFR20 App.B Table 2 limits. This calculation took the expected gaseous releases from calculation TI-534 and the expected liquid releases from WBNTSR-093. These releases were scaled to design (1% failed fuel) levels from FSAR data (and justified with Westinghouse WCAP-7664 R1). The design release concentration for each isotope was divided by the 10CFR20 App.B Table 2 Effluent Concentration Limit (ECL). The concentration/ECL fraction was summed over all isotopes. Also analyzed were for the case of liquid releases at design levels, except for iodines, which were limited to Technical Specification limits of 1 uCi/gm I-131 equivalent. The results for each case can be found in the results section.

The 10CFR20 limits will not be exceeded for design (1% failed fuel) releases for gas, or liquids when the Condensate Polisher Demineralizer regeneration waste is processed by the mobile demineralizers. In the event that the long term release of this waste is projected to result in exceeding the 10CFR20 limits, the design of the plant allows the waste to be processed by the mobile demineralizer system. With the mobile demineralizer system processing the regeneration waste, the liquid design releases are below the 10CFR20 limits. The release concentrations determined in this calculation are not expected to occur because the design reactor coolant concentrations exceed the Technical Specification limits. With iodine limited to the Technical Specification limit of 1 uCi/gm I-131 equivalent, the releases will be less than the 10CFR20 limits. It can be concluded that the design of the gas and liquid radwaste systems meet the requirements of 10CFR20.

Revision 4 incorporates the alternate operation mode of Steam Generator Blowdown released directly to the environment without processing by the Condensate Polisher Demineralizers, and no Condensate processing by the Condensate Polisher Demineralizers. It is concluded that under normal conditions this release could exceed the 10CFR20 limits. The concentration of the SGB release must be less than that which would exceed the App.I limit of 5 Ci/unit = 3.67E-5 uCi/cc gross gamma, or even better, be restricted to the LLD (5E-7 uCi/cc gross gamma). Revision 4 also evaluated releases without the 20,000 gpm Cooling Tower Blowdown dilution flow. The results indicate that this cannot be done if there are releases from sources other that the SGB. If there are no other radwaste releases, the SGB may be released with no dilution flow if the concentration is 3.67E-6 uCi/cc gross gamma or less.

■ Microfilm and return calculation to Calculation Library:	Address:	☐ Microfilm and destroy.
☐ Microfilm and return calculation to:		

TVAN CALCULATION RECORD OF REVISION	
CALCULATION IDENTIFIER WBNSTR-100	
Title **Design Releases to Show Compliance with 10CFR20**	

Revision No.	DESCRIPTION OF REVISION
0	Initial Issue
1	Revision 1 was performed because the expected liquid releases from WBNTSR-093 have changed. All pages were renumbered, but only the pages that had text changes are listed in the pages changed section below. pages changed: 1-6, 10-12 pages added: 11 paged deleted: none
2	Revision 2 was performed to incorporate gas releases from the alternate mode of operation of venting containment instead of purging. Also incorporated is a case with Technical Justification limits for iodines in the liquid (instead of 1% failed fuel design). Pages added: 9.1 pages deleted: none pages changed: 1-5, 7-12 R2: 13 total pages
3	Revision 3 incorporates the continuous containment filtered vent to the annulus case. DCN D-50165-A added a filter to the vent line. The unfiltered case determined in revision 2 was retained for historical purposes. Pages added: 9.2 Pages deleted: none Pages changed: 1-5, 7-12, 9.1 R3 total pages: 14
4	Revision 4 was performed to add the alternate operation mode of direct Steam Generator Blowdown release to the river without Condensate Polisher Demineralizer processing, and no Condensate Polisher Demineralizer processing of the Condensate. Additionally, cases were also analyzed with no Cooling Tower Blowdown dilution flow (20,000 gpm). This revision supports DCN D-50502-A. All pages were renumbered. Pages with actual text changes are marked with revision bars. Pages added: new cover Pages deleted: none Pages changed:1a (old cover), 2-23 R4: 24 total pages

TVAN CALCULATION DESIGN VERIFICATION (INDEPENDENT REVIEW) FORM	
Calculation Identifier WBNTSR-100	Revision 4
Method of design verification (independent review) used: 1. Design Review ☐ 2. Alternate Calculation ☐ 3. Qualification Test ☐	
Comments:	

Design Verifier

Date

TVAN CALCULATION TABLE OF CONTENTS

Calculation Identifier: WBNTSR-100	Revision: 4

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TVAN COMPUTER OUTPUT
MICROFICHE INFORMATION SHEET

Document WBNTSR-100	Rev. 4	Plant: WBN	

Subject:
Design Releases to Show Compliance with 10CFR20

Microfiche Number	Description
	There is no microfiche associated with this calculation.

Purpose

The purpose of this calculation is to determine if 1% failed fuel (design fuel damage) will result in effluent releases exceeding 10CFR20 App.B Table 2 limits.

Introduction

The Standard Review Plan sections 11.2.III.2.c, 11.2.IV.3, 11.3.III.2.b, and 11.3.IV.3 (ref.1) require that the gaseous and liquid releases based on 1% failed fuel be within 10CFR20 App.B Table 2 limits. This calculation takes the expected gaseous releases from TI-534 (ref.2) and the expected liquid releases from WBNTSR-093 (ref.3) and scales these releases to design (1% failed fuel) levels taken from FSAR data. The design release concentration for each isotope is divided by the 10CFR20 App.B Table 2 Effluent Concentration Limit (ECL). The concentration/ECL fraction is summed over all isotopes. The 10CFR20 limit requires this sum to be less than unity. Note that the Standard Review Plan requires the design of the plant to have the concentration/ECL fraction to be less than unity. In actual practice, the ODCM allows the concentration/ECL fraction to be less than 10. Since this calculation is to show the adequacy of the plant design, the acceptance criterion is for the concentration/ECL fraction to be less than unity.

Since the design (1% failed fuel) reactor coolant inventory exceeds the technical specification equivalent of 1 uCi/gm I-131 equivalent, a liquid release case utilizing the technical specification limit for iodine (and 1% failed fuel for the remaining isotopes) is performed. This will show that the plant will meet 10CFR20 limits under maximum allowable operating conditions, since the design inventories cannot be experienced in the plant .

Three cases for gaseous release are performed based on the TI-534 modes of operation. One is for the containment portion of the gaseous effluents released via filtered purging. The other cases assume the containment is vented to the annulus, and then released via the Auxiliary Building Vent. Revision 2 had the vent release as a batch release with no filtration. These results are retained for historical purposes. Revision 3 adds a filter (DCN D-50165-A, ref.15) in the vent line and has a continuous vent of 100 cfm (ref.2). Revision 3 also eliminated a historical FSAR reference in favor of a Westinghouse WCAP.

Revision 4 is performed because DCN D-50502-A (ref.16) will allow the direct release of the Steam Generator Blowdown to the river without processing by the Condensate Polisher Demineralizers, and no processing of the Condensate by the Condensate Polisher Demineralizers. Additionally, cases were also analyzed with no Cooling Tower Blowdown dilution flow (20,000 gpm).

Assumptions

1. It is assumed that the ratio of design to expected reactor coolant concentrations can be applied to the expected releases to obtain design releases.

Technical Justification: All releases are ultimately based on the reactor coolant isotopic concentrations. It follows that any change in the reactor coolant concentrations will result in a proportional change in releases. Therefore, scaling from expected to design releases based on a design/expected reactor coolant ratio is valid.

Special Requirements/Limiting Conditions

There are no special requirements or limiting conditions in this calculation.

Calculations

I. Expected to Design Source Term and Design to Technical Specification Scaling

The normal gas and liquid releases (ref.2,3) are based on expected reactor coolant isotopic concentrations (ref.5). The design (1% failed fuel) concentrations are taken from reference 7. The iodine Technical Specification limit of 1 uCi/gm I-131 equivalent is taken from reference 14. The ratio of design to expected concentrations gives a scaling factor to establish the design releases. The technical specification to design concentration gives a scaling factor to establish the maximum iodine releases possible. The scaling factors are:

TABLE 1:

	Expected RCS Conc. [uCi/gm]	Design RCS Conc. [uCi/gm]	Des/Exp Ratio	Tech Spec 1 uCi/gmI-31 Equivalent [uCi/gm]	TechSpec/Design Ratio
Kr-85m	1.71E-01	2.10E+00	12.28		
Kr-85	2.66E-01	8.80E+00	33.08		
Kr-87	1.61E-01	1.20E+00	7.45		
Kr-88	3.00E-01	3.70E+00	12.33		
Xe-131m	6.54E-01	1.90E+00	2.91		
Xe-133m	7.17E-02	3.10E+00	43.24		
Xe-133	2.53E+00	2.81E+02	111.07		
Xe-135m	1.39E-01	7.00E-01	5.04		
Xe-135	9.04E-01	6.30E+00	6.97		
Xe-138	1.29E-01	7.00E-01	5.43		
Br-84	1.72E-02	4.30E-02	2.50		
I-131	4.77E-02	2.50E+00	52.41	0.656	0.2624
I-132	2.25E-01	9.00E-01	4.00	0.236	0.262222
I-133	1.49E-01	4.00E+00	26.85	1.05	0.2625
I-134	3.64E-01	6.00E-01	1.65	0.147	0.245
I-135	2.78E-01	2.20E+00	7.91	0.577	0.262273
Rb-88	2.04E-01	3.70E+00	18.14		
Cs-134	7.39E-03	3.00E-01	40.60		
Cs-136	9.08E-04	1.50E-01	165.20		
Cs-137	9.79E-03	1.50E+00	153.22		
Cr-51	3.26E-03	9.50E-04	0.29		
Mn-54	1.68E-03	7.90E-04	0.47		
Fe-59	3.16E-04	1.10E-03	3.48		
Co-58	4.84E-03	2.60E-02	5.37		
Co-60	5.58E-04	7.70E-04	1.38		
Sr-89	1.47E-04	3.30E-03	22.45		
Sr-90	1.26E-05	1.70E-04	13.49		
Sr-91	1.02E-03	1.90E-03	1.86		
Y-90	1.26E-05	2.00E-04	15.87		
Y-91	5.47E-06	6.10E-03	1115.17		
Zr-95	4.10E-04	7.00E-04	1.71		
Nb-95	2.95E-04	6.90E-04	2.34		
Mo-99	6.75E-03	5.30E+00	785.19		
Te-132	1.79E-03	2.60E-01	145.25		
Ba-140	1.37E-02	4.30E-03	0.31		
La-140	2.64E-02	1.50E-03	0.06		
Ce-144	4.21E-03	3.40E-04	0.08		
Pr-144	4.21E-03	3.40E-04	0.08		

II. Gaseous Releases

The expected annual gas release is taken from TI-534 (ref.2). TI-534 presents three different modes of operation: one with containment purge, and others with containment venting to the annulus (one with no filtration, and the other with continuous venting with filters). All three options are analyzed here. The expected release is multiplied by the scaling factor determined earlier to obtain the design releases. To determine the average design concentration, this release is multiplied by the site boundary X/Q value of 1.09E-5 sec/cum (ref.4). To correct the units, the formula used is:

[uCi/cc] = [Ci/yr]*X/Q[sec/cum]*[1 (uCi/cc)/(Ci/cum)/(60 sec/min *60 min/hr * 24 hr/day * 365 day/yr)]

The design concentration release of each isotope is then divided by the 10CFR20 App.B Table 2 Effluent Concentration Limit (ECL). This fraction is then summed over all isotopes. The acceptance criteria is for this sum to be less than unity.

Table 2: Gas Releases, Containment Purge Option

	Exp.Rel. Ci/yr	Des/Exp Ratio	Design Ci/yr	Design uCi/cc	10CFR20 ECL	C/ECL
Kr-85m	2.57E+01	12.28	3.15E+02	1.09E-10	1.0E-07	0.0010905
Kr-85	6.99E+02	33.08	2.31E+04	7.99E-09	7.0E-07	0.0114124
Kr-87	1.62E+01	7.45	1.21E+02	4.18E-11	2.0E-08	0.0020906
Kr-88	3.84E+01	12.33	4.74E+02	1.64E-10	9.0E-09	0.0181884
Xe-131m	1.19E+03	2.91	3.45E+03	1.19E-09	2.0E-06	0.0005971
Xe-133m	4.88E+01	43.24	2.11E+03	7.29E-10	6.0E-07	0.0012142
Xe-133	3.20E+03	111.07	3.55E+05	1.23E-07	5.0E-07	0.2456675
Xe-135m	8.51E+00	5.04	4.29E+01	1.48E-11	4.0E-08	0.0003703
Xe-135	1.85E+02	6.97	1.29E+03	4.46E-10	7.0E-08	0.006375
Xe-138	7.65E+00	5.43	4.15E+01	1.43E-11	2.0E-08	0.0007174
Br-84	5.07E-02	2.50	1.27E-01	4.38E-14	8.0E-08	5.478E-07
I-131	1.53E-01	52.41	8.03E+00	2.77E-12	2.0E-10	0.013875
I-132	6.74E-01	4.00	2.70E+00	9.32E-13	2.0E-08	4.66E-05
I-133	4.58E-01	26.85	1.23E+01	4.25E-12	1.0E-09	0.0042535
I-134	1.08E+00	1.65	1.78E+00	6.14E-13	6.0E-08	1.023E-05
I-135	8.45E-01	7.91	6.69E+00	2.31E-12	6.0E-09	0.0003851
Cs-134	2.27E-03	40.60	9.20E-02	3.18E-14	2.0E-10	0.0001589
Cs-136	8.01E-05	165.20	1.32E-02	4.57E-15	9.0E-10	5.079E-06
Cs-137	3.48E-03	153.22	5.33E-01	1.84E-13	2.0E-10	0.0009203
Cr-51	5.92E-04	0.29	1.73E-04	5.96E-17	3.0E-08	1.988E-09
Mn-54	4.31E-04	0.47	2.03E-04	7.01E-17	1.0E-09	7.005E-08
Fe-59	7.70E-05	3.48	2.68E-04	9.27E-17	5.0E-10	1.853E-07
Co-58	2.32E-02	5.37	1.24E-01	4.30E-14	1.0E-09	4.298E-05
Co-60	8.74E-03	1.38	1.21E-02	4.17E-15	5.0E-11	8.333E-05
Sr-89	2.98E-03	22.45	6.69E-02	2.31E-14	1.0E-09	2.313E-05
Sr-90	1.14E-03	13.49	1.54E-02	5.33E-15	6.0E-12	0.0008877
Zr-95	1.00E-03	1.71	1.71E-03	5.92E-16	4.0E-10	1.481E-06
Nb-95	2.45E-03	2.34	5.73E-03	1.98E-15	2.0E-09	9.895E-07
Ba-140	4.00E-04	0.31	1.26E-04	4.34E-17	2.0E-09	2.171E-08
H-3	1.37E+02	1	1.37E+02	4.74E-11	1.0E-07	0.0004735
C-14	7.30E+00	1	7.30E+00	2.52E-12	3.0E-09	0.000841
Ar-41	3.40E+01	1	3.40E+01	1.18E-11	1.0E-08	0.0011752
total						0.3109083

Note: The above calculation is for one unit operation. Therefore, the totals must be multiplied by 2 for two unit operation.

Table 3: Gas Releases, Unfiltered Containment Vent Option

	Exp.Rel. Ci/yr	Des/Exp Ratio	Design Ci/yr	Design uCi/cc	10CFR20 ECL	C/ECL
Kr-85m	2.16E+01	12.28	2.65E+02	9.17E-11	1.0E-07	0.0009168
Kr-85	6.27E+02	33.08	2.07E+04	7.17E-09	7.0E-07	0.0102421
Kr-87	8.53E+00	7.45	6.36E+01	2.20E-11	2.0E-08	0.0010987
Kr-88	2.66E+01	12.33	3.28E+02	1.13E-10	9.0E-09	0.0125991
Xe-131m	1.15E+03	2.91	3.34E+03	1.15E-09	2.0E-06	0.0005774
Xe-133m	5.81E+01	43.24	2.51E+03	8.68E-10	6.0E-07	0.0014471
Xe-133	3.37E+03	111.07	3.74E+05	1.29E-07	5.0E-07	0.2587412
Xe-135m	4.86E+00	5.04	2.45E+01	8.46E-12	4.0E-08	0.0002115
Xe-135	1.99E+02	6.97	1.39E+03	4.79E-10	7.0E-08	0.0068477
Xe-138	4.48E+00	5.43	2.43E+01	8.40E-12	2.0E-08	0.0004201
Br-84	5.07E-02	2.50	1.27E-01	4.38E-14	8.0E-08	0.0000005
I-131	1.67E-01	52.41	8.75E+00	3.03E-12	2.0E-10	0.0151261
I-132	6.75E-01	4.00	2.70E+00	9.33E-13	2.0E-08	0.0000467
I-133	4.70E-01	26.85	1.26E+01	4.36E-12	1.0E-09	0.0043611
I-134	1.08E+00	1.65	1.78E+00	6.14E-13	6.0E-08	0.0000102
I-135	8.52E-01	7.91	6.74E+00	2.33E-12	6.0E-09	0.0003884
Cs-134	4.74E-03	40.60	1.92E-01	6.65E-14	2.0E-10	0.0003325
Cs-136	3.25E-03	165.20	5.37E-01	1.86E-13	9.0E-10	0.0002062
Cs-137	8.92E-03	153.22	1.37E+00	4.72E-13	2.0E-10	0.0023619
Cr-51	9.70E-03	0.29	2.83E-03	9.77E-16	3.0E-08	0.0000000
Mn-54	5.68E-03	0.47	2.67E-03	9.23E-16	1.0E-09	0.0000009
Fe-59	2.75E-03	3.48	9.57E-03	3.31E-15	5.0E-10	0.0000066
Co-58	4.79E-02	5.37	2.57E-01	8.89E-14	1.0E-09	0.0000889
Co-60	1.13E-02	1.38	1.56E-02	5.39E-15	5.0E-11	0.0001078
Sr-89	1.59E-02	22.45	3.57E-01	1.23E-13	1.0E-09	0.0001234
Sr-90	6.29E-03	13.49	8.49E-02	2.93E-14	6.0E-12	0.0048887
Zr-95	1.00E-03	1.71	1.71E-03	5.90E-16	4.0E-10	0.0000015
Nb-95	4.23E-03	2.34	9.89E-03	3.42E-15	2.0E-09	0.0000017
Ba-140	4.00E-04	0.31	1.26E-04	4.34E-17	2.0E-09	0.0000000
H-3	1.37E+02	1	1.37E+02	4.74E-11	1.0E-07	0.0004735
C-14	7.30E+00	1	7.30E+00	2.52E-12	3.0E-09	0.0008410
Ar-41	3.40E+01	1	3.40E+01	1.18E-11	1.0E-08	0.0011752
total						0.3236448

Note: The above calculation is for one unit operation. Therefore, the totals must be multiplied by 2 for two unit operation.

Table 4: Gas Releases, Continuous Filtered Containment Vent Option

	Exp.Rel. Ci/yr	Des/Exp Ratio	Design Ci/yr	Design uCi/cc	10CFR20 ECL	C/ECL
Kr-85m	9.83E+00	12.28	1.21E+02	4.17E-11	1.0E-07	0.0004173
Kr-85	6.77E+02	33.08	2.24E+04	7.74E-09	7.0E-07	0.0110595
Kr-87	5.85E+00	7.45	4.36E+01	1.51E-11	2.0E-08	0.0007530
Kr-88	1.35E+01	12.33	1.66E+02	5.75E-11	9.0E-09	0.0063860
Xe-131m	1.09E+03	2.91	3.18E+03	1.10E-09	2.0E-06	0.0005489
Xe-133m	4.37E+01	43.24	1.89E+03	6.54E-10	6.0E-07	0.0010892
Xe-133	2.92E+03	111.07	3.24E+05	1.12E-07	5.0E-07	0.2239394
Xe-135m	4.68E+00	5.04	2.36E+01	8.15E-12	4.0E-08	0.0002038
Xe-135	9.29E+01	6.97	6.47E+02	2.24E-10	7.0E-08	0.0031954
Xe-138	4.34E+00	5.43	2.36E+01	8.15E-12	2.0E-08	0.0004073
Br-84	5.07E-02	2.50	1.27E-01	4.38E-14	8.0E-08	0.0000005
I-131	1.53E-01	52.41	8.00E+00	2.77E-12	2.0E-10	0.0138277
I-132	6.73E-01	4.00	2.69E+00	9.30E-13	2.0E-08	0.0000465
I-133	4.57E-01	26.85	1.23E+01	4.24E-12	1.0E-09	0.0042433
I-134	1.08E+00	1.65	1.77E+00	6.13E-13	6.0E-08	0.0000102
I-135	8.43E-01	7.91	6.67E+00	2.30E-12	6.0E-09	0.0003841
Cs-134	2.27E-03	40.60	9.20E-02	3.18E-14	2.0E-10	0.0001589
Cs-136	8.01E-05	165.20	1.32E-02	4.57E-15	9.0E-10	0.0000051
Cs-137	3.48E-03	153.22	5.33E-01	1.84E-13	2.0E-10	0.0009203
Cr-51	5.92E-04	0.29	1.73E-04	5.96E-17	3.0E-08	0.0000000
Mn-54	4.31E-04	0.47	2.03E-04	7.01E-17	1.0E-09	0.0000001
Fe-59	7.70E-05	3.48	2.68E-04	9.27E-17	5.0E-10	0.0000002
Co-58	2.32E-02	5.37	1.24E-01	4.30E-14	1.0E-09	0.0000430
Co-60	8.74E-03	1.38	1.21E-02	4.17E-15	5.0E-11	0.0000833
Sr-89	2.98E-03	22.45	6.69E-02	2.31E-14	1.0E-09	0.0000231
Sr-90	1.14E-03	13.49	1.54E-02	5.33E-15	6.0E-12	0.0008877
Zr-95	1.00E-03	1.71	1.71E-03	5.92E-16	4.0E-10	0.0000015
Nb-95	2.45E-03	2.34	5.73E-03	1.98E-15	2.0E-09	0.0000010
Ba-140	4.00E-04	0.31	1.26E-04	4.34E-17	2.0E-09	0.0000000
H-3	1.37E+02	1	1.37E+02	4.74E-11	1.0E-07	0.0004735
C-14	7.30E+00	1	7.30E+00	2.52E-12	3.0E-09	0.0008410
Ar-41	3.40E+01	1	3.40E+01	1.18E-11	1.0E-08	0.0011752
total						0.2711263

Note: The above calculation is for one unit operation. Therefore, the totals must be multiplied by 2.

III. Liquid Releases

The expected annual liquid release is taken from WBNTSR-093 (ref.3). The expected release is multiplied by the scaling factor determined earlier to obtain the design releases. To determine the average design concentration, the release is divided by volume released and the dilution flow (the minimum cooling tower blowdown flow = 20,000 gpm = 2.88E7 gal/day). The volume released is sum of all sources from WBNTSR-093 = 16141.654 gal/day. Note: the WBNTSR-093 flow values for the condensate resin regeneration waste is for the input streams to the condensate polishers, not the waste. The waste volume is 3400 gpd per NUREG-0017. The formula used is then:

[uCi/gm] = [Ci/yr]*(1e6 uCi/Ci)/((16141.654+2.88E7gal/day)*8.34 lb/gal * 453.59 g/lb * 365 day/yr)

The design concentration release of each isotope is then divided by the 10CFR20 App.B Table 2 Effluent Concentration Limit (ECL). This fraction is then summed over all isotopes. The acceptance criterion is for this sum to be less than unity. A second calculation (last column of the following table) is determined using the Technical Specification limits (1 uCi/gm I-131) for iodines instead of design values. The sum of the concentration/ECL for this scenario will be for the Tech Spec iodines and the previously determined design values for all other isotopes. Again, the acceptance criterion is for the sum to be less than unity.

Table 5

	Exp.Rel. Ci/yr	Des/Exp Ratio	Design Ci/yr	Design uCi/gm	10CFR20 ECL	Design C/ECL	Tech Spec C/ECL
Br-84	0.0003696	2.50	0.00092408	2.32E-11	4.0E-04	5.806E-08	
I-131	0.471244	52.41	24.6983229	6.21E-07	1.0E-06	0.6207393	0.162882
I-132	0.055475	4.00	0.2219	5.58E-09	1.0E-04	5.577E-05	1.46E-05
I-133	0.388058	26.85	10.4176644	2.62E-07	7.0E-06	0.0374037	0.009818
I-134	0.0166222	1.65	0.02739923	6.89E-10	4.0E-04	1.722E-06	4.22E-07
I-135	0.212508	7.91	1.68171799	4.23E-08	3.0E-05	0.0014089	0.00037
Rb-88	0.0071992	18.14	0.13057373	3.28E-09	4.0E-04	8.204E-06	
Cs-134	0.095136	40.60	3.8620839	9.71E-08	9.0E-07	0.1078502	
Cs-136	0.0092913	165.20	1.53490639	3.86E-08	6.0E-06	0.0064294	
Cs-137	0.126735	153.22	19.4180286	4.88E-07	1.0E-06	0.4880304	
Cr-51	0.0432857	0.29	0.01261393	3.17E-10	5.0E-04	6.34E-07	
Mn-54	0.0249083	0.47	0.01171282	2.94E-10	3.0E-05	9.813E-06	
Fe-59	0.0059574	3.48	0.02073778	5.21E-10	1.0E-05	5.212E-05	
Co-58	0.078189	5.37	0.42002355	1.06E-08	2.0E-05	0.0005278	
Co-60	0.021121	1.38	0.02914541	7.33E-10	3.0E-06	0.0002442	
Sr-89	0.0018825	22.45	0.04226074	1.06E-09	8.0E-06	0.0001328	
Sr-90	0.0001736	13.49	0.00234156	5.89E-11	5.0E-07	0.0001177	
Sr-91	0.0011378	1.86	0.00211934	5.33E-11	2.0E-05	2.663E-06	
Y-90	0	15.87	0	0.00E+00	7.0E-06	0	
Y-91	0.0002072	1115.17	0.23102897	5.81E-09	8.0E-06	0.0007258	
Zr-95	0.0060943	1.71	0.01040494	2.62E-10	2.0E-05	1.308E-05	
Nb-95	0.0056138	2.34	0.01313056	3.30E-10	3.0E-05	1.1E-05	
Mo-99	0.0430858	785.19	33.8303319	8.50E-07	2.0E-05	0.0425126	
Te-132	0.0125817	145.25	1.82751531	4.59E-08	9.0E-06	0.0051034	
Ba-140	0.1461456	0.31	0.04587052	1.15E-09	8.0E-06	0.0001441	
La-140	0.2108406	0.06	0.01197958	3.01E-10	9.0E-06	3.345E-05	
Ce-144	0.0560926	0.08	0.00453004	1.14E-10	3.0E-06	3.795E-05	
Pr-144	0	0.08	0	0.00E+00	6.0E-04	0	
H-3	1289.52	1	1289.52	3.24E-05	1.0E-03	0.0324093	
Total						1.3440061	0.857482

Note: The above numbers are based on one unit operation.

The sum over all isotopes of the concentrations/ECL value from the previous table is greater than unity for the case where all isotopes are at design values. The bulk of the release is due to the condensate resin regeneration waste (untreated, ref.3). Per the ODCM (ref.10), the condensate regeneration waste will not be a continuous release if the activity in the secondary side is greater than 1E-6 uCi/gm. From WBNNAL3-003 (ref.5), the activity of some of the isotopes in the secondary side is greater than 1E-6 uCi/gm. This means that the regeneration waste will be in batch mode, and monitored. From references 11, 12 and 13 the condensate regeneration waste can be rerouted through the mobile demineralizers. If the long term releases from the condensate regeneration waste is greater than the 10CFR20 concentration limits, then routing the fluid stream through the mobile demineralizers will be performed. With mobile demineralizer processing of condensate regeneration waste the release concentrations become (with releases from ref.3):

Table 6

	Exp.Rel. Ci/yr	Des/Exp Ratio	Design Ci/yr	Design uCi/gm	10CFR20 ECL	C/ECL
Br-84	0.0001655	2.50	0.00041384	1.04E-11	4.0E-04	2.6E-08
I-131	0.0267889	52.41	1.4040304	3.53E-08	1.0E-06	0.0352873
I-132	0.0131973	4.00	0.05278928	1.33E-09	1.0E-04	1.327E-05
I-133	0.0531932	26.85	1.42800537	3.59E-08	7.0E-06	0.0051271
I-134	0.0062726	1.65	0.01033938	2.60E-10	4.0E-04	6.496E-07
I-135	0.047673	7.91	0.37726835	9.48E-09	3.0E-05	0.0003161
Rb-88	0.006893	18.14	0.12502022	3.14E-09	4.0E-04	7.855E-06
Cs-134	0.0293419	40.60	1.19114452	2.99E-08	9.0E-07	0.0332632
Cs-136	0.002558	165.20	0.4225837	1.06E-08	6.0E-06	0.0017701
Cs-137	0.0403515	153.22	6.18255414	1.55E-07	1.0E-06	0.1553852
Cr-51	0.007062	0.29	0.00205793	5.17E-11	5.0E-04	1.034E-07
Mn-54	0.0050082	0.47	0.00235505	5.92E-11	3.0E-05	1.973E-06
Fe-59	0.0024229	3.48	0.00843428	2.12E-10	1.0E-05	2.12E-05
Co-58	0.0225906	5.37	0.12135446	3.05E-09	2.0E-05	0.0001525
Co-60	0.0144067	1.38	0.01988019	5.00E-10	3.0E-06	0.0001665
Sr-89	0.0001932	22.45	0.00433748	1.09E-10	8.0E-06	1.363E-05
Sr-90	2.21E-05	13.49	0.00029821	7.49E-12	5.0E-07	1.499E-05
Sr-91	0.0002847	1.86	0.00053033	1.33E-11	2.0E-05	6.664E-07
Y-90	0	15.87	0	0.00E+00	7.0E-06	0
Y-91	9.009E-05	1115.17	0.10046131	2.52E-09	8.0E-06	0.0003156
Zr-95	0.001395	1.71	0.00238175	5.99E-11	2.0E-05	2.993E-06
Nb-95	0.0021083	2.34	0.00493128	1.24E-10	3.0E-05	4.131E-06
Mo-99	0.0042347	785.19	3.32501585	8.36E-08	2.0E-05	0.0041784
Te-132	0.0011232	145.25	0.16314782	4.10E-09	9.0E-06	0.0004556
Ba-140	0.0103815	0.31	0.00325843	8.19E-11	8.0E-06	1.024E-05
La-140	0.0164352	0.06	0.00093382	2.35E-11	9.0E-06	2.608E-06
Ce-144	0.0068919	0.08	0.00055659	1.40E-11	3.0E-06	4.663E-06
Pr-144	0	0.08	0	0.00E+00	6.0E-04	0
H-3	1289.52	1	1289.52	3.24E-05	1.0E-03	0.0324093
Total						0.2689259

Note: The above calculations are for 1 unit operation.

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DCN D-50502-A (ref.16) will allow the direct release of Steam Generator Blowdown to the river without Condensate Polisher Demineralizers, and no processing of the Condensate by the Condensate Polisher Demineralizers. Calculation WBNTSR-093 performed 3 cases. One case was a release with expected concentrations. That release exceeded the App.I limit of 5 Ci/unit. A second case limited the release of the SGB fluid to the Lower Limit of Detection (LLD = 5E-7 uCi/cc gross gamma). The third case was for the SGB fluid stream limited to the maximum allowable and still meet the App.I limit of 5 Ci/unit. The following table presents the case where there is SGB expected release, modified to design limits:

Table 7: Direct Steam Generator Blowdown Release, No Condensate Polisher Demineralizer

	ANSI Ci/yr	des/ansi	des Ci/yr	des uCi/cc	10CFR20	C/ECL	1 tech spec C/ECL
Br-84	0.0022083	2.50	0.005520825	1.39E-10	4.0E-04	3.46885E-07	
I-131	4.475344	52.41	234.5566134	5.90E-06	1.0E-06	5.895081804	0.162982
I-132	0.436255	4.00	1.74542	4.39E-08	1.0E-04	0.000438674	1.462E-05
I-133	3.404858	26.85	91.40558389	2.30E-06	7.0E-06	0.328183094	0.0098185
I-134	0.1098622	1.65	0.181091538	4.55E-09	4.0E-04	1.13784E-05	4.218E-07
I-135	1.697608	7.91	13.43351655	3.38E-07	3.0E-05	0.011254086	0.0003695
Rb-86	0.0075057	18.14	0.136132794	3.42E-09	4.0E-04	8.55351E-06	
Cs-134	0.160996	40.60	6.535696868	1.64E-07	9.0E-07	0.182511896	
Cs-136	0.0160313	165.20	2.648342811	6.66E-08	6.0E-06	0.0110934	
Cs-137	0.213205	152.22	32.66675179	8.21E-07	1.0E-06	0.821008556	
Cr-51	0.3696257	0.29	0.107713011	2.71E-09	5.0E-04	5.41427E-06	
Mn-54	0.2041882	0.47	0.096017106	2.41E-09	3.0E-05	8.04395E-05	
Fe-59	0.0377994	3.48	0.13158019	3.31E-09	1.0E-05	0.000330699	
Co-58	0.583629	5.37	3.135197107	7.88E-08	2.0E-05	0.003939822	
Co-60	0.08160996	1.38	0.112615895	2.83E-09	3.0E-06	0.000943453	
Sr-89	0.017101524	22.45	0.383911763	9.65E-09	8.0E-06	0.0012061	
Sr-90	0.001537951	13.49	0.020750133	5.22E-10	5.0E-07	0.00104302	
Sr-91	0.00882285	1.86	0.01643472	4.13E-10	2.0E-05	2.06526E-05	
Y-90	0	15.87	0	0.00E+00	7.0E-06	0	
Y-91	0.001261989	1115.17	1.407314161	3.54E-08	8.0E-06	0.004421027	
Zr-95	0.04843032	1.71	0.082665910	2.06E-09	2.0E-05	0.000103907	
Nb-95	0.037194792	2.34	0.086997988	2.19E-09	3.0E-05	7.28836E-05	
Mo-99	0.3930958	785.19	308.6529985	7.76E-06	2.0E-05	0.387866515	
Te-132	0.11581174	145.25	16.82181698	4.23E-07	9.0E-06	0.046975583	
Ba-140	1.3692456	0.31	0.429763218	1.08E-08	8.0E-06	0.001350147	
La-140	1.9622406	0.06	0.111490943	2.80E-09	9.0E-06	0.000311343	
Ce-144	0.4995426	0.08	0.040326956	1.01E-09	3.0E-06	0.000337844	
Pr-144	0	0.08	0	0.00E+00	6.0E-04	0	
H-3	1289.52	1	1289.52	3.24E-05	1.0E-03	0.032409318	
total						7.731010454	1.6691262

Note: The above calculations are for 2 unit operation.

The above values indicate that the design concentration limits are <u>exceeded</u>, although the ODCM will allow the release (concentration/ECL fraction <10).

For the cases of SGB release to the river without processing (and no Condensate Polisher Demineralizer processing of the Condensate) where the release is limited, the LLD SGB component of the release was determined in WBNTSR-093 to be 0.06 Ci and for the maximum allowable SGB release would be 4.402 Ci. These totals have to be broken down into each component isotope. Therefore, taking the isotopic relative fractions of the SGB component from WBNTSR-093, summing, and then normalizing each isotope to either 0.06 Ci or 4.402 will give the activity released for each isotope.

Table 8

	WBNTSR-093 SGB Ci/yr expected	Ci/yr scaled to 0.06 Ci total SGB at LLD	Ci/yr scaled to 4.402 Ci total SGB max conc*
Br-84	2.043E-04	7.122E-06	5.225E-04
I-131	4.449E-01	1.551E-02	1.138E+00
I-132	4.232E-02	1.475E-03	1.082E-01
I-133	3.352E-01	1.169E-02	8.573E-01
I-134	1.036E-02	3.612E-04	2.650E-02
I-135	1.650E-01	5.752E-03	4.220E-01
Rb-88	3.065E-04	1.069E-05	7.839E-04
Cs-134	6.586E-02	2.296E-03	1.684E-01
Cs-136	6.740E-03	2.350E-04	1.724E-02
Cs-137	8.647E-02	3.014E-03	2.212E-01
Cr-51	3.626E-02	1.264E-03	9.274E-02
Mn-54	1.992E-02	6.944E-04	5.095E-02
Fe-59	3.538E-03	1.233E-04	9.049E-03
Co-58	5.616E-02	1.958E-03	1.436E-01
Co-60	6.721E-03	2.343E-04	1.719E-02
Sr-89	1.691E-03	5.895E-05	4.325E-03
Sr-90	1.516E-04	5.285E-06	3.877E-04
Sr-91	8.539E-04	2.977E-05	2.184E-03
Y-90	0.000E+00	0.000E+00	0.000E+00
Y-91	1.172E-04	4.086E-06	2.998E-04
Zr-95	4.704E-03	1.640E-04	1.203E-02
Nb-95	3.509E-03	1.223E-04	8.975E-03
Mo-99	3.889E-02	1.356E-03	9.947E-02
Te-132	1.147E-02	3.999E-04	2.934E-02
Ba-140	1.359E-01	4.738E-03	3.476E-01
La-140	1.946E-01	6.784E-03	4.977E-01
Ce-144	4.925E-02	1.717E-03	1.260E-01
Pr-144	0.000E+00	0.000E+00	0.000E+00
total	1.721E+00	6.000E-02	4.402E+00

* maximum concentration is that concentration at which the App. I limit of 5 Ci/unit is reached.

Utilizing the annual releases determined above, the 10CFR20 calculation with the SGB limited to LLD (0.06 Ci total) is as follows. The total release is the SGB release at the LLD with the remaining radwaste release scaled to design limits:

Table 9

no process/ SGBD at LLD/ with 20000 gpm dilution

other release paths at design limit

	ANSI Ci/yr	Ci/yr Scaled to 0.06 Ci	des/ansi	Ci/yr	liquid uCi/cc	liquid 10CFR20	C/ECL
Br-84	0.00016533	7.122E-06	2.50	0.00042045	1.06E-11	4.0E-04	2.642E-08
I-131	0.026344	1.551E-02	52.41	1.39622267	3.51E-08	1.0E-06	0.0350911
I-132	0.013155	1.475E-03	4.00	0.05409534	1.36E-09	1.0E-04	1.36E-05
I-133	0.052858	1.169E-02	26.85	1.43069229	3.60E-08	7.0E-06	0.0051368
I-134	0.0062622	3.612E-04	1.65	0.01068347	2.69E-10	4.0E-04	6.713E-07
I-135	0.047508	5.752E-03	7.91	0.38171474	9.59E-09	3.0E-05	0.0003198
Rb-88	0.0068927	1.069E-05	18.14	0.12502534	3.14E-09	4.0E-04	7.856E-06
Cs-134	0.029276	2.296E-03	40.60	1.19076688	2.99E-08	9.0E-07	0.0332526
Cs-136	0.0025513	2.350E-04	165.20	0.42170523	1.06E-08	6.0E-06	0.0017664
Cs-137	0.040265	3.014E-03	153.22	6.17231989	1.55E-07	1.0E-06	0.155128
Cr-51	0.0070257	1.264E-03	0.29	0.00331144	8.32E-11	5.0E-04	1.665E-07
Mn-54	0.00498828	6.944E-04	0.47	0.00304012	7.64E-11	3.0E-05	2.547E-06
Fe-59	0.0024194	1.233E-04	3.48	0.0085453	2.15E-10	1.0E-05	2.148E-05
Co-58	0.022029	1.958E-03	5.37	0.12029542	3.02E-09	2.0E-05	0.0001512
Co-60	0.01439996	2.343E-04	1.38	0.02010522	5.05E-10	3.0E-06	0.0001684
Sr-89	0.000191524	5.895E-05	22.45	0.00435847	1.10E-10	8.0E-06	1.369E-05
Sr-90	0.000021951	5.285E-06	13.49	0.00030145	7.58E-12	5.0E-07	1.515E-05
Sr-91	0.00028385	2.977E-05	1.86	0.00055851	1.40E-11	2.0E-05	7.018E-07
Y-90	0	0.000E+00	15.87	0	0.00E+00	7.0E-06	0
Y-91	8.99686E-05	4.086E-06	1115.17	0.1003347	2.52E-09	8.0E-06	0.0003152
Zr-95	0.00139032	1.640E-04	1.71	0.00253771	6.38E-11	2.0E-05	3.189E-06
Nb-95	0.002104792	1.223E-04	2.34	0.0050454	1.27E-10	3.0E-05	4.227E-06
Mo-99	0.0041958	1.356E-03	785.19	3.29583576	8.28E-08	2.0E-05	0.0041417
Te-132	0.00111174	3.999E-04	145.25	0.16188165	4.07E-09	9.0E-06	0.0004521
Ba-140	0.0102456	4.738E-03	0.31	0.00795345	2.00E-10	8.0E-06	2.499E-05
La-140	0.0162406	6.784E-03	0.06	0.00770681	1.94E-10	9.0E-06	2.152E-05
Ce-144	0.0068426	1.717E-03	0.08	0.00226954	5.70E-11	3.0E-06	1.901E-05
Pr-144	0	0.000E+00	0.08	0	0.00E+00	6.0E-04	0
H-3	1289.52		1	1289.52	3.24E-05	1.0E-03	0.0324093
total							0.2684814

Note: The above calculations are for 2 unit operation.

Utilizing the annual releases determined above, the 10CFR20 calculation with the SGB at the maximum release (4.402 Ci total) is as follows. The total release is the SGB release at the maximum allowable to meet App.I limits with the remaining radwaste release scaled to design limits :

Table 10

no process/ SGBD at max App.I/ with 20000 gpm dilution

	ANSI Ci/yr	Ci/yr scaled to 4.402 Ci	des/ansi	des Ci/yr	liquid des uCi/cc	Liquid 10CFR20	C/ECL
Br-84	0.00016533	0.000522532	2.50	0.00093586	2.35E-11	4.0E-04	5.88E-08
I-131	0.026344	1.137908188	52.41	2.51862098	6.33E-08	1.0E-06	0.0633001
I-132	0.013155	0.108240671	4.00	0.16086067	4.04E-09	1.0E-04	4.043E-05
I-133	0.052858	0.857331591	26.85	2.2763383	5.72E-08	7.0E-06	0.008173
I-134	0.0062622	0.02649748	1.65	0.03681979	9.25E-10	4.0E-04	2.313E-06
I-135	0.047508	0.422015849	7.91	0.79797844	2.01E-08	3.0E-05	0.0006685
Rb-88	0.0068927	0.000783926	18.14	0.12579858	3.16E-09	4.0E-04	7.904E-06
Cs-134	0.029276	0.168448265	40.60	1.35691917	3.41E-08	9.0E-07	0.0378925
Cs-136	0.0025513	0.017238708	165.20	0.43870897	1.10E-08	6.0E-06	0.0018377
Cs-137	0.040265	0.221161881	153.22	6.3904673	1.61E-07	1.0E-06	0.1606107
Cr-51	0.0070257	0.09274118	0.29	0.09478855	2.38E-09	5.0E-04	4.765E-06
Mn-54	0.00498828	0.050948822	0.47	0.0532945	1.34E-09	3.0E-05	4.465E-05
Fe-59	0.0024194	0.009049043	3.48	0.017471	4.39E-10	1.0E-05	4.391E-05
Co-58	0.022029	0.143638849	5.37	0.26197645	6.58E-09	2.0E-05	0.0003292
Co-60	0.01439996	0.017190112	1.38	0.03706102	9.31E-10	3.0E-06	0.0003105
Sr-89	0.000191524	0.004325023	22.45	0.00862454	2.17E-10	8.0E-06	2.709E-05
Sr-90	0.000021951	0.000387743	13.49	0.00068391	1.72E-11	5.0E-07	3.438E-05
Sr-91	0.00028365	0.002183996	1.86	0.00271274	6.82E-11	2.0E-05	3.409E-06
Y-90	0	0	15.87	0	0.00E+00	7.0E-06	0
Y-91	8.99686E-05	0.000299759	1115.17	0.10063037	2.53E-09	8.0E-06	0.0003161
Zr-95	0.00139032	0.012031288	1.71	0.01440501	3.62E-10	2.0E-05	1.81E-05
Nb-95	0.002104792	0.00897487	2.34	0.01389794	3.49E-10	3.0E-05	1.164E-05
Mo-99	0.0041958	0.099467857	785.19	3.39394786	8.53E-08	2.0E-05	0.004265
Te-132	0.00111174	0.029336496	145.25	0.19081828	4.80E-09	9.0E-06	0.0005329
Ba-140	0.0102456	0.347587599	0.31	0.35080337	8.82E-09	8.0E-06	0.0011021
La-140	0.0162406	0.497722934	0.06	0.4986457	1.25E-08	9.0E-06	0.0013925
Ce-144	0.0068426	0.125965337	0.08	0.12651795	3.18E-09	3.0E-06	0.0010599
Pr-144	0	0	0.08	0	0.00E+00	6.0E-04	0
H-3	1289.52		1	1289.52	3.24E-05	1.0E-03	0.0324093
total							0.3144386

Note: The above calculations are for 2 unit operation.

It is desired to determine if the SGB with no processing can be released to the river without the Cooling Tower Blowdown (CTB) dilution flow of 20,000 gpm. The following table takes the Table 9 annual release and converts it to a concentration without the 20,000 gpm CTB dilution.

Table 11

no process/ SGBD at LLD/ no 20000 gpm dilution

	ANSI Ci/yr	Ci/yr scaled to 0.06	des/ansi	des Ci/yr	liquid des uCi/cc	liquid 10CFR20	C/ECL
Br-84	0.00016533	7.122E-06	2.50	0.00042045	1.89E-08	4.0E-04	4.716E-05
I-131	0.026344	1.551E-02	52.41	1.39622267	6.26E-05	1.0E-06	62.64469
I-132	0.013155	1.475E-03	4.00	0.05409534	2.43E-06	1.0E-04	0.0242711
I-133	0.052858	1.169E-02	26.85	1.43069229	6.42E-05	7.0E-06	9.1701782
I-134	0.0062622	3.612E-04	1.65	0.01068347	4.79E-07	4.0E-04	0.0011983
I-135	0.047508	5.752E-03	7.91	0.38171474	1.71E-05	3.0E-05	0.5708832
Rb-88	0.0068927	1.069E-05	18.14	0.12502534	5.61E-06	4.0E-04	0.0140239
Cs-134	0.029276	2.296E-03	40.60	1.19076688	5.34E-05	9.0E-07	59.362724
Cs-136	0.0025513	2.350E-04	165.20	0.42170523	1.89E-05	6.0E-06	3.1534599
Cs-137	0.040265	3.014E-03	153.22	6.17231989	2.77E-04	1.0E-06	276.9351
Cr-51	0.0070257	1.264E-03	0.29	0.00331144	1.49E-07	5.0E-04	0.0002972
Mn-54	0.00498828	6.944E-04	0.47	0.00304012	1.36E-07	3.0E-05	0.0045467
Fe-59	0.0024194	1.233E-04	3.48	0.0085453	3.83E-07	1.0E-05	0.0383404
Co-58	0.022029	1.958E-03	5.37	0.12029542	5.40E-06	2.0E-05	0.2698663
Co-60	0.01439996	2.343E-04	1.38	0.02010522	9.02E-07	3.0E-06	0.3006887
Sr-89	0.000191524	5.895E-05	22.45	0.00435847	1.96E-07	8.0E-06	0.0244441
Sr-90	0.000021951	5.285E-06	13.49	0.00030145	1.35E-08	5.0E-07	0.0270504
Sr-91	0.00028385	2.977E-05	1.86	0.00055851	2.51E-08	2.0E-05	0.0012529
Y-90	0	0.000E+00	15.87	0	0.00E+00	7.0E-06	0
Y-91	8.99686E-05	4.086E-06	1115.17	0.1003347	4.50E-06	8.0E-06	0.5627179
Zr-95	0.00139032	1.640E-04	1.71	0.00253771	1.14E-07	2.0E-05	0.005693
Nb-95	0.002104792	1.223E-04	2.34	0.0050454	2.26E-07	3.0E-05	0.0075458
Mo-99	0.0041958	1.356E-03	785.19	3.29583576	1.48E-04	2.0E-05	7.3937565
Te-132	0.00111174	3.999E-04	145.25	0.16188165	7.26E-06	9.0E-06	0.8070207
Ba-140	0.0102456	4.738E-03	0.31	0.00795345	3.57E-07	8.0E-06	0.0446062
La-140	0.0162406	6.784E-03	0.06	0.00770681	3.46E-07	9.0E-06	0.0384204
Ce-144	0.0068426	1.717E-03	0.08	0.00226954	1.02E-07	3.0E-06	0.0339426
Pr-144	0	0.000E+00	0.08	0	0.00E+00	6.0E-04	0
H-3	1289.52		1	1289.52	5.79E-02	1.0E-03	57.857233
total							479.294

The above scenario exceeds all release limits (design and ODCM), and therefore is not to be implemented.

From Table 11, it can be seen that as long as the normal radwaste system operates, the 10CFR20 limits will be exceeded with no SGB processing. The following table presents the case where the SGB is the only release and is limited to the LLD. The annual release is at the 0.06 Ci limit as determined in WBNTSR-093, however the concentration has to be scaled twice in order to achieve the 5E-7 uCi/cc LLD limit.

Table 12

no process/ SGB at LLD/ no 20000 gpm dilution/
SGB is the only release path

	LLD Ci/yr	uCi/cc	uCi/cc Scaled to LLD	10CFR20	liquid C/ECL
Br-84	7.122E-06	3.20E-10	5.94E-11	4.0E-04	1.48E-07
I-131	1.551E-02	6.96E-07	1.29E-07	1.0E-06	1.29E-01
I-132	1.475E-03	6.62E-08	1.23E-08	1.0E-04	1.23E-04
I-133	1.169E-02	5.24E-07	9.74E-08	7.0E-06	1.39E-02
I-134	3.612E-04	1.62E-08	3.01E-09	4.0E-04	7.52E-06
I-135	5.752E-03	2.58E-07	4.79E-08	3.0E-05	1.60E-03
Rb-88	1.069E-05	4.79E-10	8.90E-11	4.0E-04	2.23E-07
Cs-134	2.296E-03	1.03E-07	1.91E-08	9.0E-07	2.13E-02
Cs-136	2.350E-04	1.05E-08	1.96E-09	6.0E-06	3.26E-04
Cs-137	3.014E-03	1.35E-07	2.51E-08	1.0E-06	2.51E-02
Cr-51	1.264E-03	5.67E-08	1.05E-08	5.0E-04	2.11E-05
Mn-54	6.944E-04	3.12E-08	5.79E-09	3.0E-05	1.93E-04
Fe-59	1.233E-04	5.53E-09	1.03E-09	1.0E-05	1.03E-04
Co-58	1.958E-03	8.78E-08	1.63E-08	2.0E-05	8.16E-04
Co-60	2.343E-04	1.05E-08	1.95E-09	3.0E-06	6.51E-04
Sr-89	5.895E-05	2.64E-09	4.91E-10	8.0E-06	6.14E-05
Sr-90	5.285E-06	2.37E-10	4.40E-11	5.0E-07	8.81E-05
Sr-91	2.977E-05	1.34E-09	2.48E-10	2.0E-05	1.24E-05
Y-90	0.000E+00	0.00E+00	0.00E+00	7.0E-06	0.00E+00
Y-91	4.086E-06	1.83E-10	3.40E-11	8.0E-06	4.26E-06
Zr-95	1.640E-04	7.36E-09	1.37E-09	2.0E-05	6.83E-05
Nb-95	1.223E-04	5.49E-09	1.02E-09	3.0E-05	3.40E-05
Mo-99	1.356E-03	6.08E-08	1.13E-08	2.0E-05	5.65E-04
Te-132	3.999E-04	1.79E-08	3.33E-09	9.0E-06	3.70E-04
Ba-140	4.738E-03	2.13E-07	3.95E-08	8.0E-06	4.94E-03
La-140	6.784E-03	3.04E-07	5.65E-08	9.0E-06	6.28E-03
Ce-144	1.717E-03	7.70E-08	1.43E-08	3.0E-06	4.77E-03
Pr-144	0.000E+00	0.00E+00	0.00E+00	6.0E-04	0.00E+00
H-3		0.00E+00	0.00E+00	1.0E-03	0.00E+00
total	0.06	2.69204E-06	5.00E-07		0.21056788

The same analysis as in the above Table 12 is performed, except that the SGB release is at the maximum allowable for App.I limits. The concentration determined in Table 12 is multiplied by the factor 4.402/0.06 where 4.402 is the maximum allowable App.I release (from WBNTSR-093) and the 0.06 is the LLD release. Note that the C/ECL value is greater than unity. The release is normalized to 10 ECL to determine the maximum concentration (uCi/cc) which would result in a 10 ECL release.

Table 13

no process/ SGB max App.I/ no 20000 gpm dilution,
SGB only release path

	uCi/cc, LLD	max App.I uCi/cc	10CFR20	liquid C/ECL	normalized 10 C/ECL	max uCi/cc for 10 ECL
Br-84	5.94E-11	4.35E-09	4.0E-04	1.09E-05	7.05E-06	2.82E-09
I-131	1.29E-07	9.48E-06	1.0E-06	9.48E+00	6.14E+00	6.14E-06
I-132	1.23E-08	9.02E-07	1.0E-04	9.02E-03	5.84E-03	5.84E-07
I-133	9.74E-08	7.14E-06	7.0E-06	1.02E+00	6.61E-01	4.62E-06
I-134	3.01E-09	2.21E-07	4.0E-04	5.52E-04	3.57E-04	1.43E-07
I-135	4.79E-08	3.52E-06	3.0E-05	1.17E-01	7.59E-02	2.28E-06
Rb-88	8.90E-11	6.53E-09	4.0E-04	1.63E-05	1.06E-05	4.23E-09
Cs-134	1.91E-08	1.40E-06	9.0E-07	1.56E+00	1.01E+00	9.09E-07
Cs-136	1.96E-09	1.44E-07	6.0E-06	2.39E-02	1.55E-02	9.30E-08
Cs-137	2.51E-08	1.84E-06	1.0E-06	1.84E+00	1.19E+00	1.19E-06
Cr-51	1.05E-08	7.73E-07	5.0E-04	1.55E-03	1.00E-03	5.00E-07
Mn-54	5.79E-09	4.25E-07	3.0E-05	1.42E-02	9.16E-03	2.75E-07
Fe-59	1.03E-09	7.54E-08	1.0E-05	7.54E-03	4.88E-03	4.88E-08
Co-58	1.63E-08	1.20E-06	2.0E-05	5.98E-02	3.87E-02	7.75E-07
Co-60	1.95E-09	1.43E-07	3.0E-06	4.78E-02	3.09E-02	9.27E-08
Sr-89	4.91E-10	3.60E-08	8.0E-06	4.51E-03	2.92E-03	2.33E-08
Sr-90	4.40E-11	3.23E-09	5.0E-07	6.46E-03	4.18E-03	2.09E-09
Sr-91	2.48E-10	1.82E-08	2.0E-05	9.10E-04	5.89E-04	1.18E-08
Y-90	0.00E+00	0.00E+00	7.0E-06	0.00E+00	0.00E+00	0.00E+00
Y-91	3.40E-11	2.50E-09	8.0E-06	3.12E-04	2.02E-04	1.62E-09
Zr-95	1.37E-09	1.00E-07	2.0E-05	5.01E-03	3.24E-03	6.49E-08
Nb-95	1.02E-09	7.48E-08	3.0E-05	2.49E-03	1.61E-03	4.84E-08
Mo-99	1.13E-08	8.29E-07	2.0E-05	4.14E-02	2.68E-02	5.37E-07
Te-132	3.33E-09	2.44E-07	9.0E-06	2.72E-02	1.76E-02	1.58E-07
Ba-140	3.95E-08	2.90E-06	8.0E-06	3.62E-01	2.34E-01	1.87E-06
La-140	5.65E-08	4.15E-06	9.0E-06	4.61E-01	2.98E-01	2.68E-06
Ce-144	1.43E-08	1.05E-06	3.0E-06	3.50E-01	2.26E-01	6.79E-07
Pr-144	0.00E+00	0.00E+00	6.0E-04	0.00E+00	0.00E+00	0.00E+00
H-3	0.00E+00					
total	5.00E-07	3.67E-05		15.4486633	10	2.37453E-05

The following table determines the 10CFR20 C/ECL release if each isotope is released at the 10CFR20 limit. Of course, the results indicate that since each isotope is at it's limit, the C/ECL fraction is equal to the number of isotopes examined.

Table 14
release at 10CFR20 limit (each isotope)

		10CFR20	C/ECL
Br-84	4.0E-04	4.0E-04	1.00E+00
I-131	1.0E-06	1.0E-06	1.00E+00
I-132	1.0E-04	1.0E-04	1.00E+00
I-133	7.0E-06	7.0E-06	1.00E+00
I-134	4.0E-04	4.0E-04	1.00E+00
I-135	3.0E-05	3.0E-05	1.00E+00
Rb-88	4.0E-04	4.0E-04	1.00E+00
Cs-134	9.0E-07	9.0E-07	1.00E+00
Cs-136	6.0E-06	6.0E-06	1.00E+00
Cs-137	1.0E-06	1.0E-06	1.00E+00
Cr-51	5.0E-04	5.0E-04	1.00E+00
Mn-54	3.0E-05	3.0E-05	1.00E+00
Fe-59	1.0E-05	1.0E-05	1.00E+00
Co-58	2.0E-05	2.0E-05	1.00E+00
Co-60	3.0E-06	3.0E-06	1.00E+00
Sr-89	8.0E-06	8.0E-06	1.00E+00
Sr-90	5.0E-07	5.0E-07	1.00E+00
Sr-91	2.0E-05	2.0E-05	1.00E+00
Y-90	7.0E-06	7.0E-06	1.00E+00
Y-91	8.0E-06	8.0E-06	1.00E+00
Zr-95	2.0E-05	2.0E-05	1.00E+00
Nb-95	3.0E-05	3.0E-05	1.00E+00
Mo-99	2.0E-05	2.0E-05	1.00E+00
Te-132	9.0E-06	9.0E-06	1.00E+00
Ba-140	8.0E-06	8.0E-06	1.00E+00
La-140	9.0E-06	9.0E-06	1.00E+00
Ce-144	3.0E-06	3.0E-06	1.00E+00
Pr-144	6.0E-04	6.0E-04	1.00E+00
H-3	1.0E-03	1.0E-03	1.00E+00
total	3.65E-03		29

Results

The results of this calculation are:

```
Mode of   Σ(Conc/ECL)
Release   1 Unit

Gas       0.311 (with containment purge )
          0.324 (with unfiltered containment venting)
          0.271 (with continuous filtered containment venting)
Liquid    1.344 (unprocessed cond.demin.waste)
          0.857 (unprocessed cond.demin, iodine at tech spec limits)
          0.269 (processed cond.demin. waste)
          7.731 (no SGB processing, unlimited release)
          1.669 (no SGB processing, unlimited rel. I at tech spec)
          0.268 (no SGB processing, SGB release limited to LLD)
          0.314 (no SGB processing, SGB rel. limited to max App.I)
          479.3 (no SGB processing,SGB at LLD,no 20,000 gpm dilution
          0.211 (SGB at LLD,SGB only release path,no 20,000gpm dilution
          15.45 (SGB at max App.I, no 20,000 gpm dilution)

Maximum concentrations for no 20,000 gpm dilution, SGB only release path:
      for 10 ECL release: 2.37E-5 uCi/cc
      for 1 ECL release: 2.37E-6 uCi/cc
```

Discussion and Conclusion

The gas design release concentrations are below the 10CFR20 App.B Table 2 limits (one unit operation). The continuous filtered containment venting option results in the lowest gas release because Xe-133 does not reach the same levels in containment due to decreased residence time in containment of it's parent I-133. Xe-133 is the dominant gaseous isotope released. The liquid design release concentrations with no Condensate Polisher Demineralizer regeneration waste processing will be above the 10CFR20 limits. However, when the secondary side activity reaches 1E-6 uCi/gm the condensate regeneration waste is not continuously released, but is released in batch mode and is monitored. In the event that the long term release of this waste is projected to result in exceeding the 10CFR20 limits, the design of the plant allows the waste to be processed by the mobile demineralizer system. With the mobile demineralizer system processing the regeneration waste, the liquid design releases are below the 10CFR20 limits. Note that the design concentrations under consideration in this calculation are significantly above the technical specification limits. For example, I-131 in the design reactor coolant is 2.5 uCi/yr (ref.3) but the technical specification is 1.0 uCi/gm I-131 equivalent. This means that the design reactor coolant has greater than 2.5 times the technical specification limits. When iodines are kept at the Technical Specification limit, and all other isotopes at design levels, then the release concentrations are below the limits. It can be concluded that the realistic release concentrations will then be less than the 10CFR20 limits. The design of the gas and liquid radwaste systems meet the requirements of 10CFR20.

Revision 4 incorporates the alternate operation mode of Steam Generator Blowdown released directly to the environment without processing by the Condensate Polisher Demineralizers, and no Condensate processing by the Condensate Polisher Demineralizers. It is concluded that under normal conditions this release could exceed the 10CFR20 limits. The concentration of the SGB release must be less than that which would exceed the App.I limit of 5 Ci/unit = 3.67E-5 uCi/cc gross gamma (Table 13), or even better, be restricted to the LLD (5E-7 uCi/cc gross gamma).

Revision 4 also evaluated releases without the 20,000 gpm Cooling Tower Blowdown dilution flow. The results indicate that this cannot be done if there are releases from sources other that the SGB. If there are no other radwaste releases, the SGB may be released with no dilution flow if the concentration is 2.37E-6 uCi/cc gross gamma or less.

References

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2. TI-534 R5 "Annual Routine Radioactive Airborne Releases from the Operation of One Unit"
3. WBNTSR-093 R5 "Liquid Radioactive Waste Releases"
4. Memorandum RIMS# T50 950109 844
5. WBNNAL3-003 R1 "Reactor Coolant and Secondary Side Activities in Accordance with ANSI/ANS-18.1-1984" RIMS# B26 930210 254
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7. WCAP 7664 R1 "Radiation Analysis Design Manual, 4-Loop Plant" RIMS# NEB 810126 316
8. System Description N3-77C-4001 R2 "Liquid Radwaste Processing System" RIMS# T29 930403 988
9. Technical Specification 3.4.16
10. Offsite Dose Calculation Manual (ODCM)
11. System Description N3-14-4002 R2 "Condensate Polishing Demineralizer System" RIMS# B26 880714 022
12. WBN CCD drawing 1-47W838-3 R11
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14. WBNTSR-008 R6 "Control Room Operator and Offsite Dose Due to a Steam Generator Tube Rupture"
15. DCN D-50165-A
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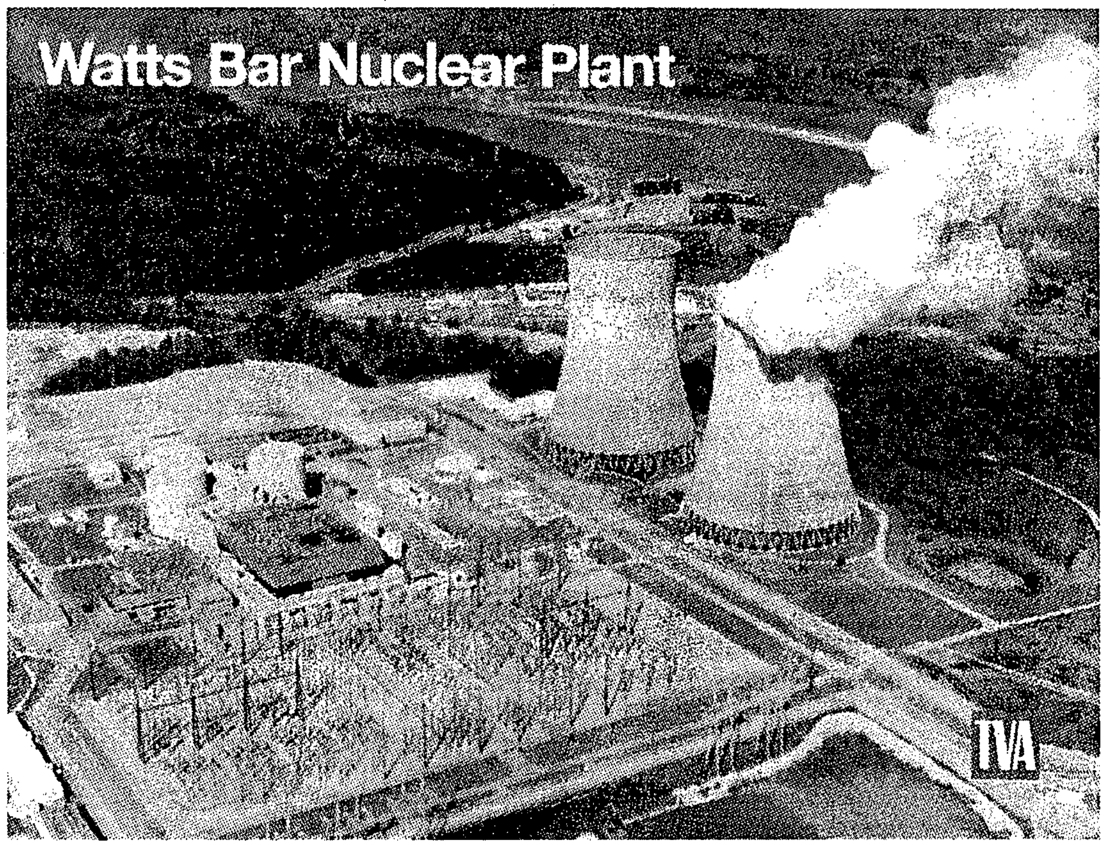
WATTS BAR NUCLEAR PLANT SUPPLEMENTAL CONDENSER COOLING WATER SYSTEM FISH MONITORING PROGRAM



Final Report
January 2001

WATTS BAR NUCLEAR PLANT SUPPLEMENTAL CONDENSER COOLING WATER SYSTEM FISH MONITORING PROGRAM

Prepared by

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Final Report
January 2001

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Executive Summary

The Watts Bar Nuclear Plant (WBN) Supplemental Condenser Cooling Water (SCCW) system, designed to augment the makeup water supply system for WBN, became operational July 19, 1999. As required by the National Pollutant Discharge Elimination System (NPDES) Permit (Number TN0020168) issued to the Tennessee Valley Authority (TVA) for SCCW operation, TVA evaluated impacts of the newly installed SCCW system on resident aquatic communities in the upper two-thirds of Chickamauga Reservoir. As documented in the SCCW Environmental Assessment (TVA 1998), no nuclear licensing issues were involved with the SCCW project.

The SCCW intake is the same one that was used during operation of the Watts Bar Fossil (WBF) Plant, but with about 50 percent less flow for SCCW operation. Densities and relative abundance of ichthyoplankton in the forebay of Watts Bar Reservoir in 2000 were similar to those documented in 1975 (TVA 1976). Low-volume larval fish entrainment reported in 1975 for the Watts Bar Fossil (WBF) water intake resulted in a determination of insignificant losses. Similar projections based on 2000 larval fish community densities and lower SCCW water intake volume suggest no significant impact to ichthyoplankton populations from entrainment resulting from WBN SCCW operation. Impingement of adult and juvenile fish on the intake traveling screens during the first year of operation using the SCCW was also low (the vast majority being gizzard shad and bluegill).

Sauger and striped bass movement was unimpeded by the thermal discharge. The most recent Reservoir Fish Assemblage Index (RFAI) evaluation of the upper Chickamauga Reservoir fishery was completed in fall 1999. This evaluation found the fishery to be in "Good" condition which approximated scores from previous sample years. Further down river in Chickamauga Reservoir, near Sequoyah Nuclear Plant (SQN), the fish community also received a "Good" RFAI score. Benthic macroinvertebrate studies conducted in 1999, found the benthic community to be in relatively "Fair" condition near the dam and "Excellent" condition at the transition zone, in the vicinity of SQN. Although the benthic macroinvertebrate condition near the dam has declined over three consecutive sample years, it is considered to be unrelated to SCCW operation, since the decline began prior to the SCCW system going on-line. Overall, it was concluded that the WBN SCCW system operation, including both water intake and thermal discharge has had no impact to aquatic life in the forebay of Watts Bar Reservoir and the upper two-thirds of Chickamauga Reservoir.

Introduction

1.1 Plant Description

Watts Bar Nuclear Plant (WBN) is located on the west bank of upper Chickamauga Reservoir near Tennessee River Mile (TRM) 528. This one-unit nuclear generating plant is designed for an electrical output of about 1270 megawatts (MW). WBN is situated approximately two miles downstream of Watts Bar Dam (WBH) (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 went into commercial operation on May 27, 1996. The plant is operated in closed cycle cooling mode, using one of the two cooling towers for heat dissipation. Blow-down from the cooling tower is discharged through multi-port 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.

The WBN intake channel cross-section opening is approximately 155 m^2 (1,650 ft^2) at Chickamauga Reservoir winter pool elevation of 206 m (675 ft) mean sea level, and 293 m^2 (3,159 ft^2) at summer pool level of 208 m (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 flow rate 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).

Blow-down 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 WBH, WBN blow-down 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 90 m into the channel with a 50 m long, 1.35 m diameter diffuser section located in the deepest (5-6 m) portion of the 400 m wide channel. The upstream pipe segment extends 140 m with a 25 m long, 1.0 m diameter diffuser section beginning where the downstream diffuser section ends. The diffuser sections are half buried in the river bottom with two rows of 2.5 cm (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 blow-down temperature is 35°C, so the approximate 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 has resulted in a near-field dilution of at least 15. Far-field mixing depends on releases from WBH. The permitted diffuser mixing zone at

WBN is 240-ft wide and extends 240-ft downstream over the entire river depth.

1.2 Supplemental Condenser Cooling Water System Description

The installation of the WBN SCCW system was completed and became operational in July, 1999. The SCCW is designed to provide between 115,000 and 135,000 gallons of water per minute (gpm) from Watts Bar Reservoir to WBN, depending on the pool elevation, to supplement the cooling capacity of the existing cooling tower.

Water from the reservoir flows through an intake screen house that is adjacent to the west upstream side of WBH. The water enters the screen house through six intake sluice gates with bottoms at elevation 710, and traveling water screens. The gates tend to act as water skimmers since normal summer headwater is at elevation 740.5. The water flows approximately 3,200 ft to the fossil plant through two 78-inch diameter concrete pipes. A new 90-inch diameter reinforced concrete pipe was tied into the existing 78-inch pipes approximately 200-ft north of the WBF switchyard. This pipe runs along the east side of WBF skirting the side of the existing ash ponds and the coal yard on the fossil plant site. After leaving the WBF property, the pipe traverses the northeast portion of the WBN site to a new inlet structure at the Unit 2 tower. A motor operated valve, located in the pipeline, is required to stop the flow to the tower basin whenever cooling tower blow-down is suspended during periodic chemical treatment of the Condenser Cooling Water (CCW).

The SCCW is conveyed through the Unit 2 tower basin to the Unit 1 tower discharge flume. Here it mixes with the warmer cold water from the Unit 1 tower prior to being pumped to the inlet of the Unit 1 main condenser.

To maintain the level and volume of the CCW system and to take advantage of the cooling effect, warm water is discharged at the same flow rate as the supplemental supply. To accomplish this, an overflow weir structure is provided on the side of the Unit 1 cooling tower basin. A 60 to 72-inch diameter reinforced pipe conveys the discharge flow by gravity from the tower to the existing WBF discharge canal. This pipe is routed along the new supply pipe from the WBN tower to the vicinity of the WBF discharge.

In addition, a partial 42-inch bypass pipeline with a control valve diverts up to 40% of the supplemental flow from the supply pipeline to the new WBN discharge line. This is used in cooler months to reduce the amount of heat and lower the temperature of water discharged through the WBF discharge structure. This bypass provides for a gradual change in discharge temperature during periods of system startup and shutdown.

Water from the SCCW system is discharged through the old WBF discharge structure located on the Tennessee River approximately 1.1 miles upstream of the nuclear plant intake. It consists of an open discharge canal, an overflow weir drop structure, and a below water discharge tunnel. This discharge tunnel is a rectangular culvert 7-ft wide by 15-ft high at the discharge point. The elevation of the top of the culvert outlet is 675 ft, which coincides with the normal minimum pool elevation of the 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 ft.

1.3 Improved Plant Performance

The CCW system for 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 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 back pressure above the optimum design. Reducing the temperature of the water to the main condenser improves efficiency and output. By routing cooler water from upstream of the WBH to WBN, the water mixes with and lowers the temperature of the water from the towers resulting in increased turbine-generator output. This increased capacity occurs predominately in the warm weather months of May through August when the cooling tower cooled water is warmest.

Projected Aquatic Community Impacts

As described in the SCCW Environmental Assessment (EA) (TVA 1998), the SCCW water intake located in the forebay of Watts Bar Reservoir was determined to have low potential for aquatic community affects. Additionally, thermal impact modeling indicated operation of the SCCW system would increase the annual thermal discharge to the river, compared to the pre-existing cooling tower blow-down, by a factor of 10 (TVA 1998). The SCCW EA noted that the potential impact of this discharge on resident Tennessee River biological communities included limited mortality of individuals of some temperature sensitive fish species, however no significant adverse affects on individual populations or the structure and function of the entire resident fish community near the SCCW discharge were anticipated.

Entrainment-Larval Fish (and Eggs)

2.1 Introduction

Monitoring to determine spatio-temporal concentrations of ichthyoplankton in the vicinity of WBN SCCW intake was conducted during spring 2000. Data was compared with 1974-1975 larval fish composition and densities to determine if no entrainment impact conclusions of earlier operational monitoring report (TVA 1976) were relevant to current larval fish communities. Data were also used to evaluate projected proportional entrainment losses of eggs and larvae resulting from SCCW operation.

2.2 Materials and Methods

To determine the number and species of fish eggs and larvae available for entrainment, one nighttime ichthyoplankton sample was collected weekly from April through June 2000 along a transect at TRM 530.3 (Figure 1). Sample results were compared to WBF operational monitoring data collected weekly March through July 1975 from this same TRM 530.3 transect. During 1975, ten samples were collected each week at night. During both sampling efforts, samples were taken with a beam net (0.5 m square, 1.8 m long, with 505 micron "nitex" mesh netting) towed across the reservoir transect 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.

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 eggs that cannot be identified due to damage or lack of taxonomic knowledge. Taxonomic refinement is a function of specimen size and developmental stage. Any clupeid specimen identified to species level represents post-larva 20 mm or longer in total length.

Developmental stage of temperate basses 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 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.

Results of laboratory analysis of each sample were converted into densities (numbers/1000m^3) and percent relative abundance for better interpretation of potential entrainment impact.

2.3 Results and Discussion

During the WBN SCCW operational study and earlier WBF entrainment study periods, no fish eggs were collected in ichthyoplankton samples.

Taxonomic composition of larval fish collected during SCCW operational monitoring consisted of 5 taxa (Table 1). Clupeid and *Lepomis* larvae comprised 69% and 19% of the larval fish sampled and were present in 5 of 11 and 4 of 11 sample periods, respectively. Percent composition of remaining taxa were *Morone* (not *saxatilis*) (6%), *Pomoxis sp.* (4%), and Percidae (not *Stizostedion*) (1%). *Morone* (not *saxatilis*) and Percidae (not *Stizostedion*) occurred during the first 4 sample periods where *Pomoxis* sp., *Lepomis* sp. and Clupeids occurred in the last 6 sample periods (Table 1).

Reservoir densities of fish larvae for both entrainment studies (spring of 1975 and 2000) were similar except for Clupeid densities (Table 3). Clupeids collected during the spring of 2000 were significantly less numerous than spring of 1975 sampling. Clupeid populations fluctuate annually due to various environmental factors, such as extreme cold weather (relative for the area) and drought conditions (Charles Saylor, personal communication, 2000). Peak densities of larval fish for both studies occurred during mid-May (Tables 1 and 2). *Lepomis* were relatively abundant in samples during spring of 2000 compared to spring of 1975, $108/1000m^3$ and $31/1000m^3$, respectively (Table 3).

Morone larval densities during spring 1975 and 2000 entrainment studies were similar, 49 and 33 $/1000m^3$, respectively.(Table 3). *Pomoxis* larval densities were also similar, 15 and 20 $/1000m^3$ during the two respective entrainment studies. Size distribution of larval fish collected during spring 2000 are shown in Table 4.

It was concluded that the low entrainment of fish eggs and larvae (0.24%) by WBF (TVA 1976) did not adversely impact shad and sunfish populations in lower Watts Bar Reservoir. Likewise, fish larvae density and relative abundance data collected from the Watts Bar Reservoir forebay during spring 2000 indicates no significant impact to ichthyoplankton populations from WBN SCCW operation.

Impingement-Adult Fish

3.1 Introduction

Relatively low numbers of fish were impinged during WBF operation in the early 1970's (TVA 1976). Fish impingement losses were highest in March and April (mainly threadfin shad) and again in September (highest bluegill densities) during WBF monitoring. These are periods when 44% of annual impingement occurred. Impingement monitoring was done during these periods after WBN SCCW became operational in May, 1999, to verify if impingement losses remained minimal.

3.2 Material and Methods

Impingement counts were made on 5 days during each of two selected periods (March-April and September). September is also one of the months with the most potential for striped bass impingement. The only scenario where striped bass could be impinged on the SCCW intake screens would occur if the aeration system in the forebay area of Watts

Bar Reservoir failed. In low dissolved oxygen conditions, striped bass are forced into areas where water temperatures are at or above the species' lethal limit, and fish in weakened condition or already dead from the these stressors could be impinged on the intake screens. This situation can occur near the SCCW intake during mid-summer and early fall months.

The first monitoring period for fish impingement on the WBN SCCW cooling water intake traveling screens began August 31, 1999 and ran through September 29, 1999. The second period of sampling was conducted between March 7, 2000 and April 26, 2000. Results from these sampling periods are compared with impingement samples collected during WBF operational monitoring. Protocol for impingement sampling at the SCCW intake pumping station consisted of four screens rotating and back-washing 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 back-washed 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. Estimates of seasonal impingement were calculated by multiplying average number of fish impinged per sample by the number of days during the sample period.

3.3 Results and Discussion

The eleven impingement samples yielded 146 fish representing nine species (Table 5). The total number of impinged fish collected on April 19, 2000 sample was 84, however, the estimated number impinged was 188 and very few young-of-year fish were collected in the samples (Table 5). Of the fish actually enumerated, the majority were gizzard shad and bluegill (Figure 2). Skipjack herring, channel catfish, yellow bass, freshwater drum, striped bass, and a couple of unidentified shiner species were also impinged (Figure 2). Of the total number of fish impinged during SCCW monitoring, 51.2% were impinged between March and April. This is similar to impingement documented during the WBF operational study (TVA 1976). Gizzard and threadfin shad comprised the majority of fish impinged during both monitoring periods (Table 6 and 7). Of the 16 non-shad species collected only bluegill and drum were impinged at an average rate exceeding one individual per 24 hours (TVA 1975). No striped bass were impinged during the month of September, however two young-of-year were collected during spring impingement sampling (Table 5). Therefore, dissolved oxygen concentrations near the SCCW intake were apparently adequate during WBN operation using the SCCW system.

Total estimated annual impingement of 9,125 fish at the WBN SCCW intake during1999 and 2000 (Table 6) is substantially higher than the 162.2 total estimated annual number of fish impinged during 1996 and 1997 at the WBN intake located below Watts Bar Dam (TVA 1997). However, it is extremely low when compared to the 41 different species with total annual estimates of 70,022, 40,944 and 14,960 impinged at SQN during 1981-1983, respectively (TVA 1997). The lower number collected for the 1999 and 2000 study at WBN can, in part, be attributed to the SCCW intake structure at WBH operating at a reduced flow (about 50% of the former WBF flow). None of the species were impinged at WBN in sufficient numbers to impact Chickamauga Reservoir populations (TVA 2000). Additionally, no fish listed as threatened, endangered or of special concern by the State of Tennessee or the U. S. Fish and Wildlife Service were impinged on any WBN intake screens.

Reservoir Fish Assemblage Index

4.1 Introduction

Aquatic communities found in the inflow, transition, and forebay zones of all Tennessee River reservoirs, and several major embayments, are sampled routinely as part of the TVA Vital Signs Monitoring Program to assist in monitoring reservoir environmental quality. One portion of this program uses electrofishing and experimental gill netting results to calculate Reservoir Fish Assemblage Index (RFAI) scores as an expression of fish community quality (Hickman and McDonough 1996 and McDonough and Hickman 1999). RFAI results are available from the forebay area of Watts Bar Reservoir (TRM 531) in the vicinity of the SCCW intake; upper Chickamauga Reservoir inflow area (TRM 518) in the vicinity of the WBN intake and discharge diffuser and the SCCW discharge; and downstream at the Chickamauga Reservoir transition zone near Sequoyah Nuclear Plant (TRM 490.5) (TVA 2000). These monitoring activities can be used to document status of the resident fish community in the vicinity of the SCCW intake and discharge.

4.2 Materials and Methods

Shoreline electrofishing samples were collected during daylight hours from each of the aforementioned sample sites during autumn (October-November) of 1994 through 1997 and 1999. A total of 15 electrofishing runs, each covering 300 m of shoreline, was collected from each of the sampled zones. All habitats were sampled in proportion to their occurrence in each zone. Twelve experimental gill nets with five 6.1 m panels (mesh sizes of 2.5, 5.1, 7.6, 10.2, and 12.7 cm) were set for one overnight period in the Watts Bar forebay and Chickamauga transition zone. Excessive current prevented use of gill nets in the Chickamauga inflow zone, limiting sampling to only electrofishing in this location. Nets were set in all habitat types, alternating mesh sizes toward the shoreline between sets.

Total length (mm) and weight (g) were obtained for sport species and channel catfish. Remaining species captured were enumerated prior to release. During electrofishing, fish observed but not captured were included if positive identification could be made and counts were estimated when high densities of identifiable fish were encountered. Young-of-year fish were counted separately and, as in stream IBI calculations (Karr 1981), were excluded from proportional and abundance metrics due to sampling inefficiencies. Only fish examined closely as a result of obtaining length and weight measurements were inspected externally for signs of disease, parasites, and anomalies. Other species groups often included several individuals which were observed, but not captured, thus the ratio of diseased, etc. was not obtainable for these groups. Natural hybrids (i.e., those known not to be part of a fisheries management program) were included as an anomaly.

The RFAI uses 12 fish community metrics from five general categories to evaluate fish community condition (Hickman and McDonough, 1996). The 12 metrics include:

Metrics Related to Species Richness and Composition

1. **Total number of species** - Greater number of species are considered representative of healthier aquatic ecosystems.
2. **Number of piscivore species** - Higher diversity of piscivores is indicative of better quality environment.
3. **Number of sunfish species** (excluding black basses, crappies, and rock bass) - Lepomid sunfish are basically insectivores, and high diversity of this group is indicative of reduced siltation and suitable sediment quality in littoral areas.
4. **Number of sucker species** - Suckers are also insectivores but inhabit the pelagic and more riverine sections of reservoirs.
5. **Number of intolerant species -** This group is made up of species that are particularly intolerant of habitat degradation. Higher densities of intolerant individuals represent better environmental quality.
6. **Percentage of tolerant individuals** (excluding young-of-year) - This metric signifies poorer quality with increasing proportions of individuals tolerant of degraded conditions.
7. **Percentage dominance by one species** - This metric signifies poorer quality with increasing proportions of individuals tolerant of degraded conditions.

Metrics Related to Trophic Composition

8. **Percentage of Individuals as Omnivores** - Omnivores are less sensitive to environmental stresses due to their ability to vary their diets. As trophic links are disrupted due to degraded conditions, specialist species such as insectivores decline while opportunistic omnivorous species increase in relative abundance.
9. **Percentage of Individuals as Insectivores** - Due to the special dietary requirements of this group of species and the limitations of their food source in degraded environments, proportion of insectivores increases with environmental quality.

Metrics Related to Reproductive Composition

10. **Number of Lithophilic Spawning Species** - Lithophilic broadcast spawners spawn over rocky substrate and do not provide parental care. This guild is expected to be sensitive to siltation. Numbers of lithophilic spawning species increase in reservoirs providing suitable conditions reflective of good environmental quality.

Metrics Related to Abundance

11. **Total Catch Per Unit Effort** (number of individuals) - This metric is based upon the assumption that high quality fish assemblages support large numbers of individuals.

Metrics Related to Fish Health

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

In developing scoring criteria, a slightly different approach was used for species richness metrics than for abundance and proportional metrics. For species richness metrics, a list was made of all species collected from comparable locations within a reservoir class from 1990 to 1994. This species list was adjusted using inferences of experienced biologists knowledgeable of the reservoir system, resident fish species, susceptibility of each species to collection methods being used, and effects of human-induced impacts on these species. This effort resulted in a list of the maximum number of species expected to occur at a sampling location and be captured by collection devices in use. Given that only one collection effort is exerted each year, this maximum number of species would not be expected to be represented in that one collection. Therefore, the upper 5% of attained values was discarded prior to trisecting into three scoring ranges ("least degraded," "intermediate," and "most degraded"). Although even 95% of the maximum number of species at a site would not be expected to be collected in one sampling event, this "high" expectation was adopted to keep these metrics conservative in light of potential uncertainties introduced by use of professional judgment.

Scoring criteria for proportional metrics and the abundance metric were determined by trisecting observed ranges after omitting outliers (upper 5% of attained values). Next, cutoff points between the three ranges were adjusted based on examination of frequency distributions of observed data for each metric along with professional judgment. In some cases, the narrow range of observed conditions required further adjustment based on knowledge of metric responses to human-induced impacts observed in other reservoir classes. Scoring criteria for the fish health metric are those described by Karr et al. (1986).

Scoring criteria are used to separate results for each metric into three categories assumed to represent relative degrees of condition of the fish assemblage ranging from "Good" to "Poor." Each category had a corresponding value: "least degraded" = 5, "intermediate" = 3, and "most degraded" = 1. The sum of the 12 metrics constitutes the RFAI score.

Scoring criteria were applied differently to results from the two collections methods (electrofishing and experimental gill netting) depending on the metric. For taxa richness, reproductive composition, and fish health metrics, sampling results were pooled prior to scoring. For abundance and proportional metrics, electrofishing and gill netting results were scored separately, then the two scores were averaged to arrive at a final metric value. To arrive at an evaluation of the condition of the fish assemblage at a sample location, scores were evaluated according to the ranges presented in Table 8.

4.3 Results and Discussion

RFAI sampling results indicate similar fish community conditions at the inflow and transition sampling zones between 1993 and 1999 (Figure 3). During fall 1997 (the most recent pre-operational SCCW evaluation) and 1999 (after SCCW became operational in July 1999), a total of 30 and 28 native fish species were collected from the Chickamauga inflow zone (TRM 518), respectively (Tables 9 and 10). Twenty-two native fish species were collected from the transition zone (TRM 490.5), near SQN (TRM 483.6) in 1997, with 27 species being collected in 1999.

The fish assemblage rated "Excellent" at the inflow zone and "Fair" at the transition zone in 1997 (Table 10). These ratings changed in 1999 with ratings of "Good" at both the inflow and transition zones (SCCW post-operation). Although the ratings at the inflow resulted in a shift in group designation, the level of decline is small. Metrics which changed between the two sample years at the inflow site included: decline in the number of sunfish species, an increase in the dominance by one species (threadfin shad), a decrease in the percentage of insectivores, and a decline in the average number of individuals (Tables 11 and 12). The transition zone improved in 1999 with an increase in score of nine metrics (Tables 10 and 11).

No substantial change in fish community status has occurred at either the inflow or transition zones since the SCCW system became operational in July of 1999 (Figure 3). The average scores, over the six year sampling time frame for the Chickamauga Reservoir inflow and transition zones were 48 and 45 (i.e., "Good"), respectively. Annual variations within each zone are minimal and within acceptable ranges for RFAI scores (Gary Hickman, personal communication, 2000). No notable change occurred in 1999 scores following SCCW operation (Figure 3). Therefore, operation of the SCCW system has had no impact on the fish assemblage either in the vicinity of the SCCW discharge or approximately 27.5 river miles downstream.

Benthic Macroinvertebrate Community

5.1 Introduction

Benthic macroinvertebrates are usually included in aquatic monitoring programs because they are important to the aquatic foodweb and because they have limited capability of movement thereby preventing them from avoiding undesirable conditions. The macroinvertebrate community in a reservoir is expected to be vastly different from that in a free-flowing river. Also, substantial differences are expected along a longitudinal gradient with a more riverine community expected at the upper end or inflow of a reservoir (i.e., location of WBN SCCW discharge) and a more reservoir-like community expected in the pool upstream of a dam.

As part of TVA's Vital Signs monitoring, benthic macroinvertebrate samples were collected from Chickamauga Reservoir in 1994, 1995, 1997 and 1999 to assist in monitoring reservoir environmental quality. Samples were taken from the Chickamauga inflow and transition zones (TRMs 518 and 490.5 respectively) on the bottom of the reservoir using either Ponar grab samples or a Peterson dredge.

5.2 Materials and Methods

Benthic macroinvertebrate samples were collected in late fall/early winter (November to December) at the Chickamauga inflow and transition zones. At each sample location, a line-of-sight transect was established across the width of the reservoir, and one Ponar grab sample collected at 10 equally-spaced locations along this transect. When rocky substrates were encountered, a Peterson dredge was used. Care was taken to collect samples only from the permanently wetted bottom portion of the reservoir (i.e., below the elevation of the minimum winter pool level). Samples were washed, counted, and identified in the field (with the exception of the 1994 laboratory-identified sample) to either Family or Order level as appropriate (i.e., the lowest practical in the field). Samples were then transferred to a labeled collection jar, and fixed with 10% buffered formalin solution.

Seven metrics were used to evaluate benthic macroinvertebrate communities in Chickamauga Reservoir. Scoring criteria for each metric was developed from the database on all TVA "run-of-the-river" reservoirs. The benthic macroinvertebrate score is a total of these seven metrics presented below.

1. **Taxa Richness** - an increase in taxa richness indicates better conditions than low taxa richness
2. **EPT Taxa** - Higher diversity of these taxa indicates good water quality and other habitat conditions in streams
3. **Long-lived Taxa** - the presence of long-lived taxa is indicative of conditions which allow long-term survival
4. **Non-chironomid & Oligochaetes Density** - a higher abundance of non-chironomids and oligochaetes indicates good water quality conditions
5. **Percent Oligochaetes** - oligochaetes are considered tolerant organisms, so higher proportion indicates poor water quality
6. **Dominance** - dominance of one or two taxa indicates poor conditions
7. **Zero Samples** - "zero samples" indicate living conditions unsuitable to support aquatic life (i.e., toxicity, unsuitable substrate, etc.).

To arrive at an evaluation of the condition of the benthic macroinvertebrate community at a sample location, scores were categorized according to the ranges presented in Table 13.

Sample results at each site were scored using the appropriate scoring ranges for each metric and assigned a value of either 5 ("Good"), 3 ("Fair"), or 1 ("Poor"). Numerical ratings for the seven metrics were then summed.

5.3 Results and Discussion

Benthic macroinvertebrate community analysis conducted on Chickamauga Reservoir in 1994, 1995, 1997, and 1999 has shown no evidence of SCCW-related impacts to aquatic communities. Although the inflow zone has had a steady decline in benthic scores since 1995 (Figure 4 and Table 13), the decline began prior to the SCCW system going on-line in July of 1999 and is most likely a function of hydropower operation and flood control activities, as they relate to climatic events such as rapid flow and water temperature changes, heavy rainfall, spilling, heat waves, etc. (Tyler Baker and Amy Wales, personal communication, 2000). The Chickamauga inflow zone's aquatic community rating has gone from "Fair" to "Excellent" to "Good" to "Fair" as evident by the 1994, 1995, 1997, and 1999 data respectively (Figure 4 and Table 13). The Chickamauga transition zone was rated as "Excellent" in 1994, "Fair" in 1995, and "Excellent" in 1997 and 1999 (Figure3 and Table 13). The better condition of the aquatic community at the transition zone approximately 27.5 river miles downstream is attributable to the less harsh environment at that location (i.e., less rapid changes in flow and water temperature).

Sauger and Striped Bass Radio Telemetry

6.1 Introduction

Sauger is an important sport fish sought by fishermen in the vicinity of WBN. Spawning success of sauger can be adversely impacted by thermal discharges either by diverting the adult spawners away from historic spawning ground or artificially adjusting the maturation cycle during prolonged exposure to heated water.

Typical sauger life history is as follows. During late winter sauger begin congregating near spawning areas, at which time they are most vulnerable to anglers. Spawning activity begins in late March to early April as water temperatures approach 52 °F. Spawning migrations may cover considerable distances. Spawning occurs at night and extends over a 2-week period. Several males usually attend each spawning female.

Successful spawning requires firm substrates. In Chickamauga Reservoir, most sauger spawning occurs over the rubble and gravel of Hunter Shoals approximately 8.9 river miles downstream of the SCCW discharge. Instinctual sauger spawning runs take the species up river where it encounters Watts Bar Dam. They typically congregate below the dam for a short period of time (i.e., staging) and then move downstream to Hunter Shoals for spawning. Eggs are adhesive immediately after spawning, but shortly thereafter become non-adhesive and may be widely dispersed by currents. Hatching requires 21 days at water temperature of 47 °F. The larvae soon begin feeding on cladocera, copepods, and midge larvae, but, as juveniles, switch to a diet of almost exclusively fishes. Small gizzard and threadfin shad are the primary prey locally, with emerald shiners and burrowing mayfly nymphs important food where abundant. Adults disperse to deeper waters after spawning.

During 1988 TVA investigations of WBN and SQN operational impacts on sauger spawning, it was determined that thermal releases did not adversely impact sauger spawning activity in Chickamauga Reservoir (TVA 1989). However, due to the combination of the projected amount of heated water released at the WBN SCCW discharge and the proximity to the spawning shoals, TVA decided to collect and radio-tag 15 adult sauger in late February 2000 and track their movements below WBH once per week for a period of 11 weeks. In addition, five striped bass were radio-tagged to monitor their movements. The purpose of this research was to assess the potential thermal discharge impact to spawning migration of adult sauger and susceptibility of striped bass to angling, should they congregate around the heated flume and become more susceptible to anglers.

6.2 Materials and Methods

On February 29, 2000, fifteen sauger and five striped bass were collected (Table 14). Each fish was surgically implanted with a battery-operated, internal radio transmitter and sex was determined during surgery. Proper operation of the tags was confirmed prior to release. Each tag relayed location information to a receiver located onboard a TVA boat via radio waves. This method of tracking allowed TVA biologists to monitor the location of the released fish with minimal influence on behavior. In addition, it typically allows for the collection of more data then is normally gathered by techniques such as mark-and-recapture.

6.3 Results and Discussion

Tagged sauger and striped bass were tracked on a weekly basis between March 7, 2000 and May 10, 2000. Eight sauger and one striped bass were located during 11 weeks of tracking (Figure 4 and Table 14). Of the eight sauger tracked, four were monitored on more than one occasion (Table 14) and all but one was female. These findings would agree with those of a 1988 TVA study which found that typically, sexually mature male sauger return to the Hunter Shoals area prior to the mature females (TVA 1989). A tendency to remain in the immediate vicinity of WBH until peak spawning was found to be indicative of female spawning behavior (TVA 1989). The lone male striped bass was found once three weeks after release (Table 14). No fish were monitored for three weeks (between March 28, 2000 and April 10, 2000), possibly due to high flow caused by hydropower generation at WBH. On April 19 and 26, 2000, one female sauger was tracked. No fish were monitored on May 3, 2000 (Table 14). During the final tracking session on May 10, 2000, one female and one male sauger was monitored, both of which had been found on previous site visits (Table 14). Of the 15 sauger implanted with radio-tags, only three (i.e., 20%) were tracked within the thermal flume, and only one of the three was tracked in the flume on more than one occasion (Table 14).

Since all tags were in working condition upon release and none were tracked to the same location during consecutive weeks (which could indicate mortality), it was assumed that all fish survived implantation and behaved normally. Angler interviews (discussed in the next section) indicated that only one boat fisherman caught a tagged striped bass and released it following the removal of the radio-tag antenna. However, since striped bass fishing typically occurs during fall and winter months and striped bass tagging and tracking occurred between February and May, it is assumed that most of the missing striped bass were not taken by fishermen. Of the movement patterns TVA biologists were able to track, neither sauger nor striped bass demonstrated any real affinity to the SCCW thermal flume. All sauger movements during the two-month period appeared to be similar to the 1988 findings, with the males moving out of the area first, as expected. Therefore, the thermal flume had no apparent effect on sauger spawning habits nor striped bass susceptibility to fishing pressure.

Recreational and Commercial Fishing in the Vicinity of the SCCW Discharge

7.1 Introduction

During WBN operational monitoring (April 1996 through March 1997), harvest, catch, and effort data were collected to characterize the fishery in the vicinity of the WBN and WBF discharges. WBN operational creel results indicated a majority of fishing in the area below WBH (71%) was done from the bank, with 49% of this pressure being exerted along the bank adjacent to the WBF and WBN plants in the vicinity of the SCCW discharge (Baxter et al, 1998).

Catfish were the main species sought by anglers in the WBH tailwater area during WBN operational monitoring. Sauger, white bass, black basses, and striped bass also were important to the fishery. Catfish angling effort was highest during summer months, with sauger dominating the fall and winter fishery. Angling effort for white bass and crappie was highest during winter and spring months, and striped bass fishing occurred mainly during fall and winter months (Baxter et al., 1998).

WBN operational creel results, including all anglers, reveal that bluegill, white bass, catfish, yellow bass, sauger, crappie, and black bass were caught in the Watts Bar tailwater more frequently than any other species (TVA 1997). A majority of the sauger, white bass, and striped bass are caught along the side of the tailwater adjacent to the WBF and WBN plants (in the vicinity of the SCCW discharge). These species of fish orient to the current coming through the generators located in this side of WBH. Catfish also congregate along the current during summer months. During non-generation periods, individuals of all these species tend to roam the tailwater area and are not as concentrated.

7.2 Results and Discussion

Angler interviews and cursory field observations of fishermen activities were made during SCCW Radio Telemetry study. The majority of bank and boat fishermen were observed above the SCCW discharge which supports the fishing pressure findings reported earlier. Only occasionally, were fishermen noted fishing in the thermal flume. The tagged striped bass, caught by a boat fisherman and released, was caught above the SCCW discharge.

Commercial fishing in the vicinity of WBF and WBN is typically not possible due to current velocities in the area making netting virtually impossible. One commercial fisherman was observed upstream of the flume during a site visit in April. This individual was using slat baskets to capture catfish. Commercial netting is not permitted in Watts Bar Reservoir. The potential impact of the WBN SCCW project on commercial fishing is considered to be extremely low.

Summary and Conclusions

Various aspects of aquatic communities were analyzed in the vicinity of the WBN during preoperational and operational monitoring in 1982 to 1985 and 1996 to 1997, respectively. The WBN SCCW system went into operation July 19, 1999. Data gathered from the WBN preoperational and operational research was used in comparison with recent studies directed at SCCW system operation to determine if its operation was having any adverse effects on aquatic communities in the vicinity of its discharge or further down river.

Evaluation of entrainment of ichthyoplankton (fish eggs and larvae) by WBN SCCW revealed the presence of few taxa and relatively low densities. Larval samples were dominated by clupeids (69%). *Lepomis* (19%), *Morone* (6%) and *Pomoxis* (4%) were relatively abundant. Low entrainment estimates, 1976 and 2000, indicate that the operation of the WBN SCCW did not adversely impact ichthyoplankton populations.

Impingement samples collected at the WBN SCCW intake between August 31, 1999 and September 29, 1999 and again between March 7, 2000 and April 26, 2000 illustrated no trends. In fact, only an estimated 250 fish were actually impinged, an extremely low number compared to previous impingement studies. Therefore, it was determined that WBN SCCW impingement has no effect on the fish community in Watts Bar Reservoir.

RFAI results from 1990 through 1999 Vital Signs field collections indicate similar fish assemblages at the inflow and transitions zones. Since RFAI values for 1999 were similar, it can be determined that no adverse effects to fish communities at these two stations on Chickamauga Reservoir have occurred as a result of SCCW operation.

Benthic macroinvertebrate collections, another aspect of Vital Signs monitoring, found the communities to be in "Fair" to "Excellent" condition at both the inflow and transitions zones prior to operation (1997) and after SCCW operation had begun (1999).

The slightly lower scores, and subsequent decline in condition at the inflow station, is most likely the result of more harsh conditions caused by the generation of hydropower (i.e., rapid changes in flow and water temperature). Here again, this portion of Vital Signs monitoring reveals no adverse effects to the benthic macroinvertebrate communities as a result of SCCW operation.

Radio telemetry tracking of sauger and striped bass divulged no correlation between SCCW operation and sauger spawning activities or striped bass susceptibility to anglers. Sauger and striped bass movements were judged to be similar to those in a 1988 TVA study (TVA 1989) and in no way affected by SCCW operation. In fact, their movements during tracking seem to be more closely related to flow than to temperature which coincides with fishing pressure information.

And finally, fishing pressure in the vicinity of the SCCW discharge is inconsequential to the overall fish populations in Chickamauga Reservoir. Although anglers were noted during each field visit in fiscal year 2000, 1996 and 1997 creel data indicated that species such as sauger, white bass, and striped bass were attracted to the vicinity of the SCCW discharge prior to its operation. These species are drawn to the current created by hydropower generation more so than the SCCW thermal flume.

As evident by the findings of this study, we recommend that RFAI (Reservoir Fisheries Assessment Index) and Reservoir Benthic IBI (Index of Biotic Integrity) from Watts Bar Reservoir forbay, Chickamauga Reservoirs inflow and transition zone be continued to monitor continuing trends of the fish and benthic communities. In addition, we recommend SFI (Sport Fishing Index) be used to monitor important sport fish population trends of Black basses, black and white crappie and sauger.

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Table 1. Species list, total number collected (n/1000 m3), percent composition and occurrence spans of fish larvae collected during operational monitoring at Watts Bar Nuclear Plant, SCCW intake April - June, 2000.

TAXON	TOTAL COLLECTED	PERCENT COMPOSITION	SAMPLING PERIODS										
FISH LARVAE			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Clupeidae	382	69						X	X	X	X		X
Morone (not saxatilis)	34	6	X	X		X							
Lepomis sp.	107	19								X	X	X	X
Pomoxis sp.	20	4						X	X				
Percidae (not stizostedion)	7	1		X									

Table 2. Average Densities (n/1000 m3) and occurrence spans of fish larvae for Watts Bar Steam Plant, Watts Bar Reservoir, 1975.

TAXON	TOTAL COLLECTED	SAMPLING PERIODS									
FISH LARVAE		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Clupeidae	20744				X	X	X	X	X	X	X
Moronidae	49				X	X	X				
Lepomis sp.	244				X	X	X	X	X	X	X
Pomoxis sp.	15				X	X					
Percidae	1				X						
Sciaenidae	24						X	X	X	X	X

Table 3. Average Densities (n/1000 m3) of fish larvae collected in the forebay of Watts Bar Reservoir during 1975 and 2000.

TAXON	1975	2000
Clupeidae	20744	380
Moronidae	49	33
Lepomis sp.	244	108
Pomoxis sp.	15	20
Percidae	1	1
Sciaenidae	24	0

Table 4. Distribution of larval fishes by size group (mm) collected at Watts Bar Forebay Transect, during spring 2000.

2000	**Size Group (mm)**										
TAXON	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Clupeidae	20	80	67	107	47	20	20	7	7		7
Morone (not *saxalitis*)		27	7								
Lepomis sp.	7	40	33	27							
Pomoxis sp.	13	7									
Percidae (not stizostedion)			7								

Table 5. 1999 and 2000 Watts Bar Dam impingement observations.

Common Name	Scientific Name	Total Impinged	Size Range (mm)
	August 31, 1999		
No Fish			
	September 9, 1999		
No Fish			
	September 14, 1999		
1. Gizzard shad	*Dorosoma cepedianum*	1	204
2. Bluegill	*Lepomis macrochirus*	1	150
	September 23, 1999		
1. Threadfin shad	*Dorosoma petenense*	6	66-88
2. Bluegill	*Lepomis macrochirus*	3	60-64
3. Channel catfish	*Ictalurus punctatus*	1	256
	September 29, 1999		
1. Skipjack herring	*Alosa chrysochloris*	1	84
2. Channel catfish	*Ictalurus punctatus*	1	92
3. Bluegill	*Lepomis macrochirus*	1	55
	March 7, 2000		
1. Gizzard shad	*Dorosoma cepedianum*	2	118-120
2. Threadfin shad	*Dorosoma petenense*	1	90
3. Yellow bass	*Morone mississippiensis*	1	242
4. Freshwater drum	*Aplodinotus grunniens*	3	72-202
	March 15, 2000		
1. Shiner	*Notropis* sp.	3	100-122
2. Shiner	*Cyprinella* sp.	1	75
3. Freshwater drum	*Aplodinotus grunniens*	1	285

Table 5. (Continued)

Common Name	Scientific Name	Total Impinged	Size Range (mm)
		April 12, 2000	
1. Gizzard shad	*Dorosoma cepedianum*	3	104-172
2. Threadfin shad	*Dorosoma petenense*	6	118-175
3. Striped bass	*Morone saxatilis*	1	98 (YOY)
4. Bluegill	*Lepomis macrochirus*	11	51-126
		April 19, 2000	
1. Gizzard shad	*Dorosoma cepedianum*	59	131-170
2. Threadfin shad	*Dorosoma petenense*	2	118-131
3. Channel catfish	*Ictalurus punctatus*	1	YOY
4. Striped bass	*Morone saxatilis*	1	141 (YOY)
5. Bluegill	*Lepomis macrochirus*	18	55-183
6. Freshwater drum	*Aplodinotus grunniens*	3	95-244
		April 26, 2000	
1. Gizzard shad	*Dorosoma cepedianum*	3	121-161
2. Bluegill	*Lepomis macrochirus*	10	49-70
14. Channel catfish	*Ictalurus punctatus*	1	81
	Total Counts	**146**	

Table 6. Actual and estimated numbers of 11 fish impingement samples collected at Watts
Bar Nuclear Plant during two sample periods, August 31, 1999 through September 29, 1999 and March 7, 2000 through April 26, 2000.

Common Name	**Total Number of Fish Impinged**	**Estimated Annual Number of Fish Impinged**	**Percentage Composition**
Skipjack herring	1	36.5	0.4
Gizzard shad	147*	5365.5	58.8
Threadfin shad	40*	1460	16
Cyprinella sp.	1	36.5	0.4
Notropis sp.	3	109.5	1.2
Channel catfish	4	146	1.6
Yellow bass	1	36.5	0.4
Striped bass	2	73	0.8
Bluegill	44	1606	17.6
Freshwater drum	7	255.5	2.8
Total	**250**	**9125**	**100**

- Estimated total number of impinged fish

Table 7. Total Number of Each Species Impinged on the Intake Screens of Watts Bar Steam Plant in 33 Samples Collected between August 8, 1974, and May 29, 1975.

Scientific Name	Common Name	Total Number
Alosa chrysochloris	Skipjack herring	187
Dorosoma cepediamun	Gizzard shad	36
D. petenense	Threadfin shad	1,333
Hiodon tergisus	Mooneye	13
Notropis antherinoides	Emerald shiner	1
N. whipplei	Steelcolor shiner	3
Pimephales vigilax	Bullhead minnow	1
Ictiobus bubalus	Smallmouth buffalo	1
Ictalurus furcatus	Blue catfish	8
I. punctatus	Channel catfish	17
Pylodictis olivaris	Flathead catfish	3
Morone chrysops	White bass	25
M. mississippiensis	Yellow bass	1
M. saxitilis	Striped bass	1
Lepomis macrochirus	Bluegill	235
Micropterus dolomieui	Smallmouth bass	5
Pomoxis annularis	White crappie	19
Apoldinotus grunniens	Freshwater drum	232
Percina caprodes	Logperch	9
Total		**2,130**

Table 8. RFAI score ranges and associated community condition.

RFAI Score	12-21	22-31	32-40	41-50	51-60
Community Condition	Very Poor	Poor	Fair	Good	Excellent

Table 9. Species captured and catch rates during fall electrofishing and gill netting sampling on Chickamauga Reservoir, 1997 (electrofishing effort = 300 meters of shoreline and gill netting effort = net-night).

Common name	Electrofishing Inflow	Electrofishing Transition	Gill Netting Transition
Chestnut lamprey	0.1	0.3	.
Skipjack herring		.	2.5
Gizzard shad	5.7	5.5	1.6
Threadfin shad	*	.	0.1
Common carp	3.3	0.8	.
Emerald shiner	1.4	0.1	.
Spotfin shiner		.	.
Northern hogsucker		.	.
Smallmouth buffalo	.	.	0.1
Spotted sucker	1.1	0.3	1.2
Black redhorse	0.1	.	.
Golden redhorse	0.7	.	.
River redhorse	0.1	.	.
Blue catfish	.	.	0.6
Channel catfish	0.1	0.3	0.2
Flathead catfish	0.3	0.1	0.4
White bass	1.0	.	0.2
Yellow bass	5.5	.	2.8
Striped bass	.	.	.
Striped x white bass	0.1	.	0.1
Bluegill	14.8	3.5	0.1
Green sunfish	0.1	.	.
Longear sunfish	0.1	0.2	.
Redbreast sunfish	0.2	0.2	.
Redear sunfish	7.0	1.3	1.7
Warmouth	0.1	.	.
Hybrid sunfish	0.1	.	.
Largemouth bass	3.9	0.5	.
Smallmouth bass	2.2	0.6	0.6
Spotted bass	0.5	0.7	1.5
Black crappie	0.8	.	.
White crappie	0.1	0.1	.
Yellow perch	0.5	0.5	.
Logperch	0.1	0.1	.
Sauger	0.1	0.1	2.5
Freshwater drum	0.4	0.2	0.1
Total	50.5	15.4	16.3
Number of samples	15	15	10
Number collected	753	233	163
Species collected	30	19	17

• Only young-of-year collected

Table 10. 1997 scoring results for the twelve metrics and overall Reservoir Fish Assemblage Index (RFAI) for Chickamauga Reservoir.

Metric		Inflow		Transition	
		Obs.	Score	Obs.	Score
A. Species richness and composition					
1. Number of species		28	5	25	3
2. Piscivore species		9	5	9	5
3. Sunfish species		6	5	3	3
4. Sucker species		4	3	2	1
5. Intolerant species		4	3	3	3
6. Percent tolerant species	electrofishing	18.5%	5	41.2%	1.5
	gill netting	.	.	9.8%	2.5
7. Dominance*	electrofishing	29.6%	5	35.2%	2.5
	gill netting	.	.	17.8%	2.5
B. Trophic composition					
8. Percent omnivores	electrofishing	18.1%	5	41.6%	1.5
	gill netting	.	.	15.3%	2.5
9. Percent insectivores	electrofishing	53.1%	5	41.6%	1.5
	gill netting	.	.	19.0%	2.5
C. Reproductive composition					
10. Lithophilic spawning species		9	5	6	3
D. Fish abundance and health					
11. Average number of individuals	electrofishing	50.1	3	15.5	0.5
	gill netting	.	.	16.3	1.5
12. Percent anomalies		2.3%	3	2.0%	3
RFAI			52 excellent		40 fair

* Percent composition of the most abundant species

Table 11. 1999 scoring results for the twelve metrics and overall Reservoir Fish Assemblage Index (RFAI) for Chickamauga Reservoir.

Metric		Inflow Obs.	Inflow Score	Transition Obs.	Transition Score
A. Species richness and composition					
1. Number of species		28	5	30	5
2. Piscivore species		9	5	10	5
3. Sunfish species		4	3	5	5
4. Sucker species		5	3	3	1
5. Intolerant species		3	3	3	3
6. Percent tolerant species	electrofishing	13.0%	5	21.2%	2.5
	gill netting	.	.	50.8%	0.5
7. Dominance*	electrofishing	46.1%	3	15.9%	2.5
	gill netting	.	.	50.8%	0.5
B. Trophic composition					
8. Percent omnivores	electrofishing	12.3%	5	17.8%	2.5
	gill netting	.	.	54.5%	0.5
9. Percent insectivores	electrofishing	33.1%	3	59.1%	1.5
	gill netting	.	.	10.2%	1.5
C. Reproductive composition					
10. Lithophilic spawning species		9	5	7	3
D. Fish abundance and health					
11. Average number of individuals	electrofishing	39.1	1	13.9	0.5
	gill netting	.	.	24.6	1.5
12. Percent anomalies		2.3%	3	1.3%	5
RFAI			44 good		41 good

* Percent composition of the most abundant species.

Table 12. Species captured and catch per unit effort at inflow and transition sites on Chickamauga Reservoir during fall electrofishing and gill netting sampling, 1999 (electrofishing effort = 300 meters of shoreline and gill netting effort = net-night).

Common name	Electrofishing Inflow	Electrofishing Transition	Gill Netting Transition
Longnose Gar	0.1	.	.
Spotted Gar	.	0.1	.
Skipjack Herring	.	.	3.4
Gizzard Shad	3.5	1.9	12.5
Threadfin Shad	18.0	0.7	0.2
Mooneye	.	.	0.1
Common Carp	0.3	0.2	.
Golden Shiner	0.4	0.1	.
Emerald Shiner	0.5	1.8	.
Spotfin Shiner	0.6	.	.
Bluntnose Minnow	0.2	0.1	.
Northern Hog Sucker	0.3	.	.
Smallmouth Buffalo	.	0.1	0.1
Spotted Sucker	0.7	0.3	.
Shorthead Redhorse	0.1	.	.
Black Redhorse	0.3	.	.
Golden Redhorse	0.5	0.3	.
Blue Catfish	.	.	0.3
Channel Catfish	0.4	0.1	0.5
Flathead Catfish	0.4	0.1	0.1
White Bass	0.3	.	0.5
Yellow Bass	0.4	.	3.8
Striped x White Bass	.	.	0.1
Redbreast Sunfish	0.4	0.8	.
Green Sunfish	0.3	0.1	.
Bluegill	3.7	1.9	0.1
Longear Sunfish	.	0.3	.
Redear Sunfish	4.1	2.2	0.9
Hybrid Sunfish	0.1	.	.
Smallmouth Bass	0.2	0.9	.
Spotted Bass	0.7	0.9	0.1
Largemouth Bass	0.8	0.3	0.1
Black Crappie	0.3	0.1	0.1
Yellow Perch	.	0.1	.
Sauger	0.1	0.1	0.3
Walleye x Sauger	.	0.1	.
Logperch	1.3	0.1	.
Freshwater Drum	0.3	0.5	1.4
Total	39.3	14.2	24.6
Number of samples	15	15	10
Number collected	586	208	246
Species collected	28	26	18

* Only young-of-year collected

Table 13. Benthic macroinvertebrate community scoring criteria and associated community condition.

Benthic Community Score	7-12	13-18	19-23	24-29	30-35
Community Condition	Very Poor	Poor	Fair	Good	Excellent

Table 14. Watts Bar Tailwater Sauger and White bass Radio Telemetry.

Frequency (MHz)	Gender	Length (mm)	Location	Water Temperature
		Sauger, February 29, 2000		
551	F	455	RDB	
670	F	398	RDB	
501	F	406	RDB	
700	F	392	RDB	
620	F	380	RDB	
531	F	392	RDB	
591	F	435	LDB	
541	F	410	LDB	
610	M	375	LDB	
631	F	466	LDB	
580	M	370	LDB	
571	M	353	MC	
521	M	380	MC	
560	M	345	MC	
511	M	347	MC	
		Striped bass, February 29, 2000		
650		695	Upstream MC	
680	M	584		
622	M	640		
554	M	661		
888	F	601		
		Sauger, March 7, 2000		
700	F	392	Upstream RDB	12 °C
591	F	435	Upstream RDB	12 °C
531	F	392	Upstream MC	12 °C
		Sauger, March 15, 2000		
521	M	380	Upstream RDB	12.5 °C
631	F	466	In flume	14.0 °C
591	F	435	Upstream	12.5 °C
		Sauger, March 23, 2000		
531	F	392	In flume	14.75 °C
631	F	466	MC	
620	F	380	Upstream MC	

Table 14. (Continued)

Frequency (MHz)	Gender	Length (mm)	Location	Water Temperature
		Striped bass, March 23, 2000		
680	M	584	MC	
		March 28, 2000		
No fish				Bottom of flume = 12 °C, Two meters up from bottom = 13.5 °C
		April 5, 2000		
No fish. Hydro discharge, high flow.				Above & in flume = 14.0 °C
		April 10, 2000		
No fish.				14.0 °C
		Sauger, April 19, 2000		
631	F	466	Top of flume	14.5 °C
		Sauger, April 26, 2000		
631 (Hydro discharge, high flow.)	F	466	Bottom of flume	15.5 °C
		May 3, 2000		
No fish.				16.5 °C
		Sauger, May 10, 2000		
531	F	392	In flume	18.0 °C
521	M	380	In flume	18.0 °C (19.5 °C at surface)

RDB = Right descending bank.
MC = Mid-channel.
LDB = Left descending bank.

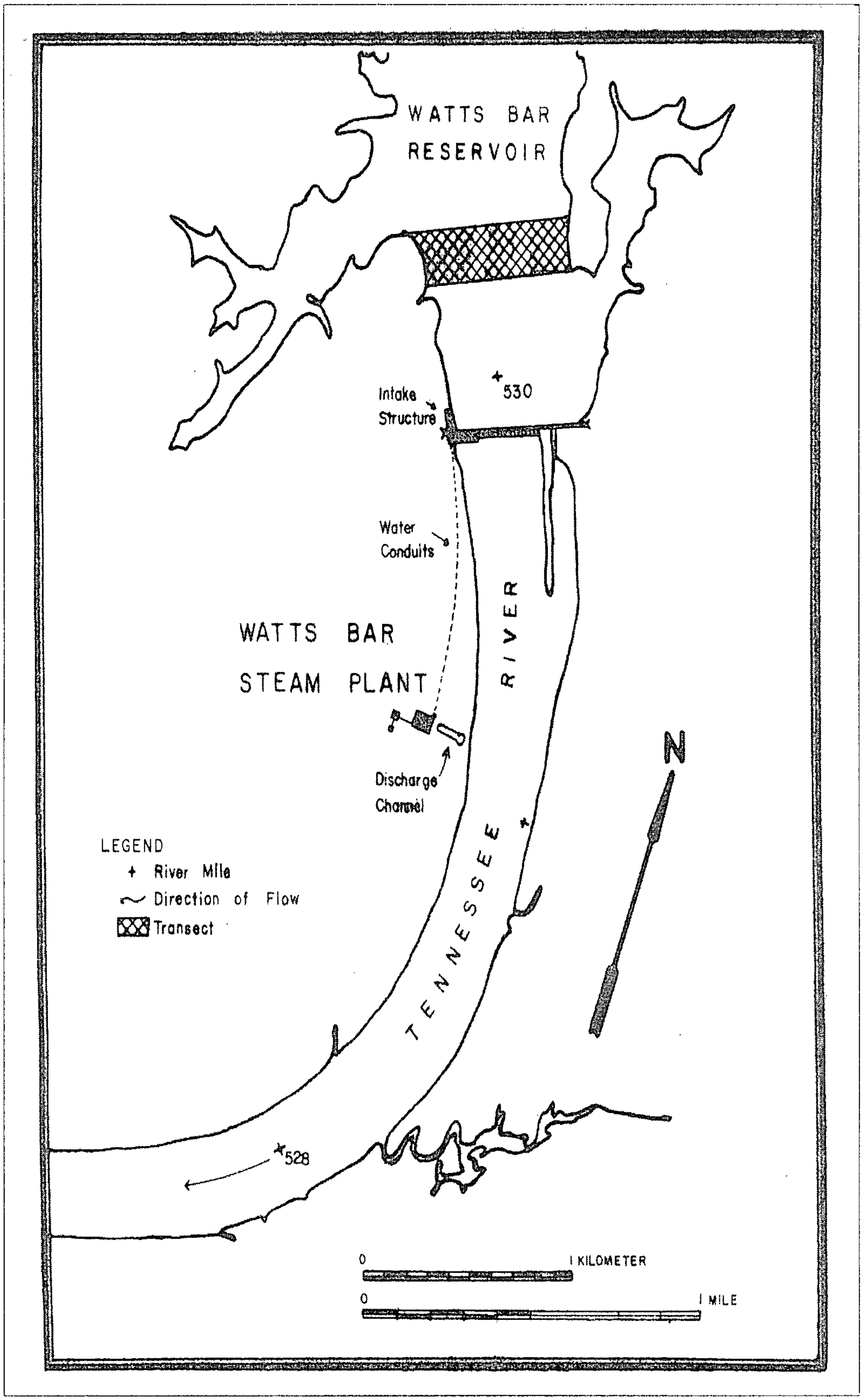

Figure 1. Location of Reservoir Transect and Intake Sampling Station, Watts Bar Steam Plant, Watts Bar Reservoir.

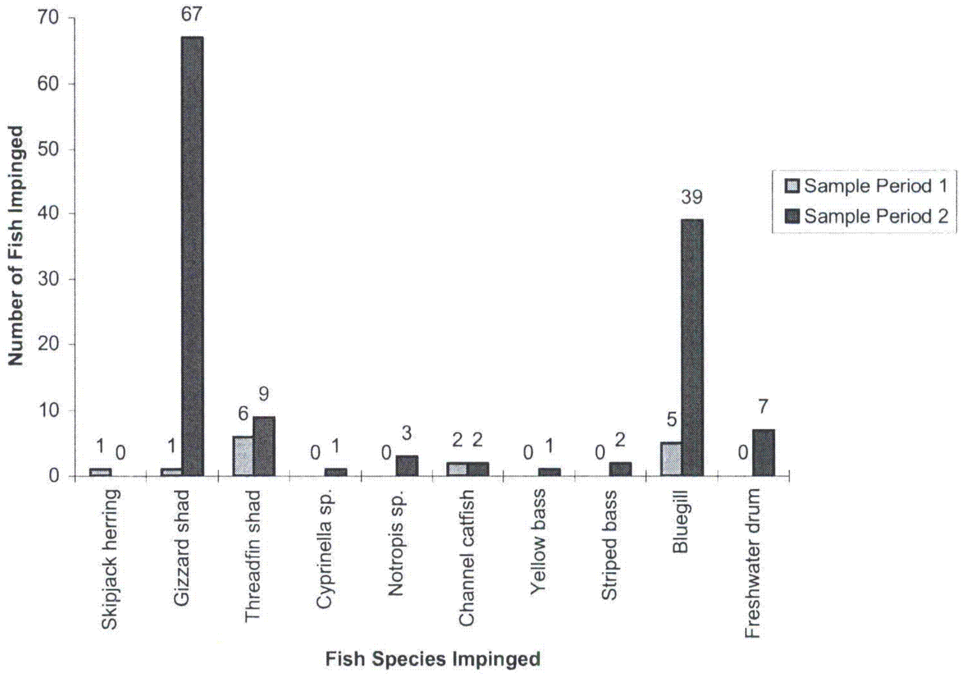

Figure 2. Actual numbers of fish impinged, by species, at Watts Bar Nuclear Plant intake during two sample periods, August 31, 1999 through September 29, 1999 (1) and March 7, 2000 through April 26, 2000 (2)

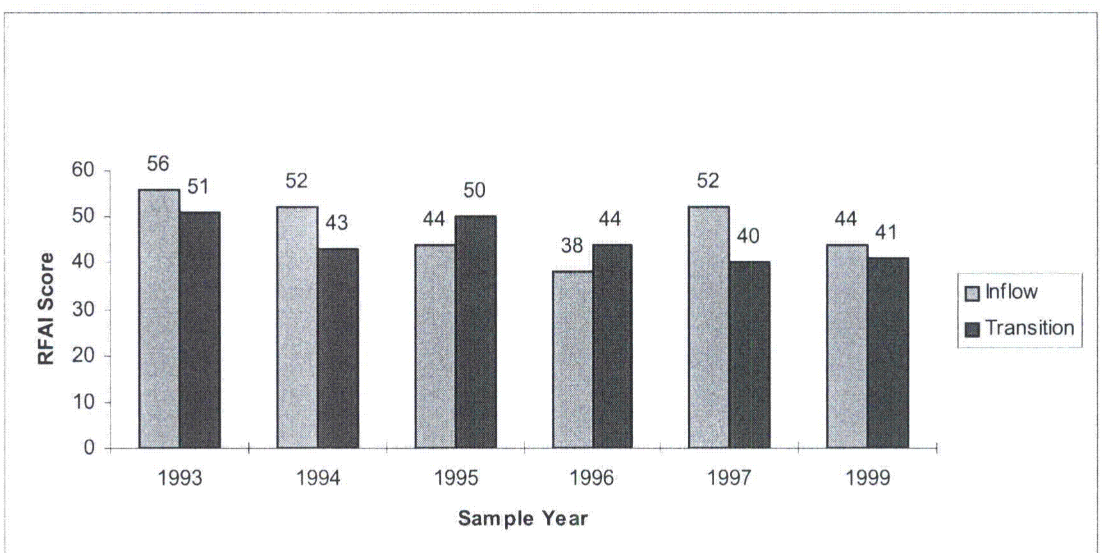

Figure 3. Chickamauga Reservoir inflow and transition zones RFAI scores 1990 to 1999.

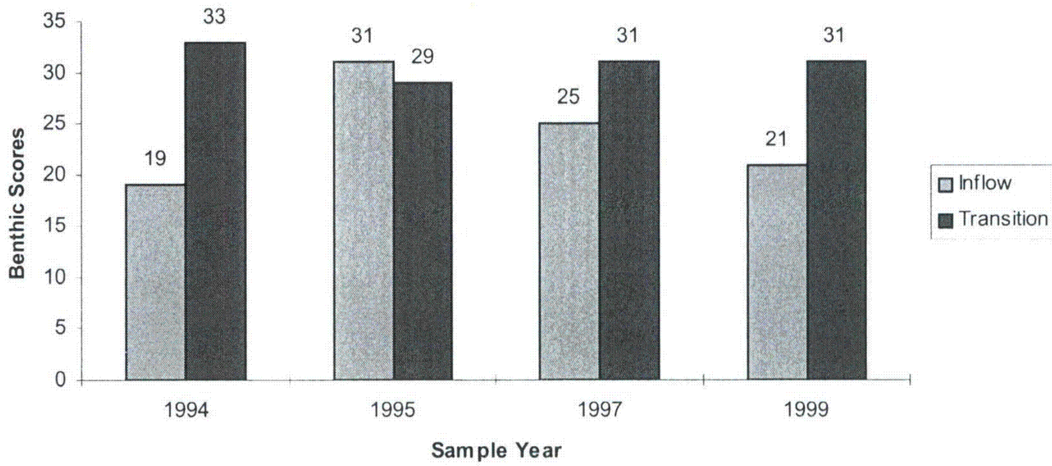

Figure 4. Benthic scores for Chickamauga Reservoir Vital Signs inflow and transition zones.

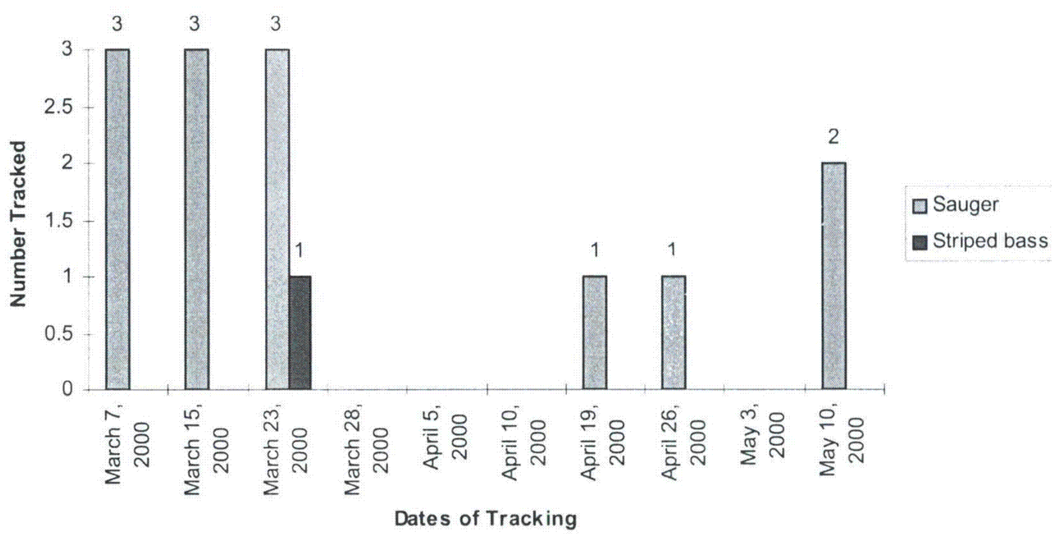

Figure 5. Number of sauger and striped bass tracked by radio telemetry following release on February 29, 2000.