H. B. Robinson Steam Electric Plant

Environmental Monitoring Program

Interpretive Report
June 1988

CP&L

Carolina Power & Light Company

H. B. ROBINSON STEAM ELECTRIC PLANT

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Executive Summary

The current NPDES permit for Carolina Power & Light Company's (CP&L) Robinson Steam Electric Plant has limits for temperature of once-through cooling water at the discharge point into the Robinson Impoundment. These current temperature limits were determined from a successful 316a Demonstration submitted by CP&L in 1976. Since those limits were imposed in 1977, the plant has occasionally exceeded the limits for short periods due primarily to more adverse meteorological conditions than those experienced during the short (approximately 1 year) 316a Demonstration study. Based on this operating experience and the results of concurrent biological monitoring, CP&L believes that some of the current limits are lower than necessary. Also, the current changes in monthly temperature limits do not keep pace with the rate of natural seasonal changes in impoundment temperatures and, therefore, cause restrictions on the operation of the plant that are not necessary to maintain a balanced and indigenous community of fish and wildlife in and on the impoundment.

Biological studies which have been conducted continuously on the impoundment since the mid-1970s, especially during adverse meteorological conditions when the temperature limits were exceeded, have documented the environmental effects of the heated water discharge to the Robinson Impoundment. These data show:

1. The impoundment can be divided into two biological areas: (1) the upper impoundment, which is shallow and narrow with abundant aquatic vegetation and affected by Black Creek inflow and (2) the middle and lower impoundment, which is wider and deeper with fewer areas of aquatic vegetation.

2. The thermal discharge has the greatest impact in the middle impoundment, especially near the point of discharge. The upper impoundment receives only minimal thermal impact. The lower impoundment is also affected by thermal discharge; however, cooling of discharge waters occurs as waters are recirculated through the impoundment.

3. When the power plant circulating water pumps are operating, there is a good mixing of the water column minimizing the areas of low-dissolved oxygen despite elevated water temperatures. Thermal stratification generally is weak during all seasons, and a thermocline is rarely established except in the middle impoundment area over the old Black Creek Channel.

4. Meteorological and hydrological conditions at the Robinson Impoundment were more severe during 1986 than any other year of the 1977-1987 period. Record low rainfall and resulting low Black Creek inflow were noted for 1986.

5. Low impoundment water levels during 1986 had the greatest impact in the upper reservoir due to the narrow, shallow morphometry. Higher ambient water temperatures, zooplankton, larval largemouth bass, and lower standing crop of juvenile and adult fish were recorded in the upper impoundment during 1986.

6. Annual mean water temperatures in the upper and lower impoundment were not statistically different over years. The middle impoundment was statistically warmer between certain years.

7. Phytoplankton and zooplankton densities were higher in the middle and lower impoundment than the upper impoundment. This is due to lake-like conditions providing more favorable conditions for plankton.

8. Copper concentrations were elevated in the middle and lower impoundment during 1977-1982 period and were lower from 1983 to 1987 after the removal of the brass condenser tubes in Unit 2.

9. Thirty-seven species of fish, typical of black water habitats in the region, have been collected from the impoundment. Sunfishes, largemouth bass, and bullhead catfish are the primary sport fishes.

10. Larvae of 21 taxa of fishes have been collected in the impoundment. Larval fish densities were highest in the upper impoundment and were not different between the middle and lower impoundment. Fewest larval fish were collected during 1977-1979.

11. Fish standing crops were lowest during 1977-1981 and higher during 1982-1985. Standing crops during 1986 and 1987 were lower than 1982-1985 but were higher than 1977-1981.

12. Elevated copper in the impoundment reduced fish reproduction and recruitment and caused deformities in fish. Since removal of the source of copper in 1982 by power plant modifications, copper concentrations have decreased in impoundment water and fish tissues. Fish deformities were eliminated and standing crops returned to normal levels.

13. Expansion of the fishery from 1982 to 1985 was rapid, especially bluegill and largemouth bass. Declines in bluegill since 1985 probably reflect a stabilization of the fishery after rapid expansion.

14. During periods of maximum thermal discharge, much of the impoundment, especially the upper and lower impoundment, remain favorable for fish and other aquatic biota.

15. No major fish kills have occurred in Robinson Impoundment.

16. The standing crop of fish is above that expected for blackwater systems such as the Robinson Impoundment.

Based on these findings, the H.B. Robinson Steam Electric Plant is believed by CP&L to have had no appreciable harm to the balanced and indigenous community of fish and wildlife in and on the impoundment. The impoundment supports a higher than expected standing crop of fish and offers good sport fishing.

In conclusion, CP&L proposes that the temperature limits in the renewed NPDES permit be revised to reflect the increased understanding of the effects of heated water discharged to the Robinson Impoundment. The limits for the spring months, specifically May, could be increased slightly to those temperatures experienced in 1986 and not cause an unacceptable adverse effect. In addition, the discharge temperature of the once-through cooling water can vary greatly over a 30-day period in response to the natural warming and cooling of the impoundment in the spring and fall months, respectively. Temperature limits set at approximately 15-day intervals would more closely parallel actual conditions. Semi-monthly limits could be determined by a simple averaging method to make the transition between months with different limits. The operation of the plant and biological monitoring over the past several years offers ample empirical evidence that the proposed limit changes are acceptable and appropriate.

The proposed minor changes would not allow the discharge temperature to be any higher than those that have been experienced before when biological monitoring has demonstrated the impoundment can maintain a balanced and indigenous fish population.

1.0 INTRODUCTION

Carolina Power & Light Company (CP&L) owns and operates the Robinson Nuclear Project that consists the H.B. Robinson Steam Electric Plant and Robinson Impoundment, the cooling reservoir for the power plant.

CP&L has conducted environmental studies on the Robinson Impoundment since the mid-1970s and submitted a successful 316a Demonstration in 1976 that documented a balanced and indigenous fish population in the reservoir.

The discharge temperature limits of the current National Pollutant Discharge Elimination System (NPDES) permit are a result of the initial 316a Demonstration and are essentially the same temperatures experienced during the initial 316a Demonstration period of 1975-1976. On a few occasions since that time, due primarily to more severe meteorological conditions than those experienced during the demonstration period, the heated water discharge temperature has exceeded the limits in the NPDES permit for short periods.

In support of the NPDES permit, biological studies have been conducted since 1973 to determine what impact, if any, the thermal discharge from the H.B. Robinson Steam Electric Plant has had on the Robinson Impoundment. Reports summarizing the results of the many studies conducted on the biota of the impoundment have been submitted to the South Carolina Department of Health and Environmental Control. These reports have usually covered a one- to three-year period with occasional comparisons to longer periods.

This report will give a broader perspective of the biota of the impoundment over the 15 years of study and will evaluate the effect of the proposed temperature limits. The objectives of this report are to (1) propose changes to the NPDES permit limits on temperatures of once-through cooling water, (2) provide an overview of the biological studies conducted on the Robinson Impoundment, and (3) assess the impact of the proposed limits.

2.0 SITE DESCRIPTION

Carolina Power & Light Company (CP&L) constructed the Robinson Impoundment (Figure 1), a 911-hectare (2,250-acre) cooling impoundment, on Black Creek in Darlington and Chesterfield Counties, South Carolina, in the late 1950s to provide cooling water for the H.B. Robinson Steam Electric Plant. The impoundment is located in the Sandhills region with a watershed of approximately 44,800 ha (173 mi^2). Much of the watershed is in the Sandhills National Wildlife Refuge with the remainder being either forested or in agricultural production.

The power plant consists of the 183-MWe coal-fired Unit 1 and the 665-MWe nuclear-fueled Unit 2. These generating units are operated with once-through cooling, discharging waste heat to the impoundment via a four-mile-long discharge canal. The waste heat enters the middle area of the impoundment designated as Transect E (Figure 1). Unit 2 (86% of the total generating capacity) contributes the primary heat load, while Unit 1 (14% of the generating capacity) contributes a lesser heat load to the impoundment.

Several transects and stations have been designated throughout the impoundment to identify biological sampling locations (Figure 1). In some cases in this report, specific sites or stations will be identified while in other cases, transects or areas are noted. Generally, the Transect G area is referred to as the upper impoundment, Transect E as the middle impoundment at or near the point of the thermal discharge, and Transect A as the lower impoundment. Stations are a specific location on a transect and are designated by both a transect and station code such as A1.

3.0 POWER PLANT OPERATION AND PERMIT LIMITS

3.1 Plant Modifications

Since the 1975 to 1976 period during which the 316a Demonstration took place, there have been numerous modifications to the Robinson Plant resulting in a slight increase in heat rejected to the impoundment. As a result of the replacement of the steam generators in 1984 and a subsequent Nuclear Regulatory Commission approval, the Unit 2 reactor began operation in 1985 at a higher output, 2300 MWt as compared to 2200 MWt. This higher thermal rating resulted in a net increase in heat rejection to the impoundment of approximately 65 MWt during full-load operation of the plant. However, there have been several equipment upgrades to Unit 2 in the past few years which have reduced heat rejected to the impoundment. These include replacement of the condenser in 1982; replacement of the feedwater heaters, some reheater bundles, and steam generators in 1984; and the replacement of the low-pressure turbine in 1987. These changes reflect a continuing effort to improve the efficiency of Unit 2 and have reduced the heat rejected to the impoundment by 30 MWt. Therefore, there has only been a net 35 MWt of additional heat rejected to the impoundment due to power plant modifications during the past several years.

It should be noted that it has been the Company's intention to operate Unit 2 at 2300 MWt since the early 1970s. In fact, the heat rejection limit in the current permit, as described later, already reflects this higher thermal rating and has not been exceeded by the modifications discussed above.

3.2 Operating History

Throughout most of its history, the Robinson Plant has operated at or above the industry average capacity factor for similar units. Whenever possible, major outages for maintenance or refueling have been scheduled in the spring or fall months when higher system peak loads are not expected. After approximately 10 years of operation, Unit 2 developed corrosion problems with the steam generators, and as a result, Unit 2 generation was reduced in 1982 and 1983 to allow preparation for replacement of the steam generators in 1984. Unit 2 was shut down from February 1984 until January 1985 for replacement of the steam generators and several other major improvements. During 1984 Unit 1 provided virtually all of the heat load to the impoundment.

Beginning in early 1985, Unit 2 returned to service and was operating at full capacity with the extra thermal upgrade of the reactor discussed above and the many efficiency improvements that reduced the heat rejection/gross generation ratio. Both units operated near full capacity during most of the 1986 drought that brought higher than normal ambient temperatures and much lower than normal inflow to the impoundment.

A summary of monthly average gross generation for each unit for the years 1975 through 1987 (Table 1) provides an indication of the relative heat load for any specific year. Monthly gross generation values for the power plant are plotted in Figure 2.

The resulting monthly average discharge temperature from the generation loads are recorded by the continuous recorder at the discharge weir in Table 2. A plot of this data (Figure 3) provides a visual comparison of the monthly discharge temperatures.

Table 1 H.B. Robinson Plant gross generation (X1000 MWH), 1975-1987.

	1975			1976		
	Unit 1	Unit 2	Plant	Unit 1	Unit 2	Plant
January	71	500	571	44	454	498
February	43	487	530	15	507	522
March	46	518	564	17	525	542
April	79	184	263	0	493	493
May	103	71	174	0	460	460
June	93	402	495	61	502	563
July	105	472	577	65	475	540
August	95	509	604	73	494	567
September	74	475	549	95	493	588
October	39	508	547	94	476	570
November	93	0	93	113	0	113
December	73	271	344	104	250	354
Total	914	4397	5311	681	5129	5810

Table 1, continued

	1977			1978		
	Unit 1	Unit 2	Plant	Unit 1	Unit 2	Plant
January	92	521	613	83	425	508
February	62	253	315	102	0	102
March	94	475	569	77	0	77
April	129	399	528	22	46	68
May	131	511	642	19	487	506
June	81	471	552	24	487	511
July	101	452	553	28	393	421
August	90	359	449	70	494	564
September	96	218	314	77	342	419
October	96	250	346	6	521	527
November	104	63	167	63	507	570
December	40	508	548	43	507	550
Total	1116	4480	5596	614	4209	4823

	1979			1980		
	Unit 1	Unit 2	Plant	Unit 1	Unit 2	Plant
January	68	491	559	67	527	594
February	60	433	493	97	484	581
March	71	521	592	103	285	388
April	103	157	360	93	208	301
May	110	0	110	85	327	412
June	104	0	104	100	461	561
July	90	114	204	121	261	382
August	66	517	583	118	52	170
September	65	474	539	104	0	104
October	86	503	589	67	55	122
November	69	497	566	23	442	465
December	53	515	568	96	300	396
Total	945	4222	5167	1074	3402	4476

	1981			1982		
	Unit 1	Unit 2	Plant	Unit 1	Unit 2	Plant
January	104	480	584	86	436	522
February	63	417	480	36	362	398
March	0	525	525	83	0	83
April	0	495	495	112	0	112
May	3	251	254	101	0	101
June	85	256	341	99	0	99
July	94	459	553	108	0	108
August	87	0	87	118	73	191
September	68	213	281	88	318	407
October	45	253	298	74	420	494
November	59	55	114	4	405	409
December	87	332	419	18	416	434
Total	695	3681	4376	927	2431	3358

Table 1, continued

	1983			1984		
	Unit 1	Unit 2	Plant	Unit 1	Unit 2	Plant
January	43	395	438	58	246	304
February	38	367	404	30	0	30
March	30	423	452	73	0	73
April	54	303	357	84	0	84
May	80	46	126	103	0	103
June	71	402	473	93	0	93
July	76	400	476	75	0	75
August	86	413	499	75	0	75
September	51	174	224	52	0	52
October	14	428	422	89	0	89
November	10	29	39	111	0	111
December	73	211	284	67	0	67
Total	625	3590	4215	910	246	1156

	1985			1986		
	Unit 1	Unit 2	Plant	Unit 1	Unit 2	Plant
January	79	43	122	95	318	413
February	43	261	304	80	0	80
March	2	513	515	93	76	169
April	42	514	556	62	529	592
May	42	535	576	48	555	603
June	75	538	613	44	507	551
July	69	529	598	74	553	627
August	72	508	580	55	431	485
September	44	479	523	29	447	476
October	60	514	573	35	567	602
November	7	530	537	14	547	561
December	67	551	618	21	524	345
Total	601	5515	6116	649	5055	5704

	1987		
	Unit 1	Unit 2	Plant
January	46	572	618
February	42	509	551
March	46	350	396
April	53	0	53
May	61	0	61
June	79	186	265
July	55	442	496
August	56	408	463
September	38	346	385
October	0	561	561
November	19	525	544
December	28	571	600
Total	523	4469	4992

NOTE: All columns and rows may not total exactly due to rounding.

Table 2 Monthly average temperature at the discharge canal weir from Robinson impoundment, 1976-1987.

Degrees Fahrenheit

Month	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Jan	69.5	66.6	64.9	72.1	74.3	69.2	66.8	70.0	58.8	50.7	67.0	72.6
Feb	78.2	64.6	49.8	69.8	71.0	69.9	72.1	70.1	52.7	58.8	51.4	73.5
Mar	84.8	85.1	55.0	82.0	68.1	78.8	67.9	75.3	56.6	77.5	64.6	71.7
Apr	88.9	90.5	68.2	30.6	76.5	87.8	74.8	75.0	65.7	88.1	87.6	67.8
May	92.3	97.4	92.0	78.9	88.5	82.1	79.6	75.5	80.0	102.2	96.0	77.3
Jun	99.1	103.6	105.0	81.9	96.5	96.7	84.0	94.0	85.6	95.0	104.0	102.8
Jul	102.7	105.9	101.3	89.0	95.5	101.0	84.9	97.8	87.0	103.5	109.7	102.6
Aug	103.3	100.6	104.8	104.6	89.8	95.6	86.1	99.3	87.7	103.2	102.5	101.2
Sep	100.9	95.2	98.4	99.9	85.6	91.2	87.8	96.5	78.9	101.3	94.9	94.5
Oct	87.9	81.8	90.7	93.3	73.8	83.6	87.2	86.3	71.3	94.2	94.1	89.0
Nov	58.5	67.5	86.4	86.4	77.6	67.0	77.4	61.7	62.8	86.3	85.1	84.2
Dec	58.8	73.0	76.7	78.7	64.5	67.4	72.7	61.2	53.0	76.9	77.1	79.8

Degrees Celsius

Month	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Jan	20.9	19.2	18.3	22.3	23.5	20.7	19.3	21.1	14.9	10.4	19.5	22.6
Feb	25.7	18.1	09.9	21.0	21.7	21.1	22.3	21.2	11.5	14.9	10.8	23.1
Mar	29.4	29.5	12.8	27.8	20.1	26.0	20.0	24.1	13.6	25.3	18.1	22.1
Apr	31.6	32.5	20.1	27.0	24.7	31.0	23.8	23.9	18.7	31.2	30.9	19.9
May	33.5	36.4	33.4	26.1	31.4	27.9	26.5	24.2	26.7	39.0	35.6	25.2
Jun	37.3	39.8	40.6	27.7	35.9	36.0	28.9	34.5	29.8	35.0	40.0	39.4
Jul	39.3	41.1	38.3	31.7	35.3	38.4	29.4	36.6	30.6	39.8	43.2	39.3
Aug	39.6	38.1	405.	40.4	32.1	35.4	30.1	37.4	31.0	39.6	39.2	38.5
Sep	38.3	35.1	36.9	37.8	29.8	32.9	31.0	35.9	26.1	38.5	35.0	34.8
Oct	31.1	27.7	32.6	34.1	23.2	28.7	30.7	30.2	21.9	34.6	34.5	31.7
Nov	14.7	19.7	30.2	30.2	25.4	19.5	25.2	16.5	17.1	30.3	29.5	29.0
Dec	14.9	22.8	24.9	26.0	18.1	19.7	22.6	16.2	11.7	25.0	25.1	26.6

3.3 Requested Changes in NPDES Permit Limits

3.3.1 Current Permit Description

The current NPDES permit issued on December 1, 1983, has the following temperature limits on Outfall 001, once-through cooling water:

Month	Daily Average °F (°C)		Daily Maximum °F (°C)	
June-September	108.7	(42.6)	111.2	(44.0)
October	95.9	(35.9)	99.5	(37.5)
November	86.0	(30.0)	91.4	(33.0)
December-February	78.8	(26.0)	85.1	(29.5)
March	86.0	(30.0)	89.6	(32.0)
April	89.6	(32.0)	95.0	(35.0)
May	93.2	(34.0)	98.6	(37.0)

These temperature limits, applied at the end of the discharge canal weir just prior to entering the impoundment, were originally assigned by the U.S. Environmental Protection Agency (EPA) after a review of the 316a Demonstration (CP&L 1976a, 1976b) and largely reflect temperatures experienced during the 1975-76 demonstration study period. In addition to the above limits, there is a gross heat rejection limit of 5.5×10^9 BTU/hr and 6.29×10^9 BTU/hr for daily average and daily maximum, respectively.

Table 3 compares the actual experienced discharge temperatures during 1985-87 to the limits specified in the permit. This is shown graphically in Figure 4.

The primary problem experienced with the current temperature limits is the abrupt change in daily maximum average limits at the beginning and end of certain months, especially during spring and fall. This sudden change in temperature reflects neither actual plant operating conditions, ambient water temperatures, or conditions optimal for aquatic life. The spring and fall months are usually a time of relatively rapid, steady change in the natural impoundment water temperature. Permit limits that impose a constant maximum limit for 30 continuous days during these periods are inherently difficult to meet while providing adequate environmental protection during the entire period. The daily maximum limit for May, for example, is higher than necessary on the first day of the month and lower than necessary during the final days. A similar but reverse situation occurs in October.

Assigning a long-term (30-day) average limit for an arbitrary period of a calendar month, especially in the rapidly changing spring and fall months, has inherent problems. Just a few days of unusually high discharge water temperatures in the final days of a month can result in an exceedance of the monthly average and, therefore, a violation for those 30 days. Compliance with the current monthly average limits might force the plant to severely cut back generation for the last few days in a month to meet temperature requirements. Then at the beginning of a next month, the new limits would allow a rapid increase in power and discharge temperature output. This type of situation is not advantageous to either the aquatic environment or the efficient operation of the plant.

In addition, recent operating experience indicates a consistent problem with the present May limits. The incremental change on both daily average and daily maximum limits from May to June is 15.5°F (8.6°C) and 12.6°F (7.0°C), respectively. This is the largest such change during the year.

3.3.2 Proposed Permit Limits

In the original 316a Demonstration, CP&L had requested and presented justification for daily average and daily maximum limits of 96.8°F (36.0°C) and 100.4°F (38.0°C) for May. However, the limits assigned (93.2°F [34.0°C] and 98.6°F [37.0°C]) were based on the temperatures actually observed during the biological study period. Since then CP&L has conducted regular monitoring studies on the various aspects of the biology of the impoundment. In 1985 the daily average and daily maximum discharge temperatures for May were 95.0°F (35.0°C) and 98.9°F (37.2°C), respectively, and in 1986 these values were 96.0°F (35.6°C) and 102.0°F (38.9°C), respectively. DHEC was timely notified when these temperatures were anticipated and when they occurred. Accordingly, CP&L believes that in May a daily average limit of 96°F (36.6°C) and a daily maximum of 102°F (38.9°C) are appropriate.

CP&L also proposes that the temperature limits for the transitional spring and fall months be revised from monthly to an approximately 15-day interval. The current daily average and maximum, with the exception of May as discussed above, would continue but would include two limit changes per month. This arrangement would allow several intermediate steps that are not now included. These intermediate steps would be determined by averaging the current permit limits (except for May) to include the final week of the month and the first week of the following month. The resulting average value would provide a new limit midway between the two previous limits. This technique would raise the limit for a cooler month a moderate amount but also cause a corresponding reduction for a portion of the adjacent hotter month. The change would result in no net difference in allowable temperature discharged. For example, the current daily maximum limits for September and October are 111.2° and 99.5°F, respectively. For the middle 15 days of those months, the limit would remain the same. For the period from September 24 through October 8, the new limit would be (111.2 + 99.5)/2 = 105.4°F. The daily average limits would be revised in the same manner. Table 2 lists the proposed new limits and Figure 5 compares the proposed limits to the current permit limits.

By allowing for semimonthly limit changes during the spring and fall months, the proposed limits more closely correspond to the actual temperature changes occurring in the impoundment. These requested changes include higher limits for May. This will provide limits that are no higher than necessary for operation of the plant nor needlessly restrain plant operation when higher discharge temperatures are environmentally acceptable. Further, biological data collected over several years and summarized in this report support these proposed limits.

Table 3 H.B. Robinson discharge temperatures and heat rejection, 1985-1987.

	Monthly average °F		Daily maximum °F		Heat (x10^9 Btu/hr)	
	Actual	Limit	Actual	Limit	Average	Maximum
January 87	72.6	78.8	75.6	85.1	4.7	5.6
February 87	73.5	78.8	77.6	85.1	4.6	5.6
March 87	71.7	86.0	81.1	89.6	3.0	4.5
April 87	67.8	89.6	75.4	95.0	0.3	0.6
May 87	77.3	93.2	83.2	98.6	0.5	0.7
June 87	85.0	108.7	102.8	111.2	1.0	4.8
July 87	102.6	108.7	107.8	111.2	4.0	5.3
August 87	101.2	108.7	107.6	111.2	3.7	5.1
September 87	94.5	108.7	104.3	111.2	3.0	5.1
October 87	89.0	95.9	96.4	99.5	4.1	4.4
November 87	84.2	86.0	89.0	91.4	4.4	5.3
December 87	79.8	78.8	83.6	85.1	5.0	5.6
January 86	67.0	78.8	75.4	85.1	2.0	4.8
February 86	59.6	78.8	65.2	85.1	0.4	0.5
March 86	64.6	86.0	82.3	89.6	1.0	4.2
April 86	87.6	89.6	93.8	95.0	4.3	5.0
May 86	96.0	93.2	102.0	98.6	4.4	5.3
June 86	104.0	108.7	106.8	111.2	4.8	5.6
July 86	109.7	108.7	112.9	111.2	5.4	6.0
August 86	102.5	108.7	111.3	111.2	4.2	5.9
September 86	94.9	108.7	103.6	111.2	3.9	5.4
October 86	94.1	95.9	104.6	99.5	4.3	5.3
November 86	85.1	86.0	90.2	91.4	4.0	4.7
December 86	77.1	78.8	82.2	85.1	4.2	5.3
January 85	50.7	78.8	57.0	85.1	1.0	3.1
February 85	58.2	78.8	76.0	85.1	3.0	5.1
March 85	77.5	86.0	85.8	89.6	4.0	5.4
April 85	88.1	89.6	97.0	95.0	4.3	5.0
May 85	95.0	93.2	98.9	98.6	4.4	5.2
June 85	102.2	108.7	104.6	111.2	5.2	5.9
July 85	103.5	108.7	107.6	111.2	4.9	5.6
August 85	103.2	108.7	108.3	111.2	4.9	5.8
September 85	101.3	108.7	106.8	111.2	4.2	5.0
October 85	94.2	95.9	97.5	99.5	3.9	4.6
November 85	85.5	86.0	90.7	91.4	3.9	4.7
December 85	76.9	78.8	85.8	85.1	4.2	4.7
				Limit:	5.5	6.29

Temperature limit exceedances are underlined.

Table 4 Proposed new H.B. Robinson NPDES temperature limits.

Month	24th of Previous Month Through the 8th of Current Month		9th Through 23rd of Current Month	
	Daily Ave.	Daily Max.	Daily Ave.	Daily Max.
January	78.8°F	85.1°F	78.8°F	85.1°F
February	78.8°F	85.1°F	78.8°F	85.1°F
March	82.4°F	87.4°F	86.0°F	89.6°F
April	87.8°F	92.3°F	89.6°F	95.0°F
May	92.8°F	98.5°F	96.0°F	102.0°F
June	102.4°F	106.6°F	108.7°F	111.2°F
July	108.7°F	111.2°F	108.7°F	111.2°F
August	108.7°F	111.2°F	108.7°F	111.2°F
September	108.7°F	111.2°F	108.7°F	111.2°F
October	102.3°F	105.4°F	95.9°F	99.5°F
November	91.0°F	95.5°F	86.0°F	91.4°F
December	82.4°F	88.3°F	78.8°F	85.1°F

4.0 BIOLOGICAL STUDIES ON ROBINSON IMPOUNDMENT

4.1 Historical Review

Many reports addressing the biota of the impoundment have been issued. The initial 316a Demonstration (CP&L 1976a, 1976b) showed that the operation of the H.B. Robinson Plant resulted in no appreciable harm to the balanced and indigenous community of fish and wildlife in and on the impoundment. Since 1979, environmental reports have been issued summarizing the results of environmental monitoring programs (CP&L 1979a, 1979b, 1980, 1982a, 1983a, 1983b, 1984, 1985, 1986, 1987). Additional studies have been conducted addressing reduced fish recruitment and bluegill deformities (LMS 1980; CP&L 1981, 1982b, 1983c; CP&L and LMS 1981; Woock 1985), and trace elements (Harrison 1984; Harrison et al. 1983; Harrison and Lam 1982; Smart 1985; Smart 1986).

These studies have all added to the knowledge and understanding of the effects of power plant operations on the biological communities in Robinson Impoundment. They have shown the continuation of the balanced biological communities over the years of study. Certain problems, such as the effects of elevated copper and zinc on fish populations, have also been addressed and the follow-up studies have indicated recovery from these problems. The various chemical, physical, biological, and climatological conditions experienced during these studies are analyzed in this report.

4.2 Results and Discussion of the Biological Studies

4.2.1 Water Chemistry

The impoundment water is darkly stained, acidic, and has low conductivity, alkalinity, and hardness (Table 3). This "blackwater" is considered low in primary productivity and nutrients. Due to the limited size of the Sandhills region and the lack of impoundments with similar topography and water chemistry, comparisons of Robinson Impoundment to other water bodies are difficult to make.

Table 5 Typical Robinson impoundment water chemistry parameter ranges.

Parameter	Range
pH	4.0-6.0
Conductivity	15-31 µmhos
Total Hardness	1.2-10.0 mg/l
Alkalinity	< 0.5-1.4 mg/l
Total organic carbon	2.3-8.3 mg/l
Total nitrogen (as N)	0.02-0.53 mg/l
Total phosphate (as P)	< 0.01-0.04 mg/l
Copper	< 20-57 µg/l

Concentrations of sodium, calcium, sulfate, and magnesium typically increase from the upper impoundment to the lower impoundment, probably a result of evaporation. Trace element concentrations have not been significantly different from those found in Black Creek above the impoundment except for copper and zinc. Turbidity has been lower in the middle and lower impoundment than in the upper impoundment and Black Creek above the impoundment indicating deposition of fine particles due to reduced flow.

Elevated copper concentrations were recorded from 1977 to 1982 and reached peak annual values of 61 µg/l at Station E2 and 44 µg/l at Station A2 in 1979 (Figure 6). These increases were determined to be a result of the erosion and corrosion of the brass condenser tubes. To remedy this, in 1982 the brass tubes were replaced with stainless steel tubes, after which impoundment copper concentrations diminished to an annual average of 4-6 μg/l.

4.2.2 Water Temperatures and Dissolved Oxygen

During biological studies, water temperature and dissolved oxygen (DO) were measured. Thermal stratification in the middle impoundment is increased by power plant operations and is most prominent over the Black Creek channel (Figure 7). However, the impoundment remains well mixed (CP&L 1987) with adequate dissolved oxygen (> 4.0 mg/l) for aquatic life.

The DO may drop below 4.0 mg/l but usually only in the lowest 2-3 meters of the impoundment, usually corresponding to the narrow former Black Creek channel. This occurs only during the warmer months of certain years and influences only a limited part of the impoundment. Boyd (1979) reports a DO of 5.0 mg/l as the minimum desirable level in ponds but that fish can survive in the range of 1.0-5.0 mg/l. While the USEPA states 5.0 mg/l as a minimum for good fish populations (USEPA 1986), they also indicate fish vary in their tolerance (by species, age, activity, etc.) and fish can survive for a while in concentrations considerably below that suitable for a thriving population. Fisheries biologists often use 4.0 mg/l DO as the minimum value for fish growth.

Approximately 13 days are required for the thermal plume to reach the intake after being discharged (CP&L 1979b). During this period thermally induced stratification decreases with distance downstream from the discharge (Swartley 1987). Little or no stratification occurs in the lower impoundment (Figure 7).

Occasionally a narrow wedge of thermally influenced water is pushed by southerly winds northward through the bridge at the SR 346 causeway, and on rare occasions, this wedge reaches Transect G. However, thermal flow is usually restricted to the upper 0.5 m of the water column and results in only minimal thermal enhancement at Transect G.

The analyses of impoundment water temperatures (Table 4) were based on monthly temperatures taken at 1-m depth at Stations A2, E2, and G2 during biological monitoring programs. Water temperature data were not taken during 1984. Stations were significantly different from each other for all tests (E2>A2>G2).

Table 6 Summaries of analysis of variance and Duncan's multiple range test* on monthly water temperature data from Robinson impoundment. Items are listed in descending order.

All Months			April-June			June-August		
A2	E2	G2	A2	E2	G2	A2	E2	G2
Jul[a]	Aug[a]	Jul[a]	Jun[a]	Jun[a]	Jun[a]	Jul[a]	Aug	Jul
Aug[ab]	Jul[a]	Aug[a]	May[b]	May[b]	May[b]	Aug[a]	Jul	Aug
Jun[b]	Jun[ab]	Jun[ab]	Apr[c]	Apr[c]	Apr[c]	Jun[b]	Jun	Jun
Sep[b]	Sep[ab]	Sep[bc]						
May[c]	May[b]	May[c]						
Oct[d]	Oct[b]	Oct[c]						
Apr[de]	Apr[c]	Apr[cd]						
Nov[e]	Nov[c]	Nov[de]						
Mar[f]	Dec[c]	Mar[ef]						
Dec[f]	Mar[cd]	Dec[f]						
Feb[g]	Feb[de]	Feb[g]						
Jan[g]	Jan[e]	Jan[h]						

All Months			April-June			June-August		
A2	E2	G2	A2	E2	G2	A2	E2	G2
'77	'85[a]	'86[a]	'77[a]	'77[a]	'81[a]	'86	'86[a]	'86
'85	'86[ab]	'77[ab]	'81[ab]	'86[a]	'77[a]	'77	'85[a]	'77
'86	'77[ab]	'78[ab]	'78[bc]	'85[a]	'86[a]	'78	'77[a]	'80
'79	'76[abc]	'85[ab]	'85[abc]	'76[ab]	'87[a]	'83	'76[ab]	'87
'78	'79[abc]	'81[ab]	'86[abc]	'81[ab]	'78[a]	'85	'78[ab]	'85
'87	'87[abc]	'82[ab]	'80[abc]	'78[abc]	'85[a]	'81	'83[ab]	'79
'76	'81[abc]	'87[ab]	'76[abc]	'80[abc]	'80[ab]	'80	'87[ab]	'81
'83	'78[abc]	'80[ab]	'79[abc]	'79[bcd]	'82[ab]	'87	'80[ab]	'78
'81	'83[bc]	'79[ab]	'87[bc]	'83[cd]	'79[ab]	'76	'79[ab]	'82
'80	'80[c]	'76[ab]	'83[c]	'87[cd]	'76[ab]	'79	'81[ab]	'83
'82	'82[c]	'83[b]	'82[c]	'82[d]	'83[b]	'82	'82[b]	'76

*Items with different superscripts are significantly different ($P \leq 0.05$), all others are not significantly different.

The warmest water temperatures occurred during the midsummer months of July and August. This is expected since discharge temperatures are based on an increase in temperature over intake water temperatures.

The highest annual mean water temperatures occurred during the 1985 to 1987 period, the 1977-78 period, and 1981. The coolest temperatures were during 1980 and 1982. No significant differences among years were detected at A2 or G2, but significant differences between years were noted at E2 (Table 4).

During the larval fish sampling months of April, May, and June, there were differences among water temperatures the years at each station (Table 4). Temperatures during certain years (1977, 1978, 1981, 1985, and 1986) were generally warmer than other years. Likewise, there were some years (1979, 1980, 1982, and 1983) where temperatures were generally cooler than the other years. These differences were mainly a result of power plant operations and occurred when Unit 2 was out of service.

Analysis of water temperatures during the summer months of June, July, and August found few significant differences (Table 4). This indicates that while there were station differences (E2>A2>G2), there was no year when the water was significantly warmer than the others during the 1977-87 period.

4.2.3 Meteorolgical and Hydrologic Conditions

The effectiveness of Robinson Impoundment for cooling is influenced by several climatological factors including, among others, surface area, meteorological conditions, and inflow from the Black Creek watershed. In order to quantify the effect of the 1986 drought conditions, rainfall, air temperature, and Black Creek inflow were examined.

According to meteorological data from the Robinson power plant site, Florence and Darlington, South Carolina, 1977-86 was relatively dry except for 1979, 1982, and 1983. Average annual departure from normal precipitation for the area was approximately 3 inches below normal with 1982-83 precipitation 2-10 inches above normal and 1986 precipitation 8-12 inches below normal. The most significant aspect of these conditions on the impoundment was the below normal rainfall, especially during 1986.

Air temperatures were at or slightly below normal for the 1977-86 period. The most extreme departure from normal was in 1986 when temperatures were greater than 2 degrees above average for the year.

Since the largest inflow to the impoundment is from Black Creek, stream flow data from the U.S. Geological Hydrologic Station on Black Creek at U.S. 1 above the impoundment (Table 5) were exami:.d.

Table 7 Flow in Black Creek at U.S. 1 above the Robinson impoundment ranked by years (listed lowest to highest).

Jan	Feb	Mar	Apr	May	Jun	Jul*	Aug*	Sep*	Oct	Nov	Dec	Ave.*
'81	'86	'85	'85	'81	'86	'86	'83	'86	'84	'82	'85	'86
'86	'81	'81	'86	'86	'81	'77	'80	'80	'82	'85	'81	'81
'85	'77	'86	'81	'85	'85	'80	'82	'83	'87	'79	'79	'85
'83	'87	'82	'82	'87	'77	'83	'77	'77	'79	'84	'78	'82
'79	'80	'78	'87	'77	'80	'85	'79	'82	'78	'87	'80	'83
'80	'78	'79	'78	'82	'78	'82	'86	'84	'86	'83	'87	'78
'84	'82	'84	'77	'83	'83	'81	'84	'78	'85	'81	'82	'77
'77	'84	'87	'79	'80	'84	'78	'78	'81	'83	'78	'83	'80
'87	'85	'77	'84	'79	'87	'79	'81	'85	'81	'77	'86	'84
'78	'83	'83	'83	'78	'82	'84	'85	'79	'77	'86	'84	'79
'82	'79	'80	'80	'84	'79				'80	'80	'77	

* ly data unavailable

During th: 1961 to 1986 period, 1986, 1985, and 1981 ranked first, second, and third, respectively, in having the lowest recorded flows. During the 1977-86 period, the five lowest flow years were all since 1981.

While annual values for rainfall and Black Creek flow give an overall indication of precipitation, the data may mask seasonal extremes. For example, the monthly ranking of Black Creek flow data in Table 5 shows 1981 was low during the first six months of the year. But beginning in July and continuing through November, the flow was among the highest for the 1977 to 1987 period. Flow for 1986 followed a similar pattern but was low longer into the year. This was further compounded by the overall low-flow conditions during 1985.

Good inflow during the spring and summer months is important since normal impoundment water levels are needed for maximum cooling. Low flows and low-water levels during this time of year also reduce available fish-spawning habitats, particularly in the upper impoundment, and limit the protected habitats. With limited areas of aquatic vegetation in the middle and lower impoundment, fish may be more likely to migrate out of normal habitats making them harder to sample with current methods.

4.2.4 Plankton and Benthos Communities

Phytoplankton have been monitored since 1973, zooplankton have been monitored since 1980, while benthic macroinvertebrates have been monitored since 1974. Analysis of variance (ANOVA) on phytoplankton and zooplankton data was performed to test for differences between stations, years, and months over the 1980-1987 period (Table 6). ANOVAs were run with Stations A2, E2, and G2 and also with G2 omitted. This was done because of habitat similarities at A2 and E2 and their dissimilarity to G2. Because of improvements in taxonomy and sampling methodology, statistical tests were inappropriate for certain data.

Table 8 Summaries of analysis of variance and Duncan's multiple range test* on organism density data from Robinson Impoundment. Items are listed in descending order. Data unavailable for 1984.

Phytoplankton	Phytoplankton (w/o G2)	Zooplankton	Zooplankton (w/o G2)	Benthos
		Station Analysis		
$A2^{a}$	A2	$A2^{a}$	$A2^{a}$	$G1^{a}$
$E2^{a}$	E2	$E2^{a}$	$E2^{a}$	$A1^{b}$
$G2^{b}$		$G2^{b}$		$E1^{b}$
		Year Analysis		
80^{a}	80^{a}	81^{a}	80^{a}	85^{a}
81^{b}	81^{b}	80^{ab}	81^{a}	87^{ab}
87^{b}	87^{bc}	82^{abc}	82^{a}	86^{b}
86^{b}	82^{bc}	86^{bc}	83^{b}	
85^{b}	86^{bc}	83^{c}	86^{bc}	
82^{b}	85^{c}	85^{c}	85^{bc}	
83^{c}	83^{d}	87^{c}	87^{c}	
		Month Analysis		
Aug^{a}	Jul^{a}	Jun^{a}	Mar^{a}	Feb^{a}
Sep^{ab}	Aug^{ab}	Jul^{ab}	Apr^{ab}	Jun^{a}
Jul^{ab}	Sep^{b}	Oct^{ab}	May^{abc}	Apr^{ab}
Oct^{bc}	Oct^{b}	Sep^{abc}	Nov^{abc}	Dec^{ab}
Jun^{bcd}	Jun^{b}	May^{abc}	Feb^{abc}	Aug^{ab}
Nov^{bcd}	Nov^{b}	Nov^{abc}	Oct^{abc}	Oct^{b}
Feb^{cd}	May^{b}	Apr^{abc}	Jun^{abcd}	
Dec^{cd}	Dec^{b}	Aug^{abc}	Jan^{bcd}	
Jan^{cd}	Feb^{b}	Dec^{bc}	Sep^{bcd}	
May^{cd}	Apr^{b}	Mar^{bc}	Dec^{cd}	
Mar^{d}	Jan^{b}	Feb^{bc}	Jul^{cd}	
Apr^{d}	Mar^{b}	Jan^{c}	Aug^{d}	

*Items with different superscripts are significantly different ($P \le 0.05$), all others are not significantly different.

Phytoplankton

e phytoplankton community composition in the impoundment is determined by the soft, acid, low-nutrient water. Organism abundance is considered to be low to moderate in abundance and species composition is typical of oligotrophic (dystrophic) waters. Light limitations from the stained water could influence phytoplankton abundance and composition. Green algae have been numerically dominant at all three stations.

Analysis of variance of phytoplankton density data indicates there were no statistical differences between densities at Stations A2 and E2 but they were higher than densities at G2 (Table 6).

Phytoplankton densities varied monthly with relatively large variation at G2 followed by E2 and A2 (Figure 8). Highest phytoplankton densities occurred during August at A2 and E2 and June at G2. Lowest phytoplankton densities occurred during March at G2 and April at A2 and E2 following periods of high inflow from Black Creek. This high inflow may have flushed the phytoplankton from this narrower [illegible] of the impoundment.

Significant differences in phytoplankton [illegible] were seen among years with 1980 having the highest densities, [illegible] the lowest, and the 1985-87 falling in between (Figure 8).

Zooplankton

The zooplankton community has been characterized as having slightly fewer taxa but with densities and biomass values equal to or greater than CP&L Piedmont reservoirs (Mallin 1986). The most abundant zooplankters are copepods (3 taxa) and rotifers (24 taxa) with cladocerans (12 taxa) less abundant. Seasonal abundance follows a bimodal spring-fall peak pattern, especially in the middle and lower impoundment (Figure 5). Copepods and cladocerans contribute the most biomass which also follows a bimodal spring-fall peak pattern. Densities at G2 were lower than at A2 and E2. When comparing only A2 and E2, a significant difference in density was found between these stations. This indicates that there is less zooplankton near the discharge but there is still greater zooplankton abundance at E2 and A2 than at G2 (Figure 8).

Zooplankton densities were significantly different between the upper impoundment (G2) and the lower impoundment (A2 and E2) (Table 6). Densities at Station G2 fluctuated during the year and followed phytoplankton density patterns (Figure 8). Low densities occurred in March, the month of highest Black Creek inflow, and high densities occurred in June and July corresponding to the months of highest phytoplankton densities.

Differences in zooplankton densities were observed over years (Figure 8). From 1980 to 1982, organism densities at A2 and E2 were higher than the 1983-87 period. This decrease in zooplankton density may have been a result of increased predation by larger numbers of larval and juvenile bluegill. Zooplankton densities in the lower and middle impoundment were lowest during 1983, 1985, 1986, and 1987 (Table 6).

During 1985 discrete depth sampling was conducted to determine if there were any effects from thermally induced stratification. Samples were taken at 1-meter (thermally enhanced) and 3-meter depth from April through September. In most cases there were no significant differences in densities between depths at each station. The only difference was for copepods at E2 where there were fewer individuals at the cooler 3-meter depth than at 1 meter. Vertical stratification is probably not an important factor influencing the vertical distribution of zooplankton in the impoundment.

Benthic Macroinvertebrates

The benthic macroinvertebrate community has been dominated by chironomids and oligochaetes, especially in the middle and lower impoundment. Taxa richness has been similar at Station G2 during the years, while at Stations A2 and E2, taxa richness has increased. This increase in taxa richness at A2 and E2 may be a result of improved field and laboratory techniques which allow better retrieval of small, delicate oligochaetes and chironomids that dominate these stations.

The increase in submerged aquatic vegetation may provide better habitats for benthic organisms (see Section 4.2.5). Aquatic vegetation also provides an area for detritus deposition. Both of these factors increase the benthic community. Areas composed mostly of exposed sand are less favorable to benthic organisms. As aquatic vegetation has spread in the middle and lower impoundment, the benthic organisms that utilize these plants will also increase in abundance and kinds.

Benthic macroinvertebrate densities during 1985-87 were not significantly different between A1 and E1 but both stations were different from G1 (Table 6). No significant differences were seen between years. Spatial density by months indicated no significant differences among most months.

4.2.5 Aquatic Vegetation

The Robinson Impoundment has supported a diverse population of native aquatic vegetation consisting of emergent, floating leaf, and submergent plants. There have been differences in aquatic vegetation composition between the upper and the middle and lower areas of the impoundment.

The upper impoundment contains the highest diversity of aquatic vegetation. Maidencane *Panicum hemitomon* is the most common emergent plant, water lilies *Nymphaea odorata* are the most common floating leaf plant, and milfoil *Myriophyllum heterophyllum* is the most common submerged plant.

The middle and lower impoundment have few areas of floating leaf plants as a result of fewer protected areas, increased wave action, and greater depth. Emergent vegetation, mostly maidencane, has spread in undisturbed riparian areas away from houses and swimming beaches and often forms a band 1-2 meters wide. Submerged vegetation, mostly spike-rush *Eleocharis baldwinii* and rush *Juncus repens*, has also increased in the lower impoundment over the period.

Most of the changes in aquatic vegetation observed over the study period are due to natural succession. These changes include increased floating-leaf vegetation in the upper impoundment, increased areas of emergent vegetation throughout the impoundment, and increased areas of submerged vegetation in the lower impoundment.

Submerged vegetation in the middle impoundment has been affected by power plant operations in the immediate discharge area. Both discharge flow and temperature appear to determine patterns of submerged vegetation. Spike-rush was the most abundant submerged plant in the middle impoundment during 1983, covering much of the bottom near the discharge weir. During 1984 when Unit 2 was out of service, the biomass of spike-rush increased. When Unit 2 returned to service in 1985 and throughout 1986, spike-rush was eliminated from the area immediately in front of the discharge weir (Figure 9). Populations of spike-rush across the impoundment from the discharge and in the lower impoundment experienced no decrease in biomass during this period indicating that the impact of the power plant discharge was limited to the immediate discharge area (Figure 9).

4.2.6 Fisheries

Fisheries studies in the Robinson Impoundment have characterized the fish populations as typical of other sandhills and regional lakes. Bluegill, warmouth, and largemouth bass were the dominant fish throughout the impoundment, especially in the middle and lower impoundment (E2, A2). Many of the other species (i.e., chubsuckers, suckers, and blackbanded and dollar sunfishes) were more common in the upper impoundment (G2) (Table 7).

Table 9 Relative abundance of fishes collected by cove rotenone sampling from Robinson Impoundment 1977-1987.

Species	Trans. A	Trans. E	Trans. G
Bowfin	+	+	+
Eastern mudminnow	+	+	+
Redfin pickerel	+	+	+
Chain pickerel	+	+	+
Golden shiner	+	+	++
Ironcolor shiner	-	+	+
Dusky shiner	+	+	-
Creek chubsucker	+	+	+
Lake chubsucker	+	+	+
Spotted sucker	+	+	+
White catfish	++	+	++
Yellow bullhead	+	++	+
Flat bullhead	+	+	+
Tadpole madtom	-	-	+
Margined madtom	-	-	+
Swampfish	-	+	+
Pirate Perch	+	+	++
Lined topminnow	+	+	++
Mosquitofish	++	+	+
Mud sunfish	+	+	+
Flier	-	-	+
Banded pigmy sunfish	+	-	+
Blackbanded sunfish	+	+	++
Bluespotted sunfish	++	+++	+++
Redbreast sunfish	+	+	+
Redear sunfish	+	+	+
Warmouth	++	++	++
Bluegill	+++	+++	++
Dollar sunfish	+	+	++
Largemouth bass	++	+	+
White crappie	+	+	+
Black crappie	+	+	+
Swamp darter	++	+	++
Tessellated darter	-	+	+
Sawcheek darter	+	+	+

- = absent, + = 1-100/ha, ++ = 101-1000/ha +++ = >1000/ha

Variations in the fishery of the impoundment have been noted over the years including increases and decreases in the total population as well as in numbers of certain species. The following sections address the fisheries of Robinson Impoundment including larval and adult fishes.

Larval Fish

Larval fish studies have examined both the planktonic and littoral larval fish habitats. The larvae of 21 taxa have been collected from the impoundment (Table 8) (McGowan 1985). Since bluegill and largemouth bass are the dominant sport fish in the impoundment, they will be discussed in addition to the total larval fish community. A nongame taxa present throughout the impoundment, *Etheostoma*, also is discussed.

Table 10 Larval fishes collected from Robinson Impoundment, 1974-1987.

Scientific Name	Common Name
Amiidae	
Amia calva	bowfin
Esocidae	
Esox spp.	pickerels
Cyprinidae	
Notemigonus crysoleucas*	golden shiner
Notropis chalybaeus	ironcolor shiner
Catostomidae	
Erimyzon spp.*	chubsuckers
Minytrema melanops*	spotted sucker
Ictaluridae	
Ictalurus natalis	yellow bullhead
I. platycephalus	flat bullhead
Amblyopsidae	
Chologaster cornuta	swampfish
Aphredoderidae	
Aphredoderus sayanus	pirate perch
Cyprinodontidae	
Fundulus lineolatus	lined topminnow
Poeciliidae	
Gambusia affinis	mosquitofish
Centrarchidae	
Enneacanthus chaetodon*	blackbanded sunfish
E. gloriosus*	bluespotted sunfish
Lepomis auritus	redbreast sunfish
L. gulosus*	warmouth
L. macrochirus*	bluegill
Lepomis spp.*	unidentified sunfish
Micropterus salmoides*	largemouth bass
Pomoxis spp.	crappies
Percidae	
Etheostoma fusiforme*	swamp darter

* = most commonly collected taxa

Data for total larval fish, *Lepomis*, and *Etheostoma* were collected using push nets (571 μ mesh), while largemouth bass were collected using Plexiglas® littoral traps. Larval fish were not sampled during 1984.

Analysis of variance of log-transformed larval fish density of each of the major species and total larval fish indicates significant differences between Transects A, E, and G (Table 9). Larval fish densities at G were higher and significantly different from E and A which were not significantly different from each other. At Transect G, larval fish densities have been consistently higher than A and E (Figure 10).

Table 11 Analysis of variance and Duncan's multiple range test* for differences in mean larval fish densities (ranked highest to lowest). Data unavailable for 1983 and 1984.

Total	Lepomis	Largemouth bass	Etheostoma
G^{a}	G^{a}	G^{a}	G^{a}
E^{b}	E^{b}	E^{ab}	E^{b}
A^{b}	A^{b}	A^{b}	A^{b}
1982^{a}	1985^{a}	1986^{a}	1982^{a}
1985^{a}	1986^{b}	1987^{ab}	1987^{b}
1987^{ab}	1981^{bc}	1982^{abc}	1981^{b}
1986^{abc}	1987^{bc}	1985^{abc}	1980^{b}
1981^{bc}	1980^{bc}	1981^{bc}	1979^{b}
1980^{bc}	1982^{bcd}	1980^{bc}	1985^{b}
1979^{cd}	1977^{bcd}	1979^{c}	1986^{b}
1977^{d}	1979^{cd}	1977^{c}	1977^{c}
1978^{d}	1978^{d}	1978^{c}	1978^{c}
May^{a}	Jun^{a}	May^{a}	Apr^{a}
Apr^{b}	May^{a}	Jun^{ab}	May^{a}
Jun^{b}	Apr^{b}	Apr^{b}	Jun^{b}

*Items with different superscripts are significantly different ($P \leq 0.05$).

For total larval fish collected during 1977-87, there were significant differences between years with many overlapping annual means. Generally, larval fish densities during the 1980-87 period were higher than the 1977-79 period, especially in the middle and lower impoundment. The years of the lowest larval fish densities were also the years of the highest copper levels in the impoundment (Figure 6).

Larval *Lepomis* abundance was highest during 1985 (Table 9). Differences between the other years were less clear at A and E where *Lepomis* larvae were lowest in 1978 and then gradually increased through 1985. *Lepomis* density at A and G then declined from 1985 to 1987 (Figure 10). At Transect E, density declined from 1985 to 1986 but increased from 1986 to 1987. Larval *Lepomis* densities peaked in May and June for the impoundment as a whole.

There were no differences in largemouth bass larval densities between G and E or E and A, but G was higher than A. The highest density occurred in 1986 but was not significantly different from all other years (Table 9). Generally there has been a gradual increase in largemouth bass larvae in the impoundment since 1977 (Figure 10). This was most evident at Transects A and E.

Etheostoma larvae were more abundant at G than at E and A and were more abundant during April and May than June. Temporal differences indicate 1982 had higher densities than all other years. The lowest larval densities were during 1977 and 1978.

Larval fish densities in the middle and lower impoundment have been relatively high since 1982 (Figure 10). *Lepomis* accounted for much of this increase in abundance, especially during 1985. During 1986 and 1987, however, *Lepomis* abundance has decreased. Largemouth bass has also increased, especially during 1987. The increase in largemouth bass may have resulted in decreased abundance of bluegill larvae because of predation. The lower larval fish densities of 1977-1980 appear to be a result of increased copper concentrations in the middle to lower impoundment. After copper concentrations decreased in the impoundment, larval fish abundance increased.

Adult Fish

During the 1977-87 period, there were fluctuations in fish standing crop. Analysis of cove rotenone data indicates significant differences among years for both density and weight. The 11 years can be grouped into three periods: (1) 1977-81, (2) 1982-85, and (3) 1986-87 based on abundance.

During the 1977-1981 period, there were low numbers of fish in the middle and lower impoundment (Figure 11). The lowest numbers occurred in 1979 with standing crops improving after that time. The upper impoundment had higher numbers of fish during these years and did not experience a similar decline. The weight of fish per hectare varied between the middle and lower impoundment stations. Fish weights from the middle impoundment declined from 1977 to 1979 when they reached the lowest level observed (Figure 11). During this period, fish weights from lower impoundment increased and was similar to the upper impoundment. This indicates there were few large fish in the lower impoundment, near normal fish populations in the upper impoundment, and few small fish in the middle impoundment.

From 1980 to 1981, there was a gradual increase in the total number of fish in the middle and lower impoundment. The weight of fish per hectare became more similar in these areas. The upper impoundment continued to maintain its fishery.

Beginning in 1982, the middle and lower impoundment experienced dramatic increases in the number of fish. The weight of fish per hectare also increased but with less rapidity. The upper impoundment did not experience similar increases but stayed within the ranges previously observed. The number of fish per hectare in the lower impoundment peaked in 1983, then declined, but remained above 1977-81 levels. The high numbers of fish in the middle impoundment varied during 1982-85 but were still the highest of any area in the impoundment.

From 1985 to 1987, fish populations in the middle impoundment decreased in both number and weight per hectare. Fish in the lower impoundment decreased in number while increasing in weight during 1985. During 1986 fish increased in number but decreased in weight. The number and weight of fish per hectare in the upper impoundment decreased in 1986 then increased in 1987.

The increase in fish standing crops during the 1981-83 period reflects an increase in bluegill abundance (Figure 12). This followed a period of lower fish abundance, especially bluegill, attributed to elevated copper (CP&L 1982b, 1983c, Woock 1985). While bluegill populations have declined since their peak in 1983, their density and standing crops currently remain above the levels of the late 1970s.

Since 1979 most bluegill were under 60 mm (Figure 12) representing a significant change from 1979 when there were very few small bluegill. The abundance of bluegill < 60 mm in the rotenone samples indicates survival through the summer following successful reproduction in spring. An abundance of small bluegill also provides prey for predators such as largemouth bass and chain pickerel.

Largemouth bass also made significant population increases since 1981 (Figure 13). This was especially evident at Transect E. After reaching a peak in 1983, the number of largemouth bass decreased to numbers similar to those at Transect G. While the number of largemouth bass dropped at Transect E, the weight of fish per hectare remained high. Transect A also experienced an increase in largemouth bass since 1979. Transect G populations remained fairly constant over the 1977 to 1987 period with increases occurring from 1985 to 1987. Both total number and weight per hectare of largemouth bass in the middle and lower impoundment have generally increased since 1981 (Figure 13).

Overall, the lower Robinson Impoundment fishery experienced a period of low numbers and poor recruitment (1977-1979) due to elevated copper concentrations. This was followed by a period of high reproductive success (1982-1985). The current status appears to be one in which the fish population is becoming stabilized after several years of fluctuation. During 1985 to 1986 plant operations and severe climatic conditions resulted in the worst environmental conditions noted to date in the impoundment, yet the fishery was at or above the levels of the 1977 to 1981 period.

When comparing Robinson Impoundment to other regional blackwater lakes, the total number and weight of fish per hectare in the impoundment was higher than most other lakes (Table 12) Although many of the comparisons were to natural lakes and not impoundments, all referenced bodies of water are considered blackwater.

Table 12 Comparison of cove rotenone data from Robinson Impoundment and other blackwater lakes in the region.

Sampling location	Total number of fish per hectare	Weight (kg) of fish per hectare
Robinson Impoundment 1974-75	14,978	81.6
Robinson Impoundment 1979	13,257	89.4
Robinson Impoundment 1982	55,641	151.9
Robinson Impoundment 1985	60,150	163.2
Robinson Impoundment 1986	24,783	107.9
Robinson Impoundment 1987	23,188	100.0
Robinson Impoundment average 1974-1987 (w/o 1976)	29,336	120.4
Singletary Lake (Louder 1961)	709	6.3
Lake Waccamaw (Louder 1961, Davis 1966)	1,100	141.3
Alligator Lake (Crowell 1966)	285	10.9
Catfish Lake (Bayless 1966)	241	1.9

Status of Copper and the Fishery

The fishery reductions of the late 1970s and early 1980s were related to elevated copper levels in the impoundment (CP&L 1982b, 1983c, Woock 1985). Since the removal of the brass condenser tubes, copper concentrations have declined. This has resulted in lower liver copper concentrations in largemouth bass, bluegill, and spotted sucker compared to the early 1980s (Table 13). During the period of declining liver copper concentrations, the fishery, especially bluegill and largemouth bass, improved. The 1987 liver concentrations were at or approaching background levels for fish in the region. Concentrations of copper in fish livers are expected to be similar to or less than those reported in 1987 in the coming years.

Table 13 Copper concentrations in livers from fish collected in the middle and lower impoundment. Concentrations are in µg/g wet weight.

	Largemouth bass			Bluegill			Spotted sucker		
Year	Mean	n	Range	Mean	n	Range	Mean	n	Range
1980	72	9	7.1-220	26	17	10-280	68	2	55-81
1981	35	17	7.9-150	191	43	< 1-860	51	19	14-100
1982	28	20	7.8-124	21	25	< 0.4-92	92	19	< 2-78
1983	25	5	12-34	4.7	5	< 2-15	37	5	25-65
1987	3.5	3	0.9-6.7	1.8	2	1.7-1.9	21	3	0.6-35

5.0 EVALUATION OF PROPOSED THERMAL EFFLUENT EFFECTS ON FISH

Monitoring of the fish populations in Robinson Impoundment over the years has shown that fish have been well distributed throughout the impoundment including the discharge area. Catch rates have been lower at times in the immediate discharge area, particularly during midsummer when discharge temperatures are highest. Once the discharge area temperatures become more favorable to fish, it has been demonstrated that fish return to the discharge area. It has also been shown that fish are attracted to this area during the winter months.

Conditions unfavorable to fish occur only during the warmest summer months (i.e., July and August). Even during this period, the area of impact is limited to the middle impoundment allowing much of the impoundment to be available for fish. This midsummer period is after the primary breeding season, and since fish are not behaviorally tied to a nest site, they would be able to avoid any unfavorable conditions.

Jensen et al. (1969) found breeding adults to be the most sensitive to temperature extremes. Most fish in the impoundment breed during March, April, May, and June prior to the months of highest thermal discharges. Even though *Lepomis* spawn throughout the summer, most reproduction occurs during spring and early summer prior to the maximum impoundment temperatures.

Larval fish capture rates are generally highest in late May and early June when temperatures are well within tolerances for breeding adults. At Transect A, the highest measured temperatures during biological sampling were 31.0°C (87.8°F) and 31.2°C (88.2°F) during June 1977 and June 1981, respectively, and 30.4°C (86.7°F) at Transect G during June 1981. Other sampling temperatures at these transects during April, May, and June did not exceed 30°C (86°F). Larval *Lepomis* catch rates are highest in late May and early June when temperatures are near 30°C (86°F) which is considered optimal for bluegill (Lemke 1977). Largemouth bass typically spawn when water temperatures are around 18°C (64.4°F) to 23°C (73.4°F) (April and May in the impoundment). Again, no extreme temperatures occur during these months when the more vulnerable spawning adults are present. The temperature preference range for young-of-year bass is from 30°C (86°F) to 32°C (89.6°F) (Ferguson 1958).

Water temperatures in the upper and lower impoundment are cooler than the middle impoundment when the power plant is operating. During the drought conditions of 1986, Station G2 was, on average, 9.6°C (17.3°F) cooler than Station E2 (midway across the middle impoundment) for May, June, and July. A difference was also seen between the Station E2 and Station A2 where during the same three-month period, A2 was 6.9°C (12.4°F) cooler than E2. While the temperatures at the discharge weir were averaging 35.6°C (96.0°F), 40.0°F (104.0°F), and 43.2°C (109.8°F) during May, June, and July 1986, respectively, much of the impoundment was suitable for spawning and growth.

Following the peak spawning period, temperatures during sampling at Transect E normally approach 38°C (100.4°F) during July and August. The lowest elevated temperature between 1977 and 1987 was 34°C (93.2°F) (September 1982), while the highest was 39.6°C (103.3°F) (August 1979) at the middle transect station. Highest temperatures at Transect G exceeded 30°C (86°F) only five times during the 11-year period with the highest temperature, 32.3°C (90.1°F), occurring in August 1979. The highest temperature at Transect A was 33.1°C (91.6°F) during the same month and year. Therefore, only Transect E temperatures ever reach values that may cause fish mortality, even though no fish kills have been reported in the impoundment. Furthermore, the highest temperatures occur during times when fish are best able to tolerate extremes. Most young-of-year and adult fish are of sufficient size by August to migrate to preferred environments. Only late spawned larval fish in the discharge area may be unable to escape temperature extremes. However, this life stage is more tolerant of hot water than older fish. Coutant (1975) found that small largemouth bass are more eurythermal than larger bass.

According to the literature, fish acclimated to higher temperatures have higher critical thermal maximums (Banner and Van Arman 1973; Cox 1974). Cairns (1956) showed that bluegill "tempered" to a 2°C/day (3.6°F/day) increase can tolerate temperatures up to 39.2°C (102.6°F) for at least a day. Siler and Clugston (1975) found that largemouth bass were collected from water with temperatures at or above those (36.4°C = 97.5°F) reported by Hart (1952) as the upper lethal limit. Bennett (1979) measured internal temperatures of bass from a heated impoundment as high as 36.2°C (97.2°F) and concluded that bass can successfully reproduce, hatch, grow, and become sexually mature in heated waters. Guest (1985) found LT_{50} values closer to 39°C (102.2°F) for both Florida and northern strains largemouth bass. Siler and Clugston (1975) also found that bass were capable of finding and migrating to "refuge" areas whenever water temperatures became elevated. In Robinson Impoundment, cool water zones exist in heated areas due to feeder springs and seeps and the narrow former Black Creek channel, but it has not been determined if these areas function as thermal refuges for large numbers of fish.

The authors referenced above report upper thermal lethal limits for bluegill and largemouth bass of 36.4°-39°C (97.5°-102.2°F). If one considers a maximum "desirable" temperature (one at which fish will leave an area, if possible) of 32°C (89.6°F), which is considerably less than the lethal limit, then during most years fish would have free passage of the entire impoundment. When addressing low DO limitations if one assumes 4.0 mg/l, a value often used by fisheries biologists, to be the lower "desirable" limit, then there is abundant available habitat for fish. While 1986, the worst drought year on record for the area, showed the impoundment "blocked" by water temperatures of 32°C or higher and DO of 4 mg/l or lower, large "favorable zones" were still available for fish both in the upper impoundment and the lower impoundment (Figure 14). This "blocked" condition only lasted for two weeks and then improved with lower temperatures and higher DO near the bottom.

Based on measured maximum temperatures in Robinson Impoundment during 1985-1987, the thermal effluent should not produce impoundment temperatures significantly detrimental to fish except in the immediate discharge vicinity and only during a relatively short time. Further, the impoundment contains a reproducing indigenous population of fish with a higher than expected standing crop for blackwater systems.

6.0 SUMMARY

The current NPDES permit for Carolina Power & Light Company's Robinson Steam Electric Plant has limits for temperature at the discharge point for once-through cooling water into Robinson Impoundment. These current temperature limits were derived from a successful 316a Demonstration submitted by CP&L in 1976. Since the limits were imposed in 1977, the plant has occasionally exceeded the limits for short periods due primarily to more adverse meteorological and hydrologic conditions than those experienced during the short (approximately 1 year) 316a Demonstration study. Biological monitoring during these exceedances has shown no adverse effects on the biota of the impoundment. Thus, it has become apparent that some of the current temperature limits are lower than necessary. The current method of monthly changes in limits does not keep pace with the natural seasonal change in impoundment temperatures and, therefore, may cause needless restrictions on the operation of the plant.

CP&L proposes that the temperature limits in the renewed NPDES permit be revised to reflect the increased understanding of the effects of heated water discharged to Robinson Impoundment. The limits for the spring months, specifically May, could be increased to those experienced in 1986 and not cause an unacceptable adverse effect.

In response to the natural warming and cooling of the impoundment in the spring and fall months, respectively, the discharge temperature of the once-through cooling water can vary greatly over a 30-day period such that temperature limits set at approximately 15-day intervals would more closely parallel actual conditions. Semimonthly limits could be determined by a simple averaging method to make the transition between months with different limits.

Studies to monitor the biological conditions of Robinson Impoundment have been conducted under a variety of environmental conditions and thermal loadings since 1973. By observing conditions over these years, overall trends in the biota are evident.

The thermal discharge has the greatest impact in the middle impoundment, especially near the point of discharge. The upper impoundment receives only minimal thermal discharge. The lower impoundment is also affected by thermal discharge; however, cooling of discharge waters occurs as waters are recirculated through the impoundment.

The impoundment can be divided into two biological areas: (1) the upper impoundment, which is shallow and narrow with abundant aquatic vegetation and affected by Black Creek inflow and (2) the middle and lower impoundment, which is wider and deeper with fewer areas of aquatic vegetation.

During 1985 and 1986, water temperatures throughout the impoundment were higher than they have been since 1980. This was a result of Unit 2 returning to service with a slightly greater heat output (< 2%) at maximum power levels, improved reliability, and the occurrence of record low rainfall and other climatological effects. The higher than normal ambient water temperatures, reduced rainfall and associated inflow from Black Creek, low impoundment water levels, and improved operation characteristics of Unit 2 during 1986 resulted in thermal conditions more severe than experienced during prior studies.

When the plant pumps are operating, there is a good mixing of the water column minimizing the areas of low-dissolved oxygen despite elevated water temperatures. Thermal stratification generally is weak during all seasons and a thermocline is rarely seen except in the middle impoundment area over the old Black Creek Channel.

The impact of the thermal discharge on the lower trophic levels (phytoplankton, zooplankton, benthos) appeared to be minimal over time, even though declines in all plankton were observed during certain years. Comparisons of annual densities of phytoplankton between Stations A2 and E2 from 1980 to 1987 indicate A2 was not different from E2. Zooplankton densities, however, at these two stations during this same period were higher at A2 than E2. Predation on zooplankton by the increasing number of larval fish is the probable reason for these differences since thermal discharges were lower than normal during much of this period.

Low fish reproduction (1977-1981), which was linked to elevated copper concentrations, increased rapidly during the 1982-85 period. This increase occurred mainly in the middle and lower impoundment and included all fish, especially bluegill and largemouth bass. The slight drop in total larval fish, including larval bluegill, during 1986 and 1987 occurred during a period of increased largemouth bass abundance and resultant predation which contributed to the drop in smaller fish.

Fish standing crops varied from low (1978 and 1979) to high (1982 to 1985). While there was a reduction in the overall number of fish per hectare as well as the weight of fish per hectare during 1986 and 1987, the total standing crop of fish was similar to or above the levels seen in 1977.

The expansion of the fishery in the impoundment during 1982 is similar to that which occurs in new impoundments when there are many habitats unoccupied in the system. The fishery expands to fill these habitats. In the case of Robinson Impoundment, there were underutilized habitats available following the fishery reductions of 1978 and 1979. When the stress of copper was removed from the impoundment, the fishery responded to occupy these habitats.

After several years of an expanding fishery, it is not unexpected to have a period of reduced recruitment while a system adjusts to a sustainable carrying capacity. Robinson Impoundment currently has a fishery above that expected for a dystrophic blackwater impoundment. The diversity of fishes in the impoundment and the dominance of bluegill and largemouth bass in the impoundment indicate a balanced and indigenous fishery with abundant sport fishes.

There was an impact from the thermal discharge on the fishery in the immediate discharge area of the impoundment during summer months, but this area was able to recover during the rest of the year. The thermal discharge may even enhance the fishery during the winter months by attracting fish such as largemouth bass into the area and extending the growing season.

The importance of other areas of the impoundment as refuge and nursery areas noted in the original 316a study are still important to the biota of the impoundment. The upper impoundment has maintained a relatively constant biological community. The lower impoundment was temporarily affected by elevated copper but has been unaffected by the thermal discharge.

The severe drought (1986) affected the impoundment in several ways, including increased ambient water temperatures and lower impoundment water levels. These conditions, along with the modification and improvements of Unit 2, resulted in thermal conditions more severe than previously experienced. These conditions, along with a normal decline in the fishery often observed after a period of rapid expansion, were the probable causes of the decrease in the fishery observed from 1985 to 1986. While there was a decrease in the fishery in 1986 and 1987, it was still at or above levels observed during the middle 1970s. Any delayed response resulting from the drought conditions may become evident in the coming years. Fluctuations in the biota, especially the fishery, are a normal response to changing environmental conditions. With a return to a more normal pattern of rainfall, the fishery should remain balanced and indigenous.

In Robinson Impoundment, a variety of environmental conditions have been observed over the past 15 years. These proposed temperature limit changes would not allow the plant's discharge temperature to be any higher than temperatures that have been experienced before when biological monitoring has demonstrated the impoundment can maintain a balanced and indigenous fish population. The operation of the plant and biological monitoring over the past several years offers ample empirical evidence that the proposed limit changes are acceptable and appropriate.

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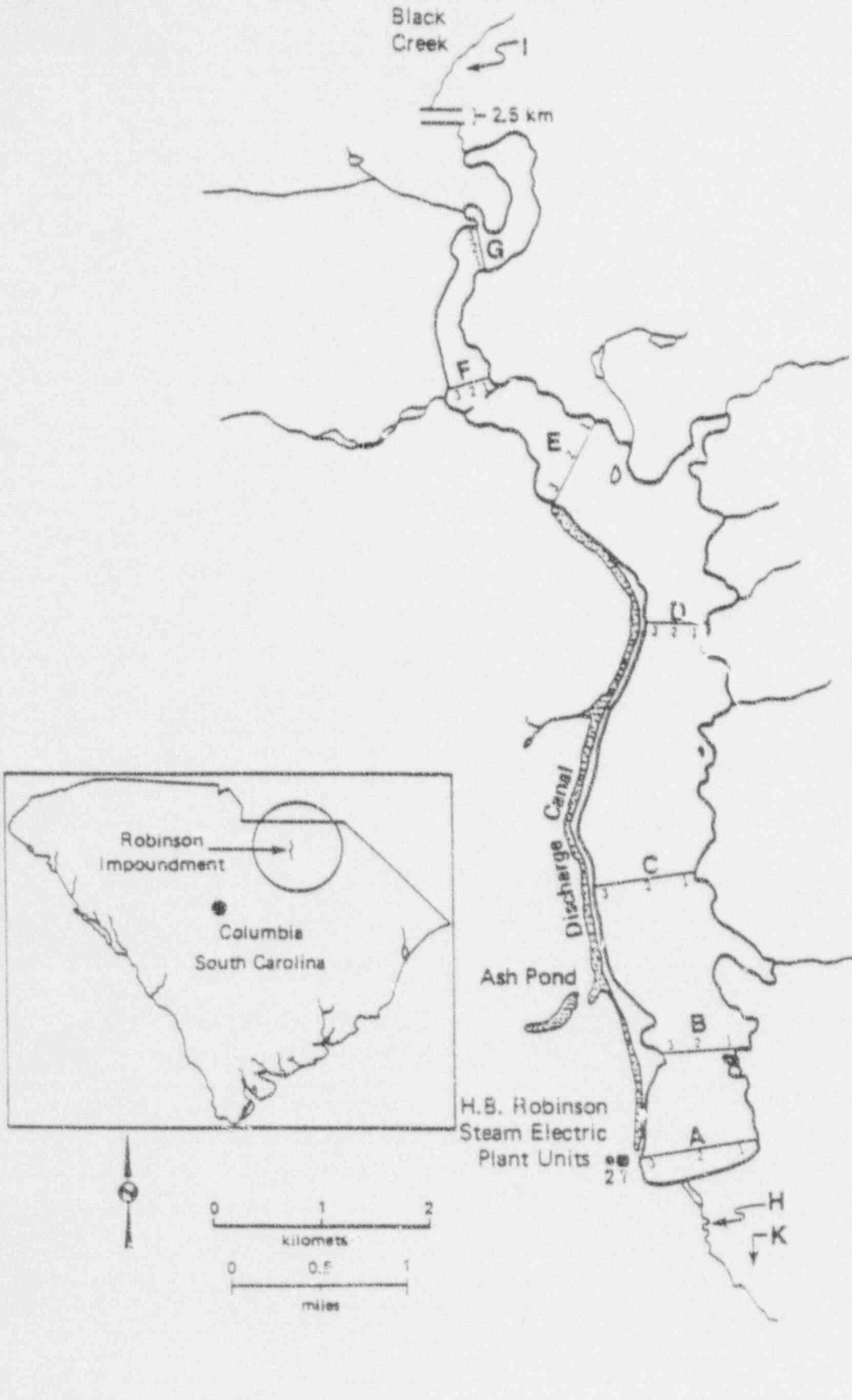


Figure 1. Robinson Impoundment sampling stations.

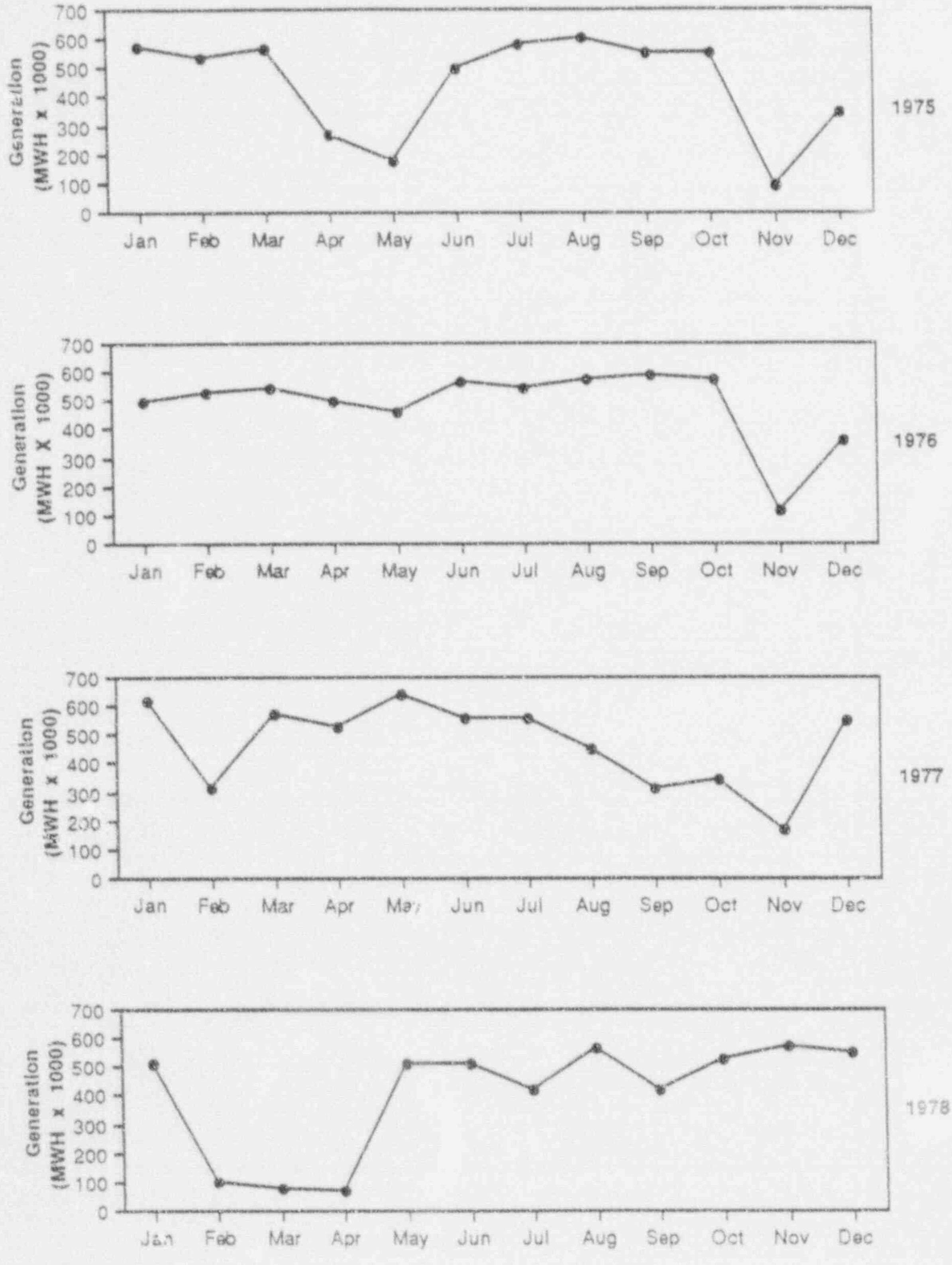
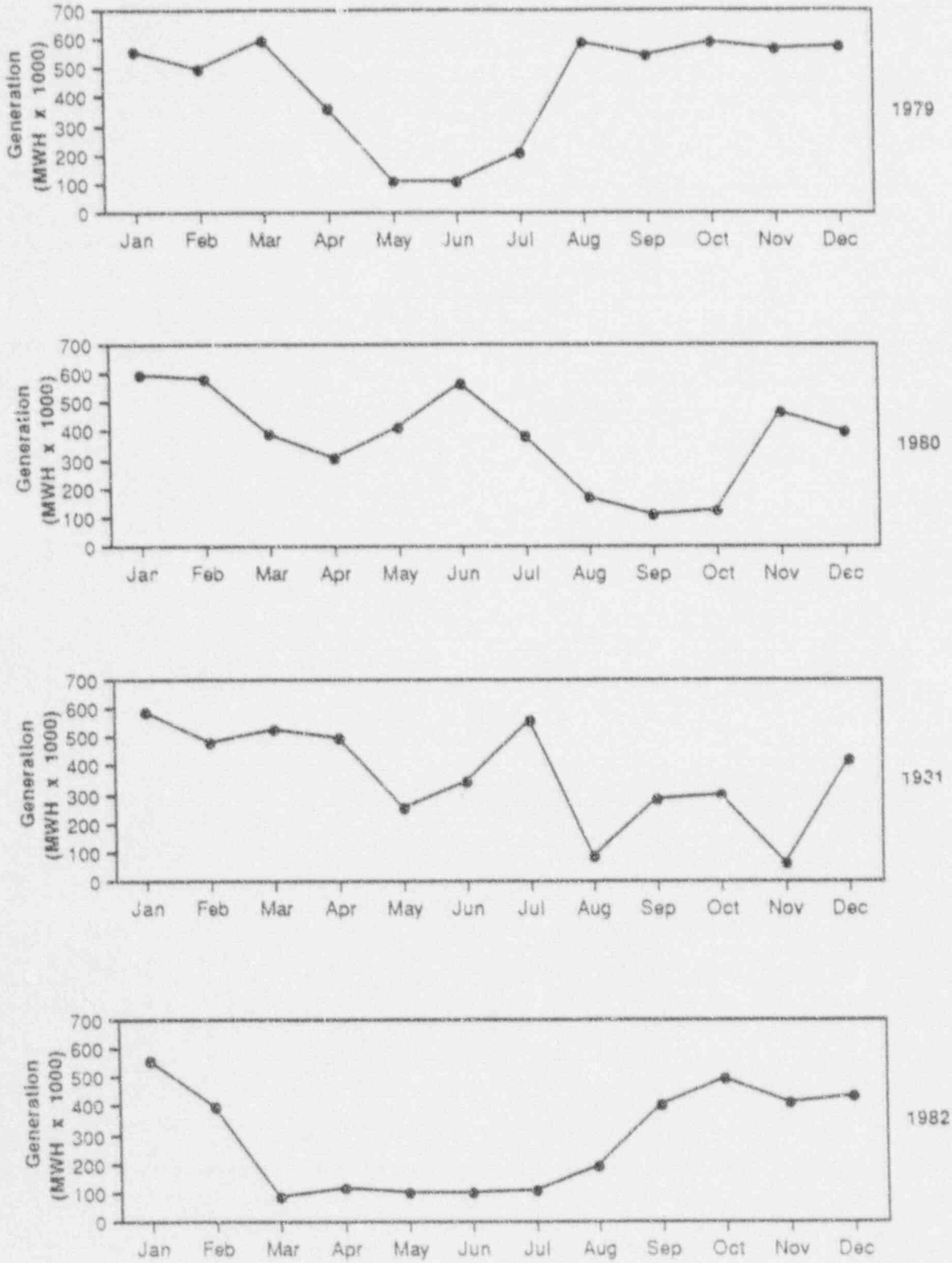


Figure 2. Gross generation of H. B. Robinson Units 1 and 2, 1975-1987.



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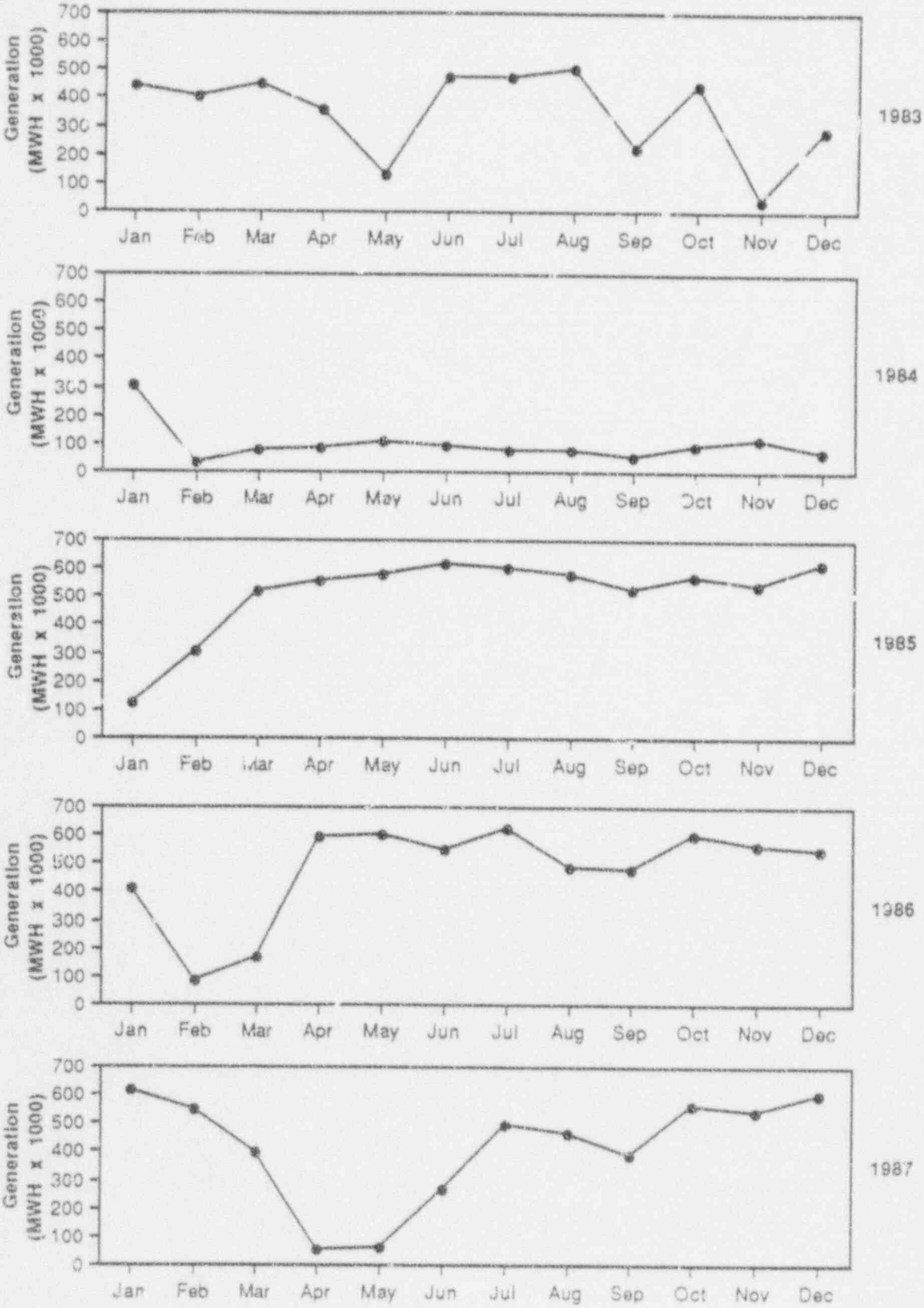

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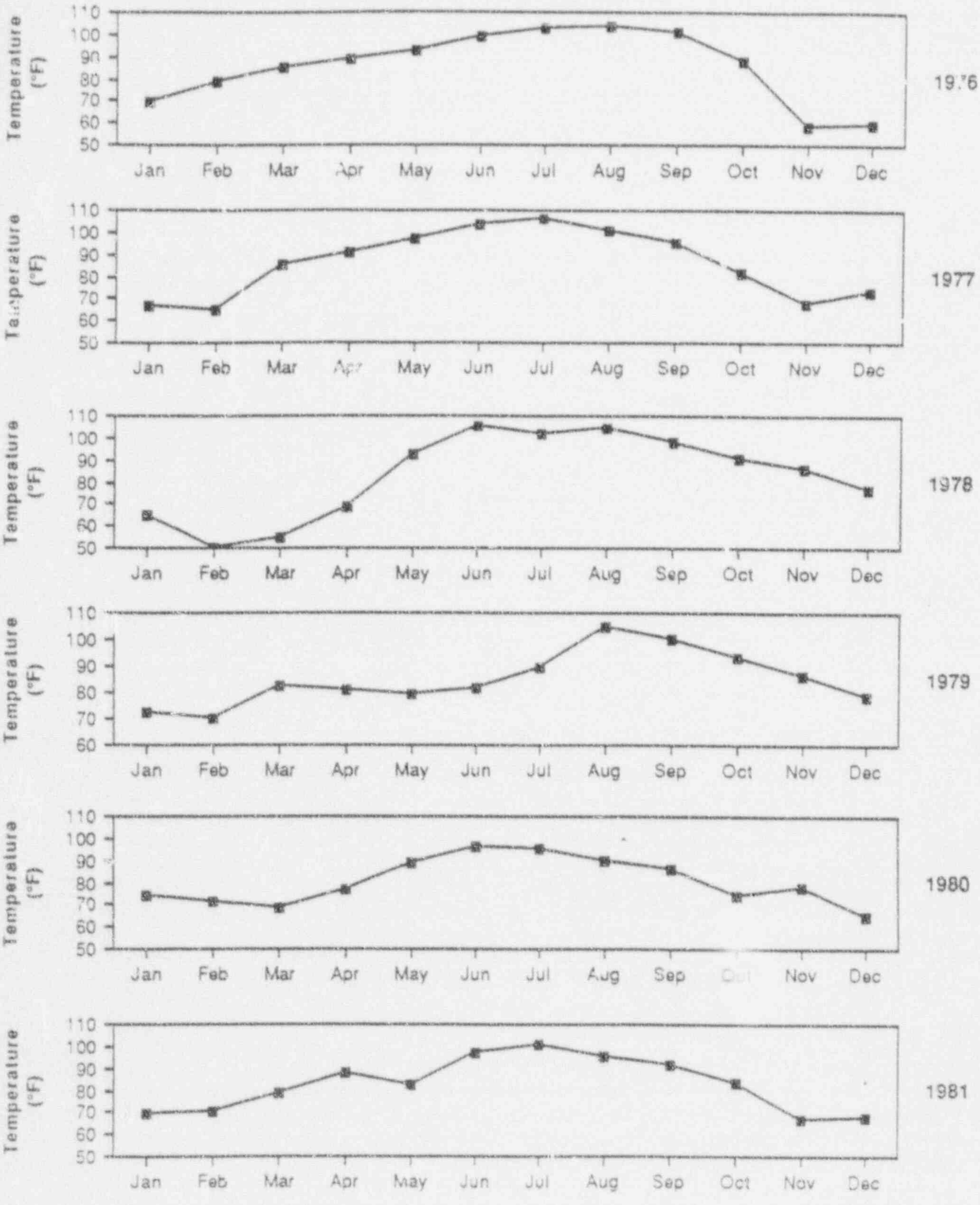
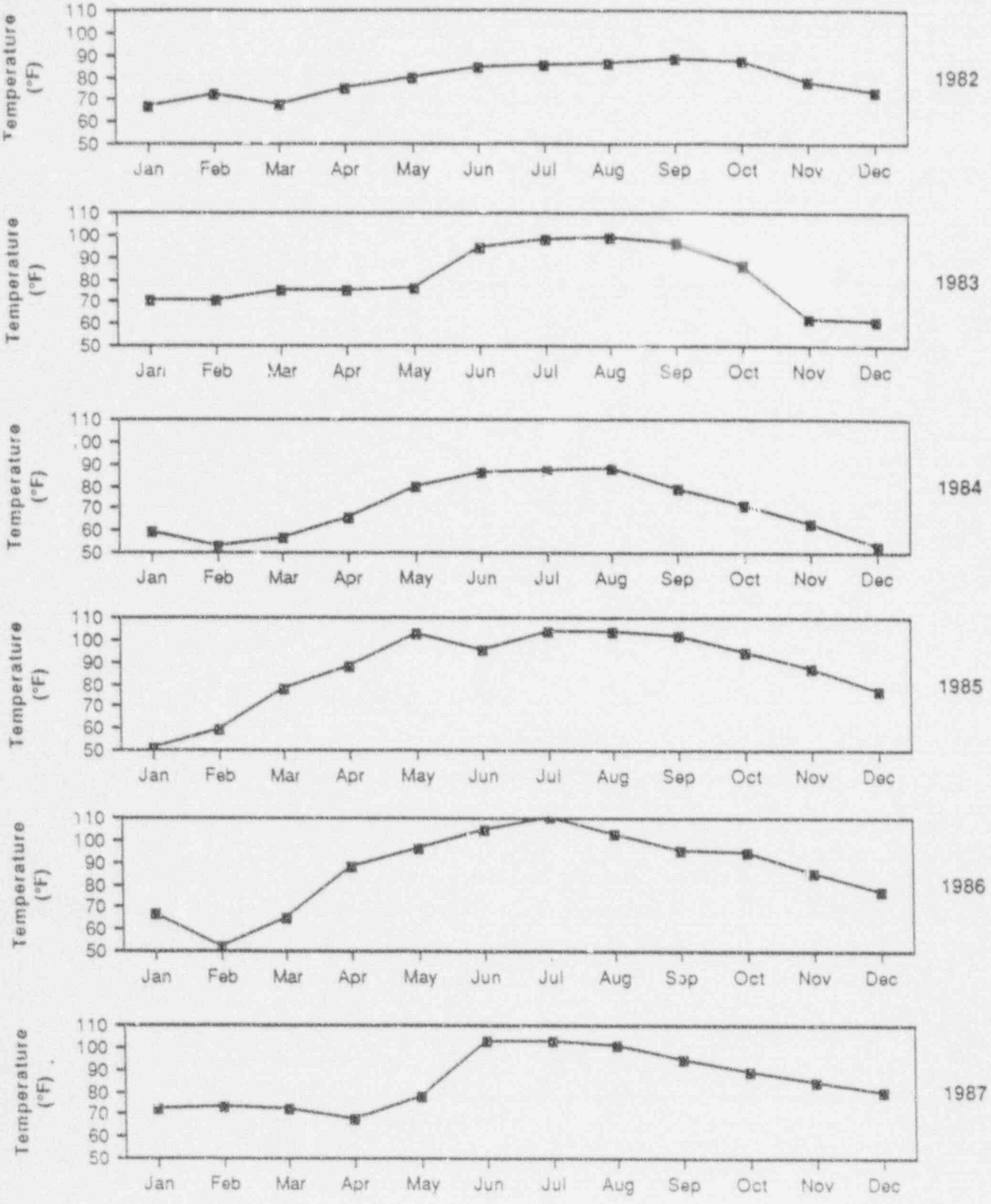


Figure 3. Monthly average discharge temperatures at Robinson Impoundment, 1976-1987.



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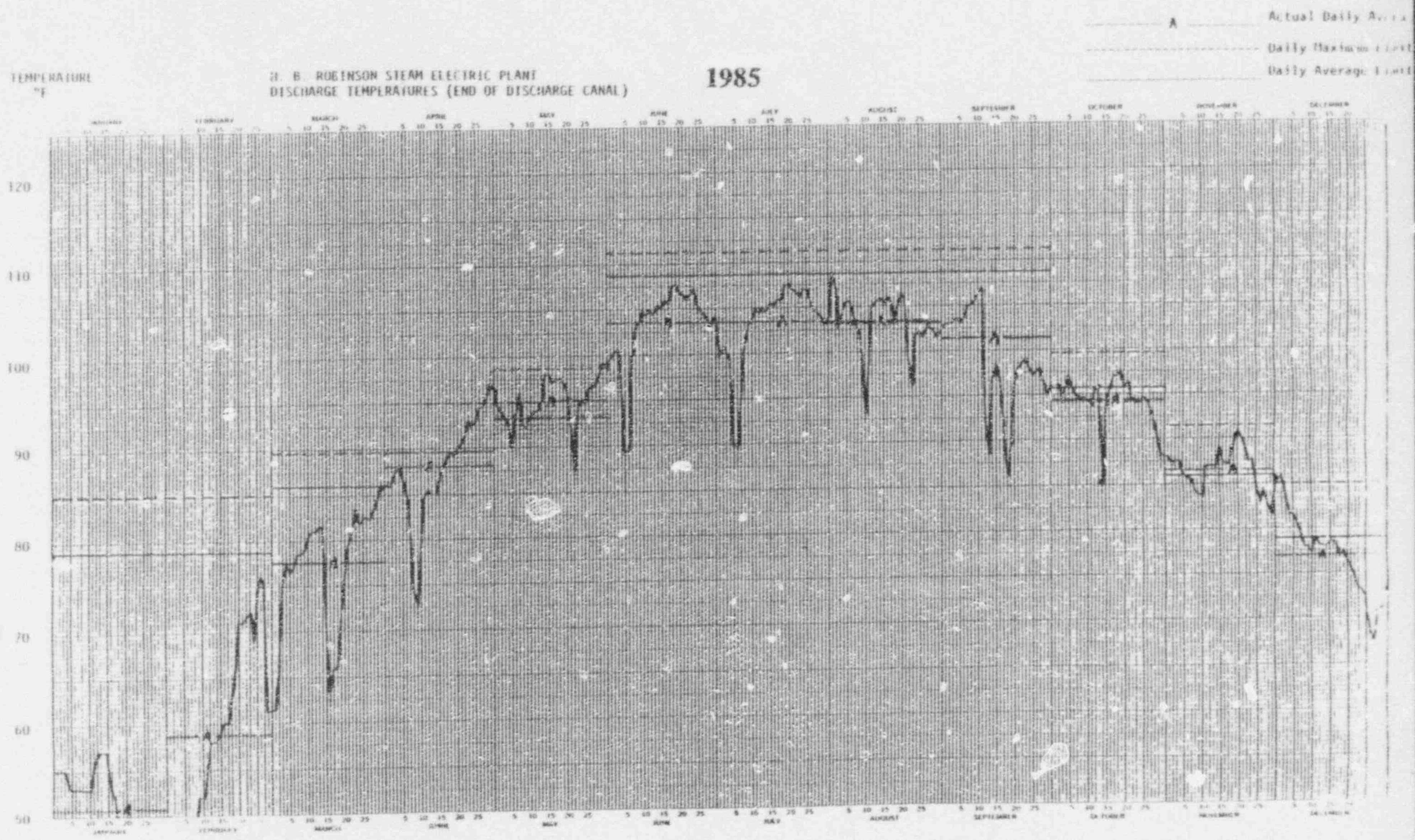


Figure 4. Actual daily discharge temperature and permit limits for the H. B. Robinson Plant, 1985-1987.

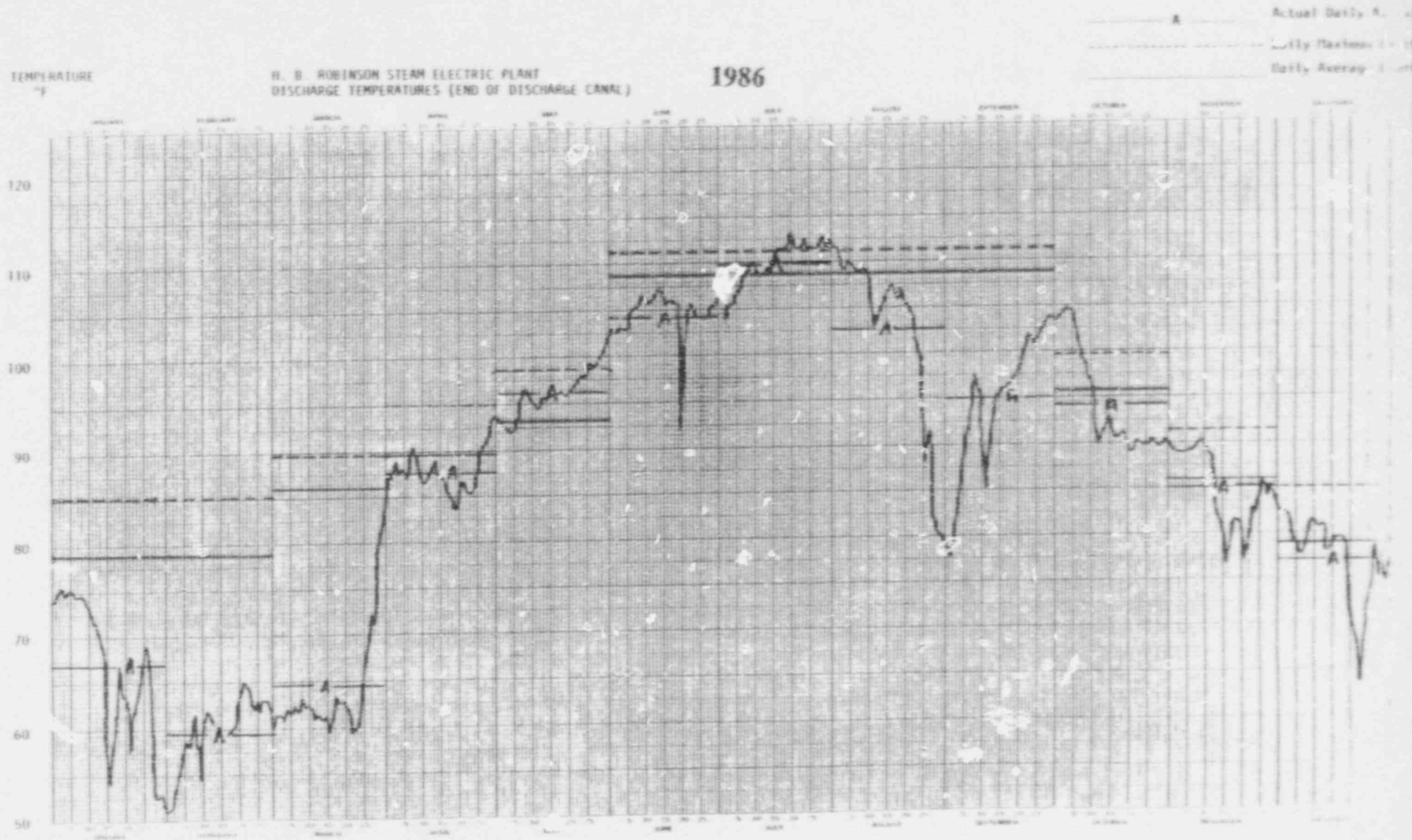


Figure 4. (Cont'd.)

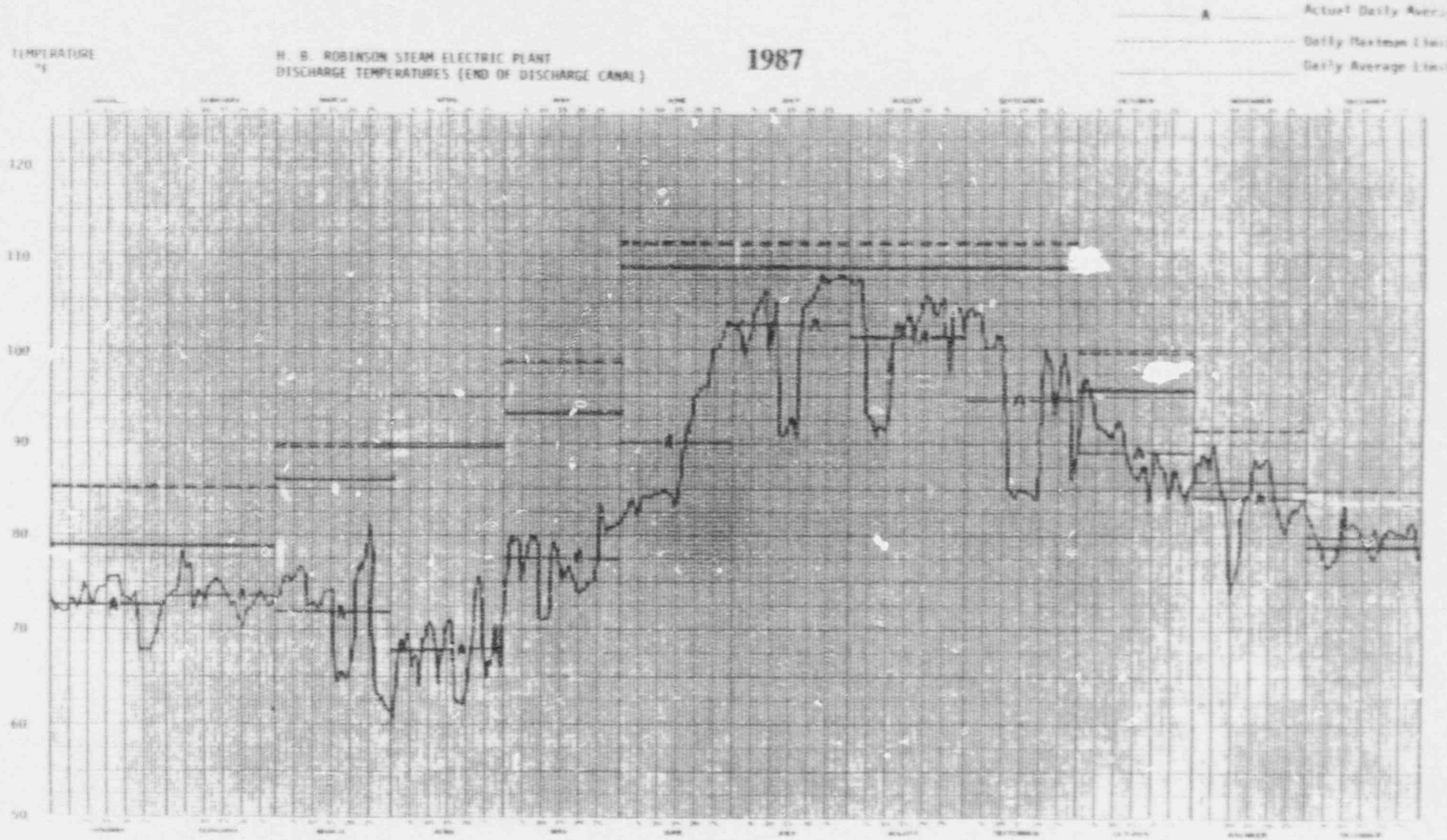


Figure 4. (Cont'd.)

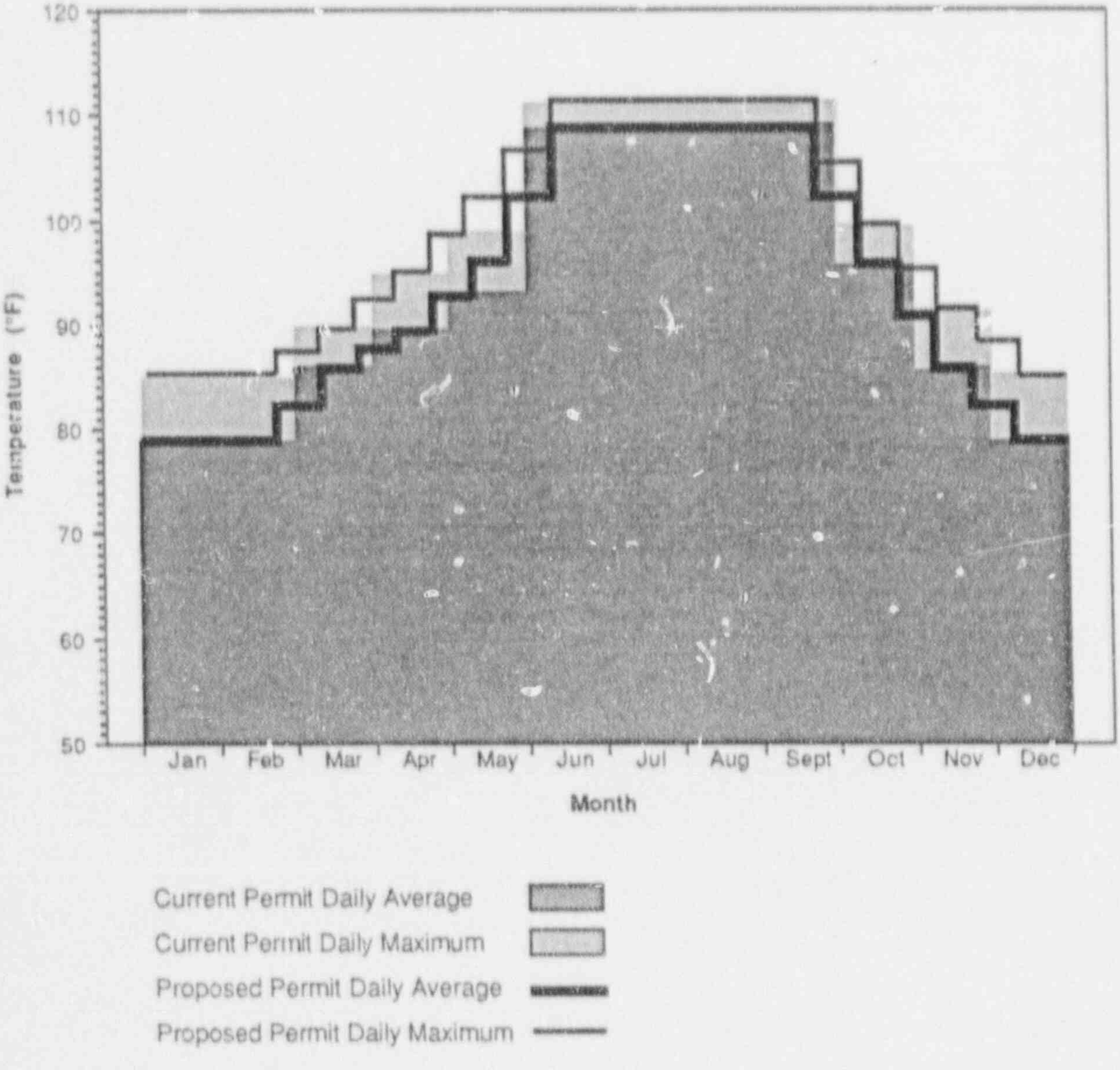
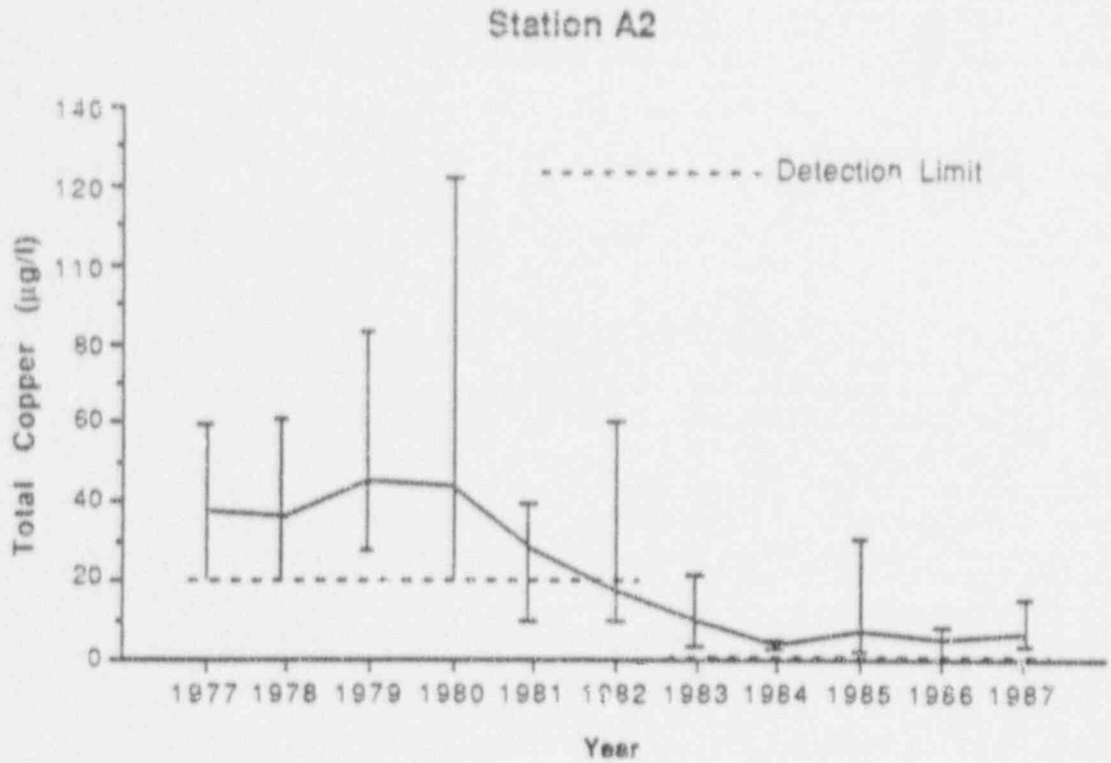


Figure 5. **Comparison of current NPDES permit temperature limits and proposed temperature limits.**



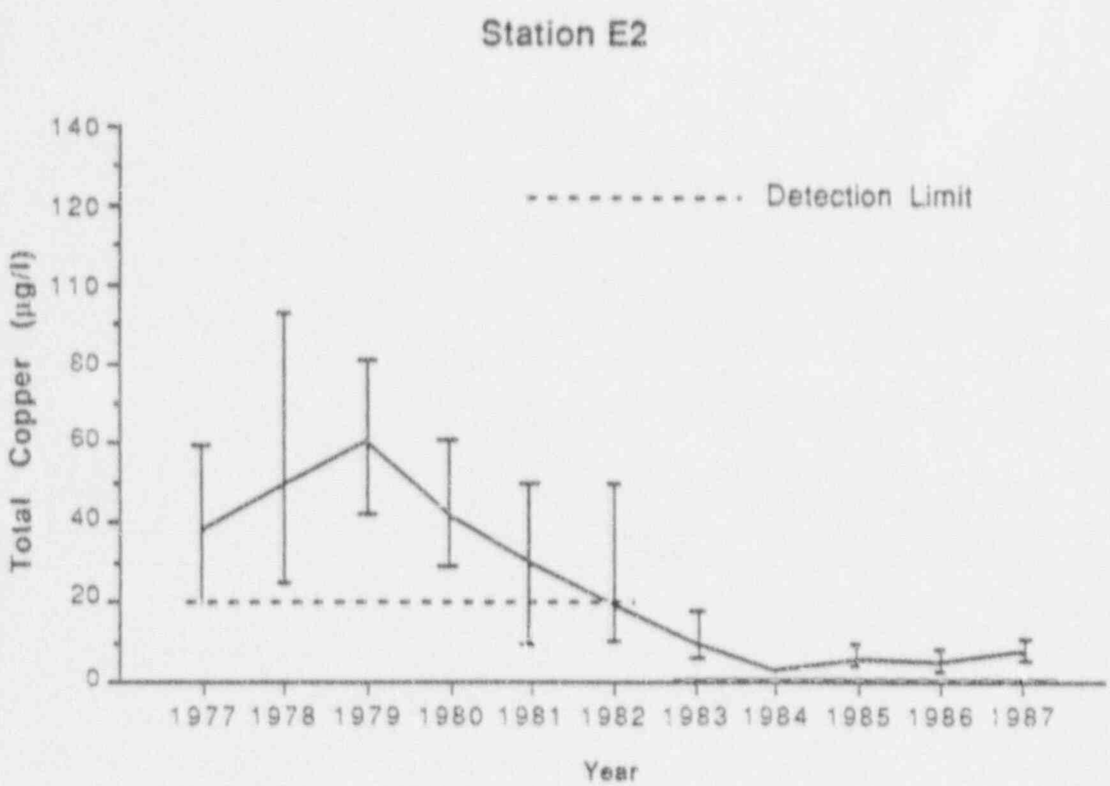


Figure 6. Mean copper concentrations in Robinson Impoundment, 1977-1987.

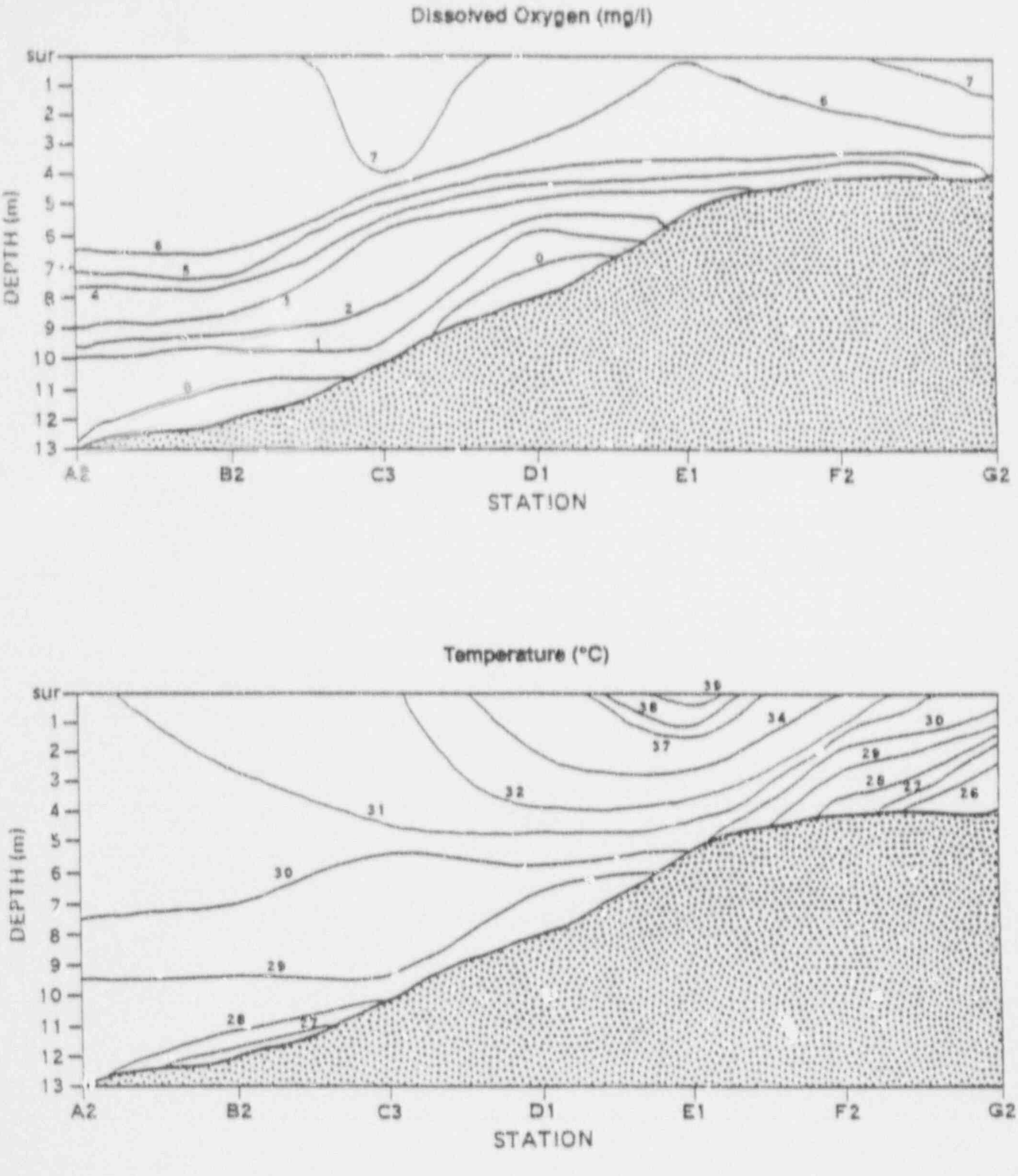
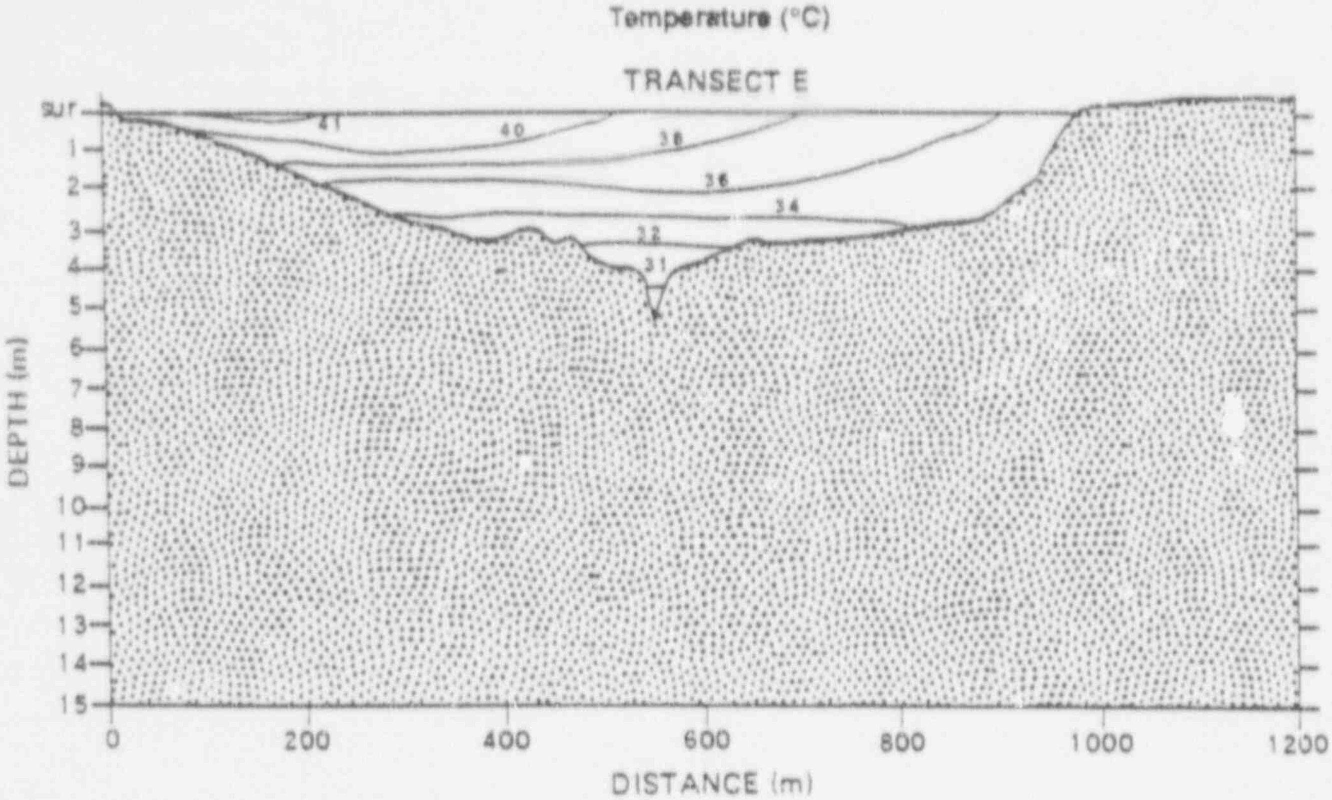


Figure 7. Temperature and dissolved oxygen in Robinson Impoundment, July 15, 1985.



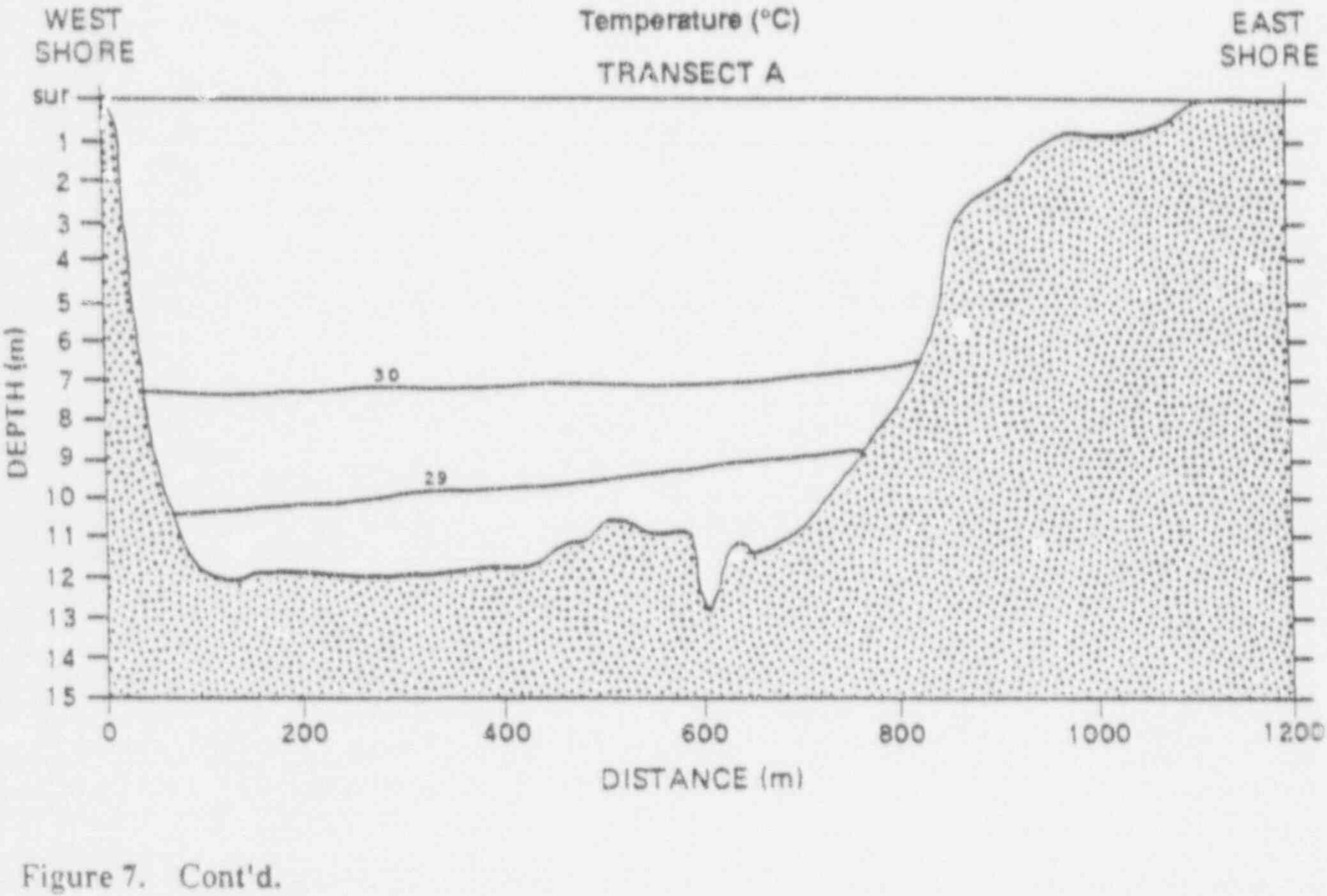


Figure 7. Cont'd.

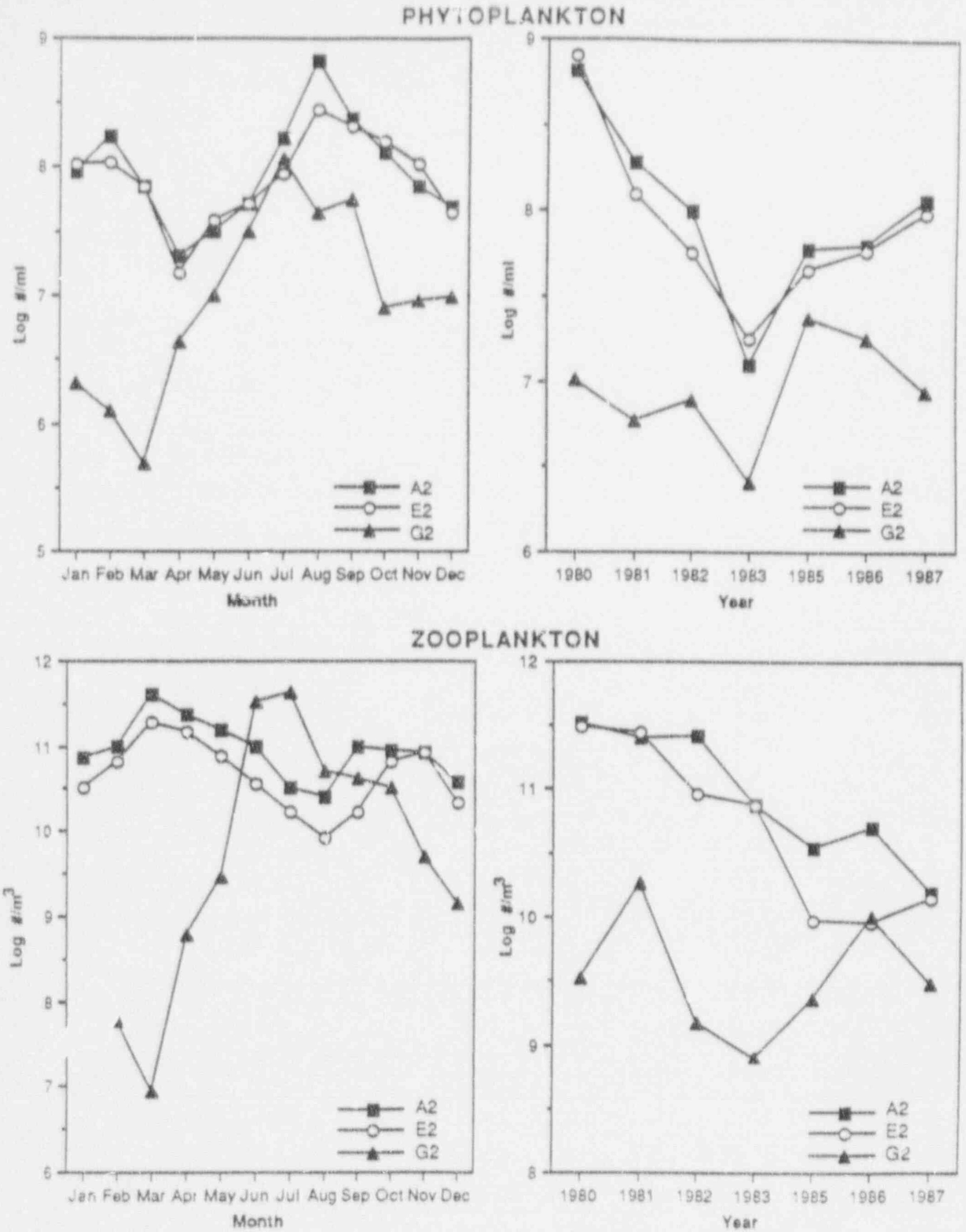


Figure 8. Phytoplankton and zooplankton density by month (all years combined) and year (all months combined) from Robinson Impoundment, 1980-1987.

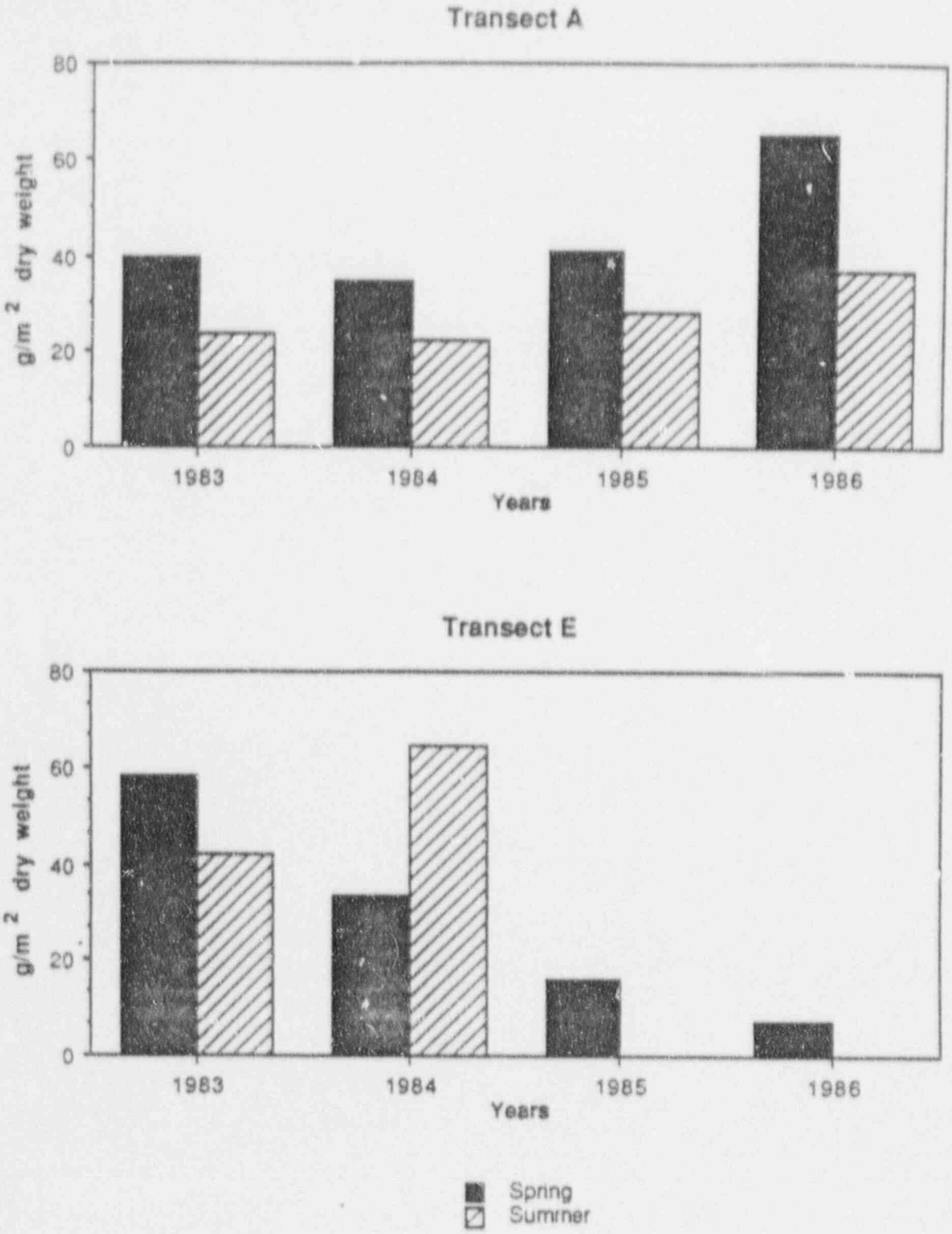


Figure 9. Biomass of *Eleocharis baldwinii* from Transects A and E in Robinson Impoundment, 1983-1986.

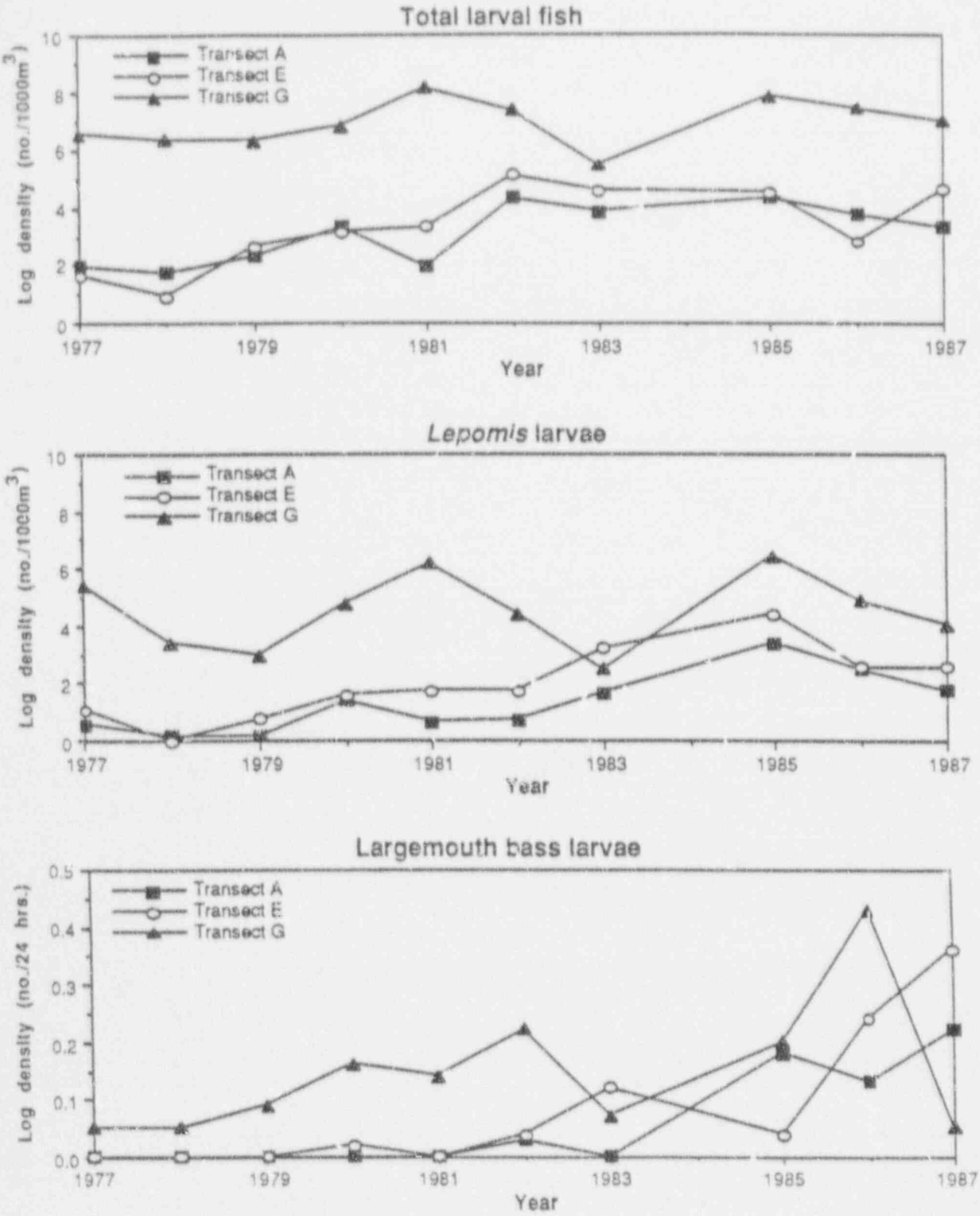
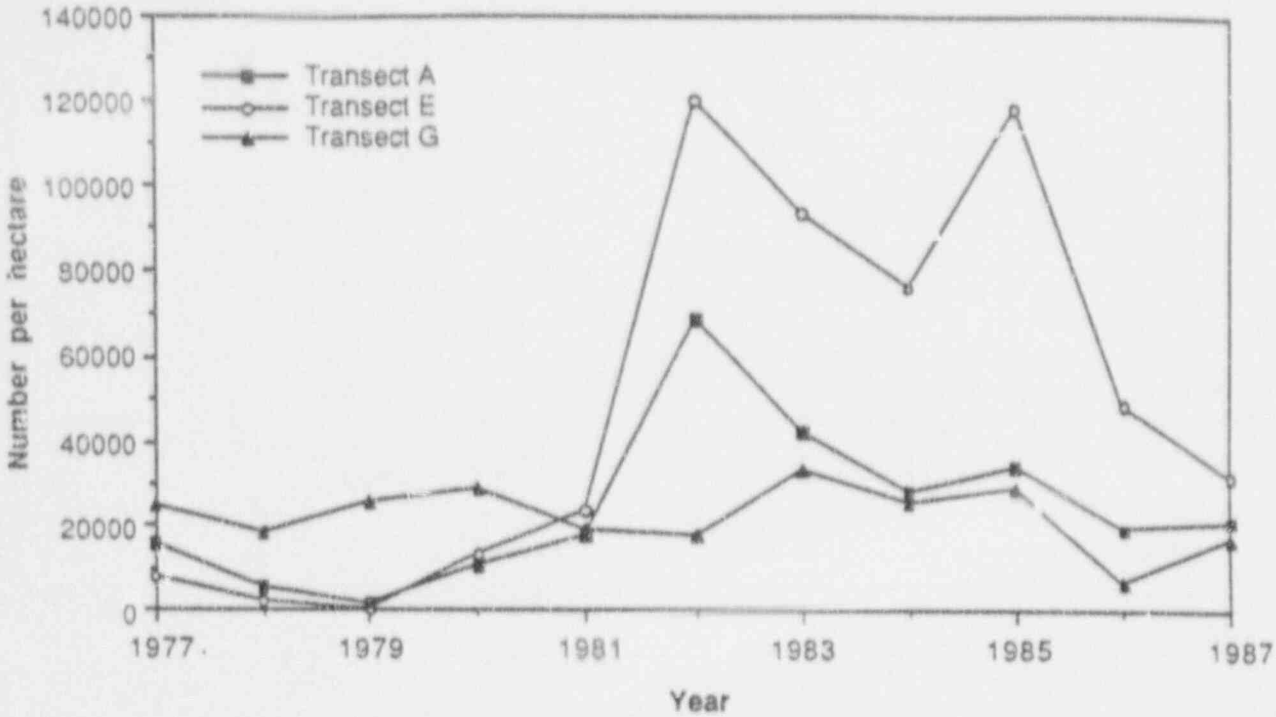


Figure 10. Mean log density of total larval fish, *Lepomis* larvae, and largemouth bass larvae in Robinson Impoundment, 1977-1987.



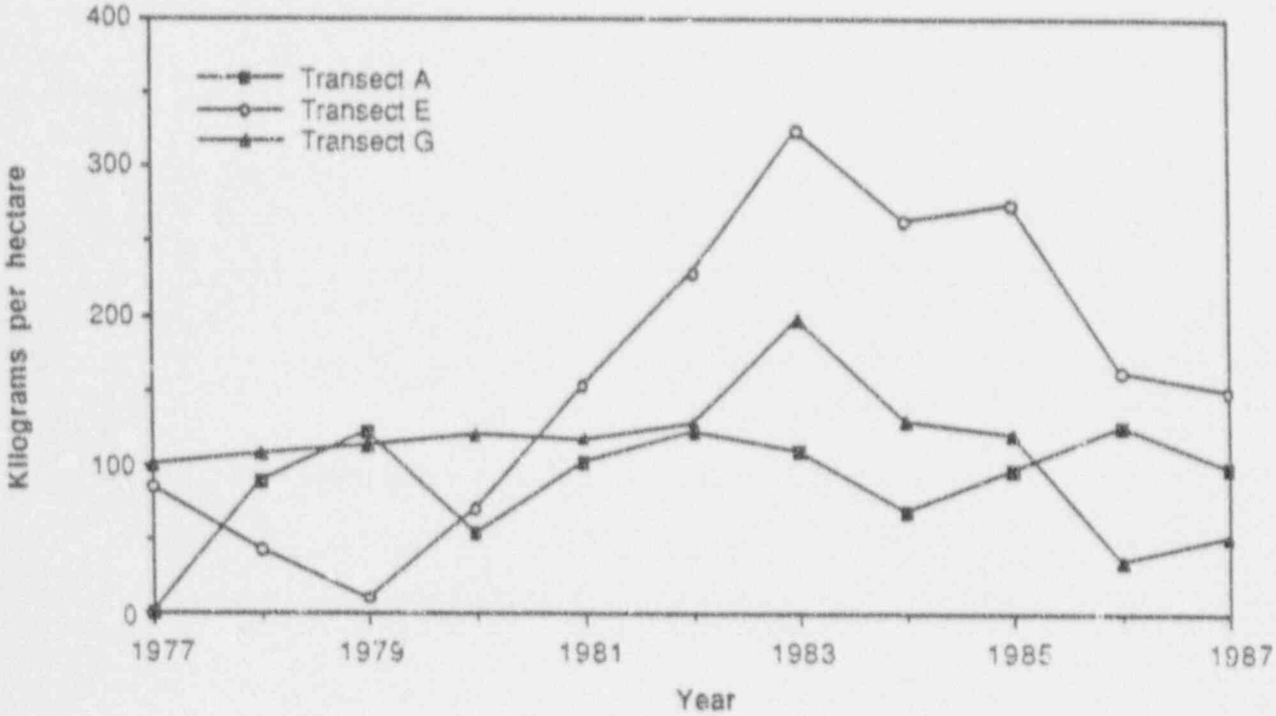


Figure 11. Total number and weight (Kg) per hectare of all fish by transect in Robinson Impoundment, 1977-1987.

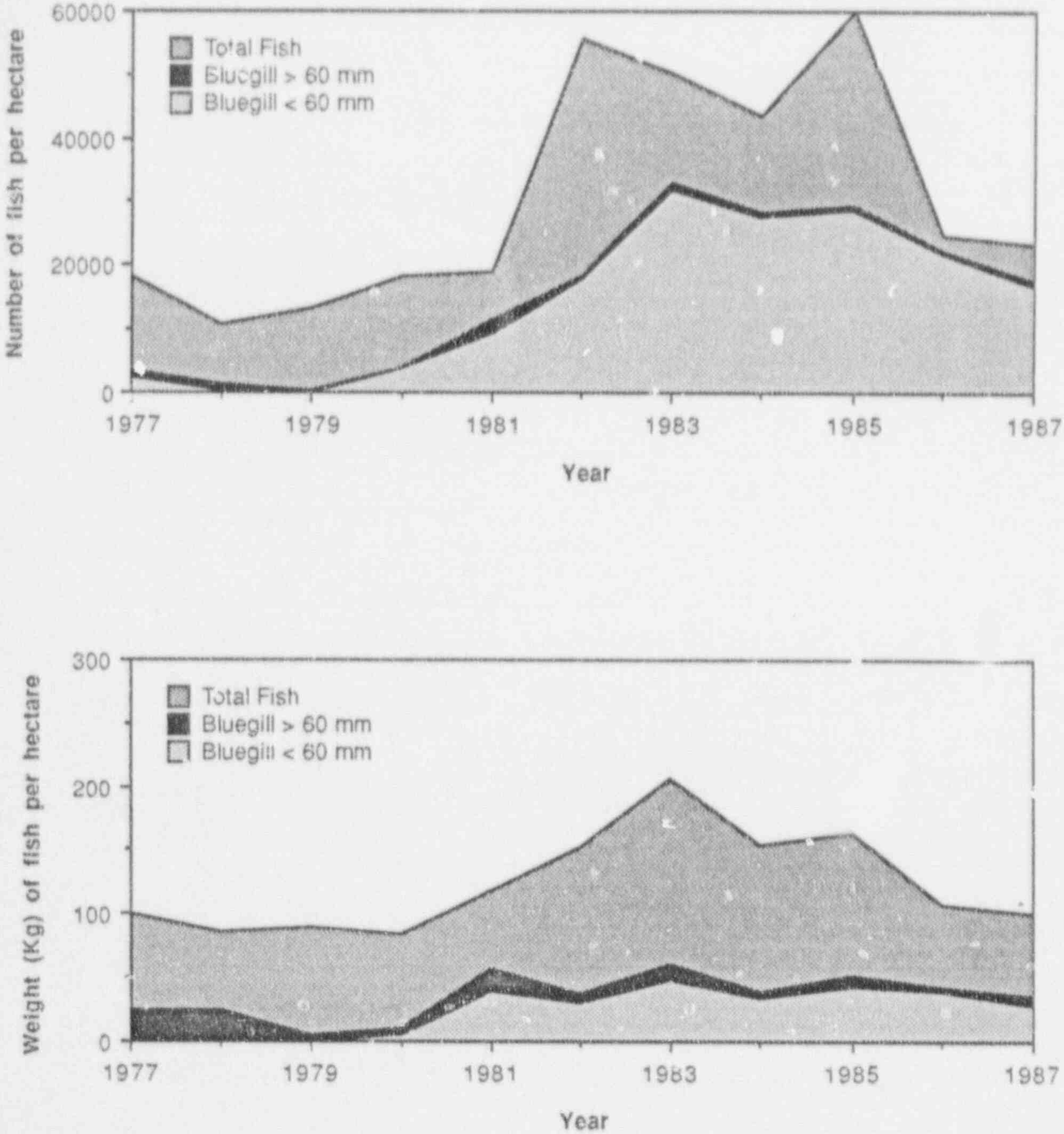


Figure 12. Total number (above) and weight (below) per hectare of all fish, bluegill > 60 mm, and bluegill < 60 mm from Robinson Impoundment, 1977-1987.

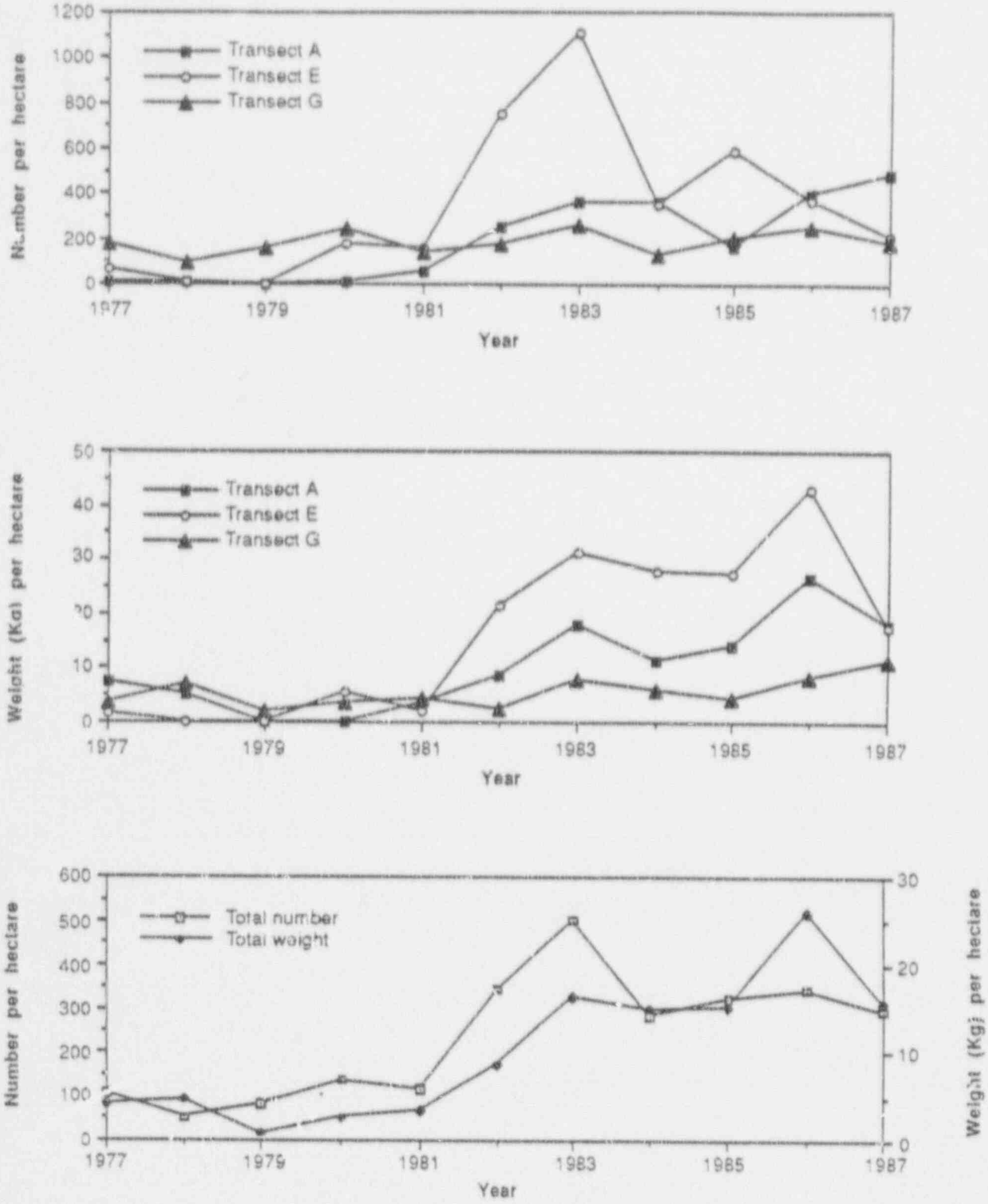


Figure 13. Total number and weight (Kg) per hectare of largemouth bass by transect and year in Robinson Impoundment, 1977-1987.

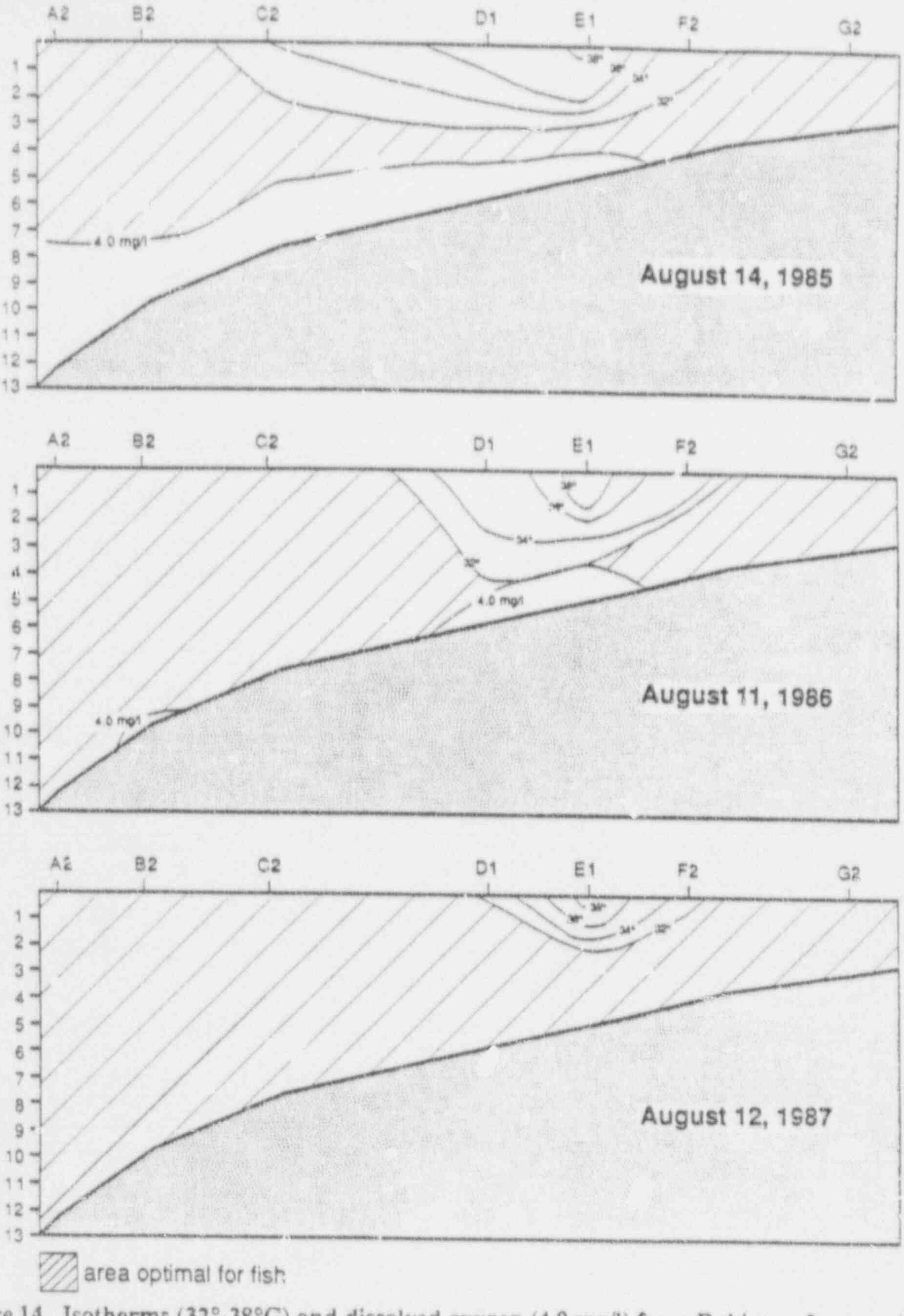


Figure 14. Isotherms (32°-38°C) and dissolved oxygen (4.0 mg/l) from Robinson Impoundment during August 1985, 1986, and 1987, indicating areas optimal for fish.