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IMPINGEMENT AND ENTRAINMENT OF FISHES AT THE SAVANNAH RIVER PLANT

AN NPDES 316b DEMONSTRATION

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT AT(07-2)-1

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by

R. W. McFarlane, R. F. Frietsche, and R. D. Miracle

Approved by

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Environmental Transport Division

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ABSTRACT

Environmental impacts of the Savannah River Plant's withdrawal of Savannah River water include impingement of juvenile and adult fish on trash removal screens, and entrainment of planktonic fish eggs and larval fish into the pumping system.

The Savannah River Plant (SRP) has the capacity to pump 3.6 million cubic meters of water per day — 25% of the minimal river discharge — for cooling and other purposes. Present removal is 7% of the actual river discharge.

In the river and intake canals reside sixty-nine species of fishes. The species composition of the resident fish community of the intake canals is similar to the species composition in the river, but different in relative species abundance. The dominant sunfishes tend to reside in the canals for long periods and seldom go from canal to canal.

The fish impingement rate at the plant ranks very low in comparison with electric power plants on inland waters. Thirty-five species of fishes were impinged during 1977. The average impingement rate of 7.3 fish per day extrapolates to 2,680 fish per year. No single species comprised more than 10% of the sample. The most commonly impinged species were bluespotted sunfish, warmouth, channel catfish, and yellow perch. The relative abundance of those species impinged deviates from their relative abundance in the canal fish population.

Assuming "worst case conditions," 6.8 million eggs (9.5%) and 19.6 million larvae (9.1%) were lost due to entrainment. An estimated 72 million fish eggs and 216 million fish larvae were transported past the cooling water intakes during spawning in April, May, and June. In samples of plankton, 96% of the fish eggs were American shad; and the fish larvae were of 22 species. The most common species were the blueback herring, spotted sucker, and black crappie.

In the absence of reliable fish data regarding the size of the spawning populations and recent population trends, the effect of a maximum 10% loss cannot be estimated.

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IMPINGEMENT AND ENTRAINMENT OF FISHES AT THE SAVANNAH RIVER PLANT: AN NPDES 316b DEMONSTRATION

INTRODUCTION

This report discusses the environmental impact on the fishes of the Savannah River caused by the removal of river water for operation of the Savannah River Plant (SRP). The SRP has the capacity to remove 3.6 million cubic meters of water for cooling and other purposes (25% of the minimum river discharge). Present pumping operations remove 7% of the average daily river discharge.

This 316b Demonstration was prepared for submission to the Administrator for Region IV of the Environmental Protection Agency as required by National Pollution Discharge Elimination System Permit SC0000175. The objective of this report is to demonstrate the adequacy of the Savannah River Plant (SRP) cooling-water intake structures to meet the requirements of Section 316b of the Federal Water Pollution Control Act.

Three general categories of information are provided in this report:

- Plant operating data which describe the cooling water requirements, river discharge, intake structure configuration, and water flow patterns
- Physical environment data which characterize the Savannah River at the SRP site and data which include seasonal variations in the river's discharge
- Biological data which describe the fish community susceptible to impact during cooling-water withdrawal, and data which quantify the impingement of juvenile and adult fishes and the entrainment of fish eggs and larval fishes

The SRP is on the middle reach of the Savannah River where it withdraws cooling water for nuclear production reactors, fossil fuel steam and electric generators, and other facilities. The flow characteristics of the Savannah River at SRP are controlled by the effects of four dams upstream of SRP, particularly the Clark Hill dam and reservoir operated by the U.S. Corps of Engineers. These dams, the SRP, and gauging stations are shown in Figure 1.

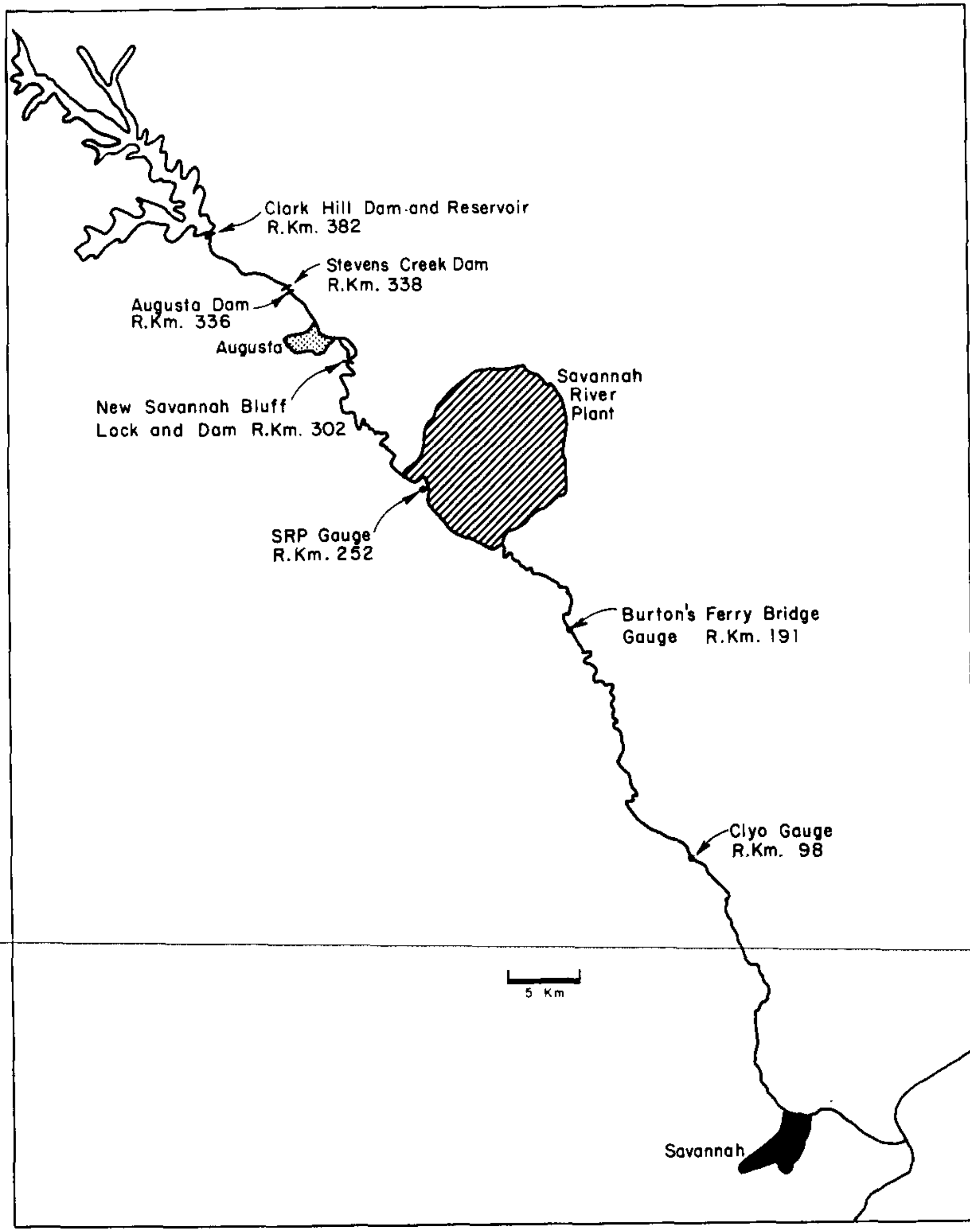


FIGURE 1. The Savannah River and Selected Reference Points

1. PLANT OPERATING DATA

1.1 Cooling Water Requirements

The Savannah River Plant operates three pumping stations on the Savannah River. Two of these, designated 1G and 3G, are identical ten-pump units each located at the terminus of a long intake canal. The third station, 5G, operates six smaller pumps on a small inlet cove of the river. (The relative locations of the pumping stations are shown in Figure 2.)

The rated capacities of the pumping stations are given in Table 1. Two of the original ten pumps at the 1G station are no longer functional. Operation of any of these pumping stations at maximum capacity is rare under current requirements.

Data for the rate of river discharge, cooling water withdrawal, and the fraction of total river discharge which this withdrawal represents for the years 1974-1976 are presented in Table 2. The annual variation in these parameters is more apparent in Figure 3. The statistics for this monthly data are given in Table 3. The data for each of the three years were tested by analysis of variance to check for significant year-to-year variations. No significant differences were found, and these data are considered to be representative of current operational conditions.

Daily variation in the rate of river discharge and cooling water withdrawal for 1977 is shown in Figure 4. Withdrawal figures are based on combined 1G and 3G pumping station data. Daily rates for the 5G station are not available. The frequency distribution of daily withdrawal rates is distinctly bimodal, with the primary mode at 23.8 m^3/sec, and the secondary mode at 13.8 m^3/sec. This bimodality is also apparent in Figure 4 and most likely reflects the cooling requirements of one versus two nuclear reactors.

The U.S. Corps of Engineers attempts to maintain a minimum flow of 170 m^3/sec at the Savannah River Plant. Under worst case conditions (minimum river discharge and maximum withdrawal), the removal of the full 41.6 m^3/sec rated capacity would consume 24.5 percent of the river discharge. The maximum fraction of available monthly river discharge which was withdrawn for cooling water during 1974-76 was 12% (Table 2). The maximum withdrawal (September 1975) during this period represented 63% of maximum (nominal) pumping capacity.

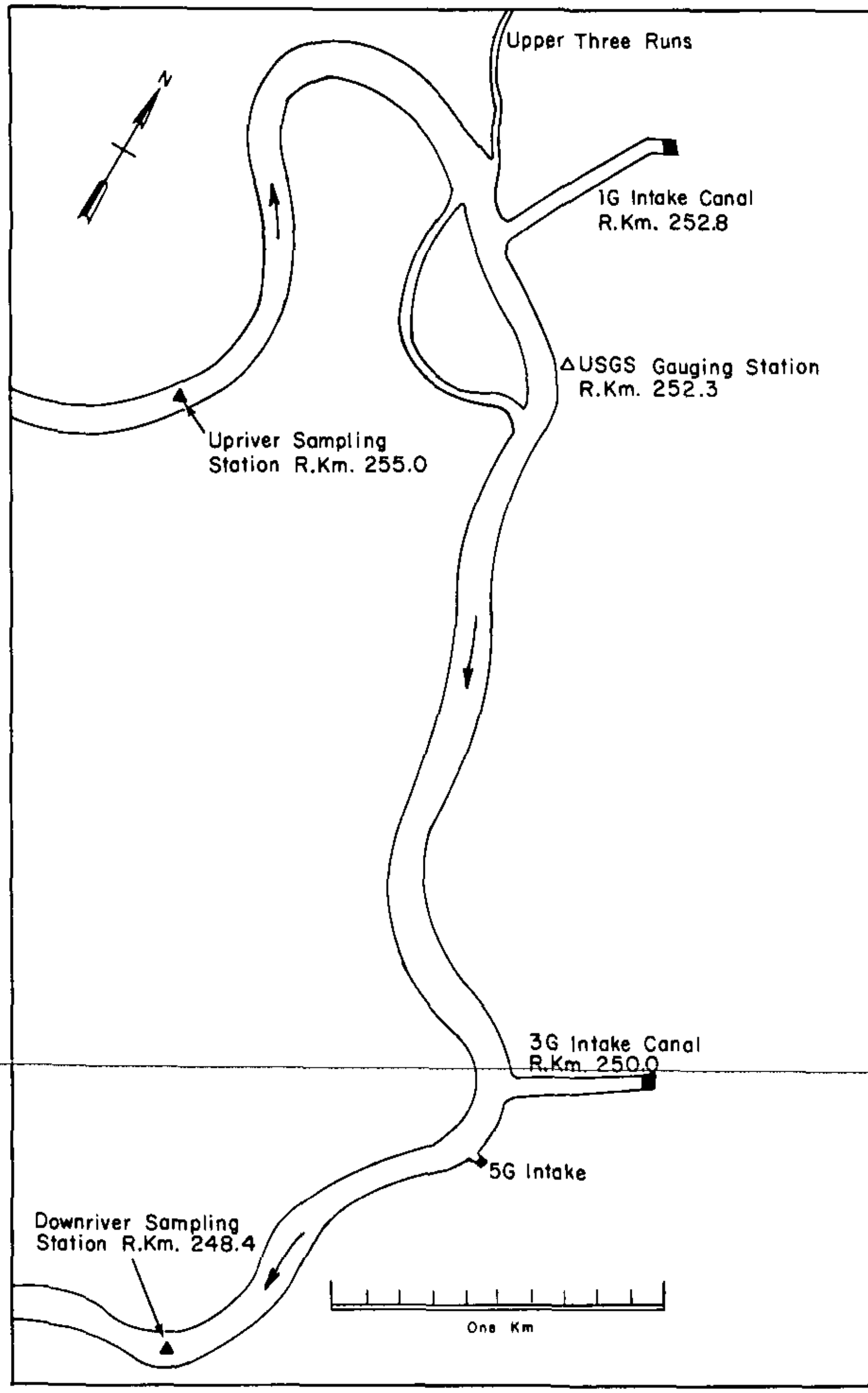


FIGURE 2. SRP Pumping and Sampling Stations

TABLE 1

Savannah River Plant Pumping Station Capacities

Pumping Station	*Number of Pumps*	*Rated Pump Capacity, gal/min*	*Maximum Sustained Station Flow* m^3/sec	*Maximum Sustained Station Flow* $m^3 \times 10^6/day$
1G	8	32,500	16.4	1.4
3G	10	32,500	20.5	1.8
5G	6	12,500	4.7	0.4
	Total SRP Capacity		41.6	3.6

TABLE 2

Rate of Cooling Water Withdrawal and River Discharge
(Cubic meters per second)

		Pumping Station 1G	3G	5G	*Total*	*River Discharge*	*Percent of Discharge Withdrawn*
1974	Jan	6.74	16.66	0.79	24.19	480.3	5.0
	Feb	6.44	15.57	0.84	22.85	544.3	4.2
	Mar	7.00	17.16	1.17	25.33	270.1	9.4
	Apr	6.14	11.69	1.21	19.04	367.0	5.2
	May	7.32	16.89	1.40	25.61	230.0	11.1
	Jun	6.83	15.80	1.80	24.43	205.2	11.9
	Jul	6.75	15.96	1.51	24.22	206.6	11.7
	Aug	4.19	11.86	1.61	17.66	236.9	7.5
	Sep	4.39	9.29	1.67	15.35	214.0	7.2
	Oct	2.95	7.36	2.18	12.49	204.1	6.1
	Nov	4.46	10.37	1.96	16.79	205.3	8.2
	Dec	4.43	10.28	1.52	16.23	209.7	7.7
1975	Jan	3.37	8.05	1.76	13.18	363.6	3.6
	Feb	4.86	8.93	1.30	15.09	507.1	3.0
	Mar	5.24	9.79	1.61	16.64	529.3	3.1
	Apr	5.29	11.25	1.74	18.28	477.5	3.8
	May	6.83	14.62	1.91	23.36	394.5	5.9
	Jun	8.24	9.11	2.33	19.68	279.1	7.1
	Jul	2.85	4.86	2.33	10.04	245.1	4.1
	Aug	10.44	13.08	2.00	25.52	212.5	12.0
	Sep	10.65	13.33	2.09	26.07	232.1	11.2
	Oct	7.28	12.44	2.05	21.77	332.8	6.5
	Nov	7.33	16.32	1.47	25.12	412.6	6.1
	Dec	7.65	15.08	1.09	23.82	384.9	6.2
1976	Jan	7.63	12.49	0.80	20.92	374.4	5.6
	Feb	5.88	14.93	1.13	21.94	329.6	6.7
	Mar	16.02	2.70	1.10	19.82	400.6	4.9
	Apr	8.90	12.66	1.42	22.98	374.8	6.1
	May	6.61	13.94	1.76	22.31	318.2	7.0
	Jun	8.31	14.08	2.11	24.50	417.7	5.9
	Jul	7.39	13.49	2.15	23.03	396.4	5.8
	Aug	7.48	13.35	1.68	22.51	209.5	10.7
	Sep	8.39	14.95	1.50	24.84	217.9	11.4
	Oct	6.62	12.43	1.51	20.56	245.7	8.4
	Nov	5.46	.47	1.12	13.05	238.7	5.5
	Dec	5.54	12.37	1.17	19.08	720.7	2.6

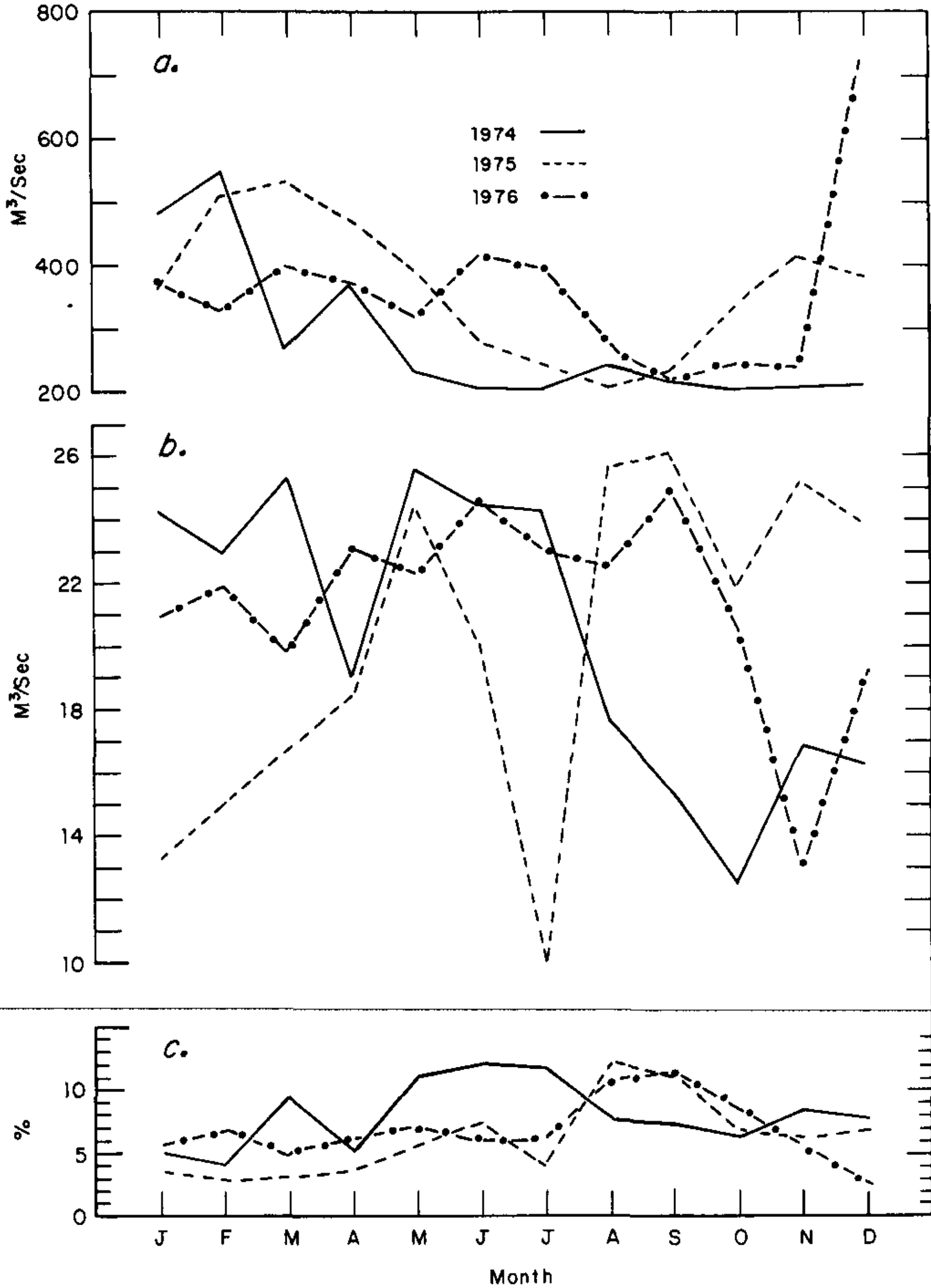


FIGURE 3. The Relationship Between (a) River Discharge, (b) Cooling Water Withdrawn, and (c) Percent of Discharge Withdrawn

TABLE 3

Monthly Averages for River Discharge and Cooling Water Withdrawal
(Cubic meters per second)

River Discharge	*Months*	*Mean*	*Std. Dev.*	*Coef. Var.*	*F**
1974	12	281.13	113.139	40.3	
1975	12	364.26	102.908	28.3	1.65
1976	12	353.68	132.176	37.4	
3 yr total	36	333.02	122.416	36.8	
Cooling Water Withdrawn					
1974	12	20.35	4.382	21.5	
1975	12	19.88	5.054	25.4	0.32
1976	12	21.30	2.991	14.1	
3 yr total	36	20.48	4.241	20.7	
Percent of Discharge Withdrawn					
1974	12	7.9	2.52	31.8	
1975	12	6.0	2.83	46.8	1.52
1976	12	6.7	2.34	34.8	
3 yr total	36	6.9	2.69	39.0	

* Analysis of variance F (for 0.95 level of significance and 2 and 33 degrees of freedom) = 3.29. Lesser numbers indicate no significant difference.

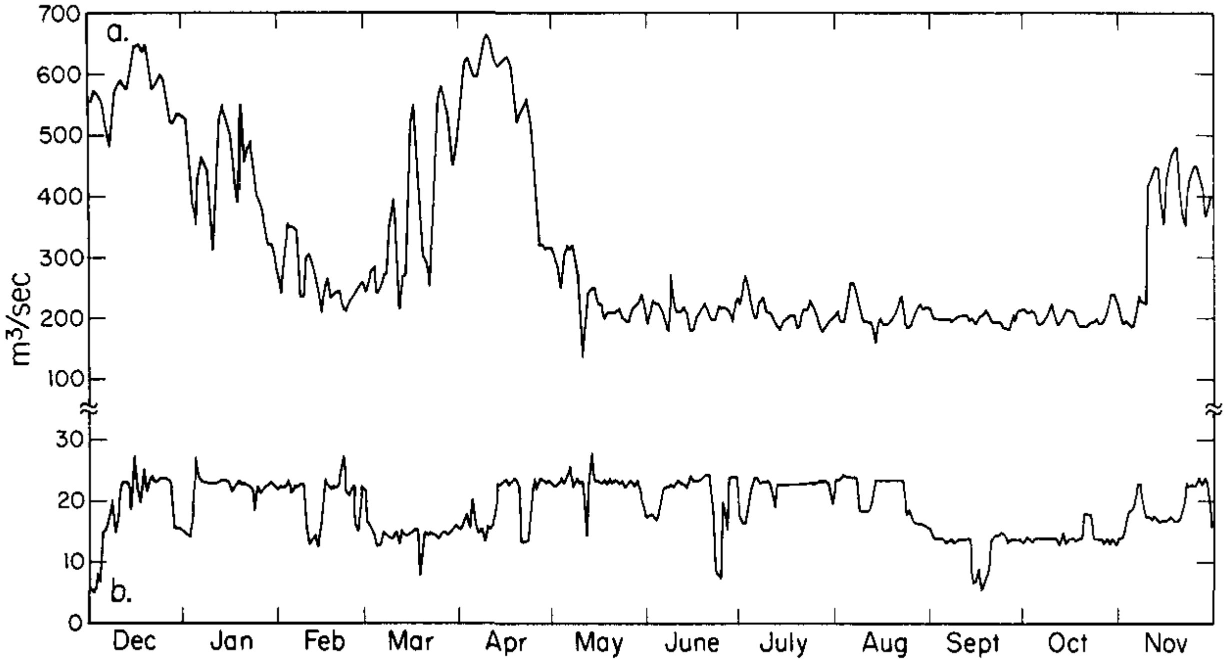


FIGURE 4. Daily Variation in River Discharge (a) and Cooling Water Withdrawal (b) from December 1, 1976 to November 30, 1977

1.2 Cooling Water Intake Structures

The general orientation of the pumping stations and intake canals to the Savannah River are shown in Figure 5.

The 1G intake canal is 550 m long with a broad, shallow cross-sectional profile (Figures 6, 7, and 8). The Savannah River fluctuates 4.3 m in elevation above sea level seasonally and the width of the canal thus varies from 30 to 70 m in response to river level, with a minimum depth of 2 m.

The 3G intake canal is 410 m long with a broad, shallow cross-sectional profile similar to 1G at low river elevations (Figures 9, 10, and 11). A more extensive berm permits greater lateral expansion at high water and width varies from 27 to more than 90 m, with a minimum depth of 2 m.

The 5G intake is located on a small cove 12 m wide and 20 m from the river to the trash gate on the pumphouse (Figures 12 and 13). The minimum depth of the cove is 2 m.

Water enters the 1G and 3G pumphouses through individual bays for each pump (Figures 14, 15, 16, and 17). The water is drawn from each bay via a 1.8 × 3.0 m rectangular gate in a lower rear corner of the bay, passes through a vertical trash screen, and enters the conduit to the pump. Water entering the 5G pumphouse passes through a vertical traveling screen and enters a bay where three pumps concertedly remove it (Figures 18 and 19).

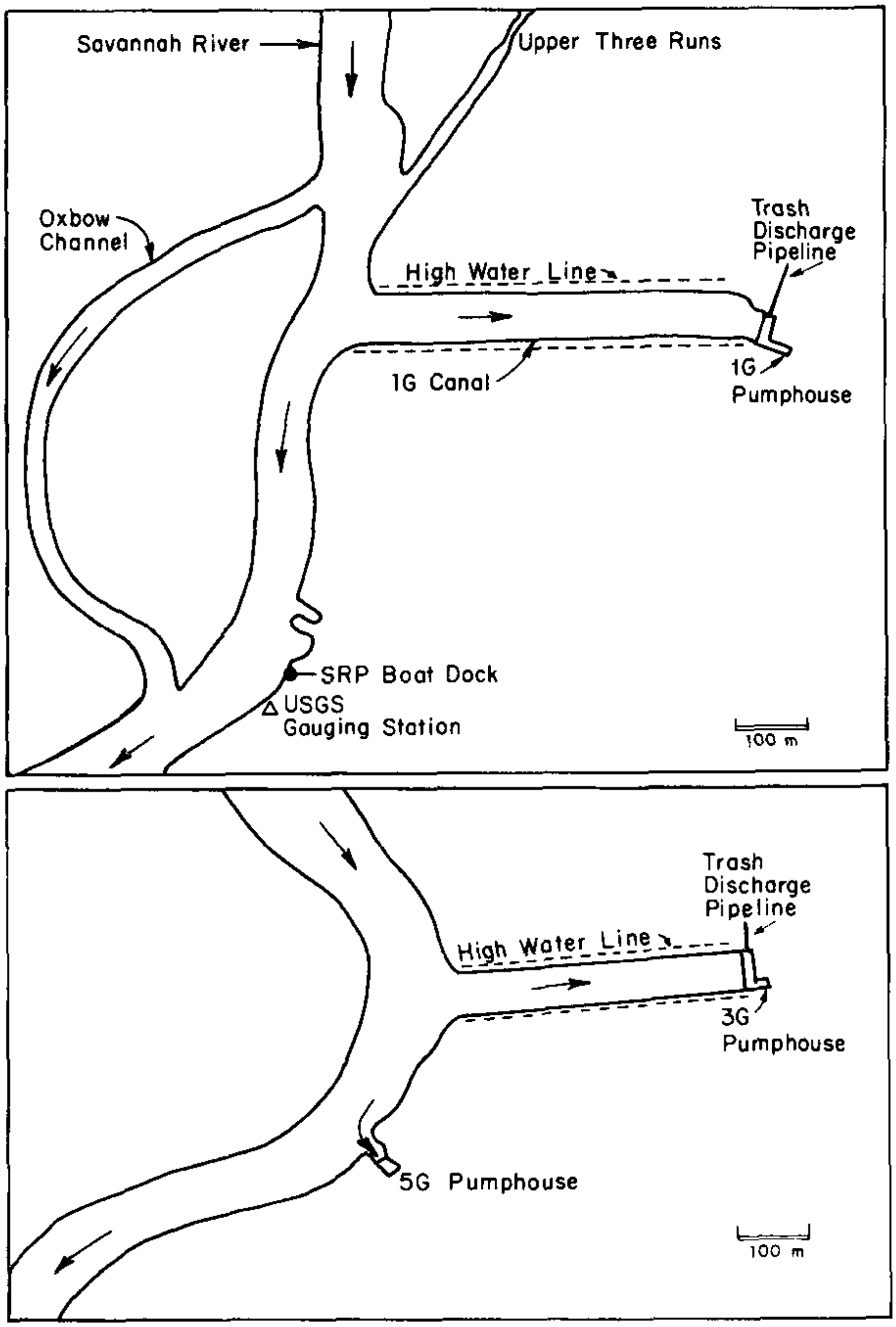


FIGURE 5. SRP Pumping Stations and Nearby Reference Points

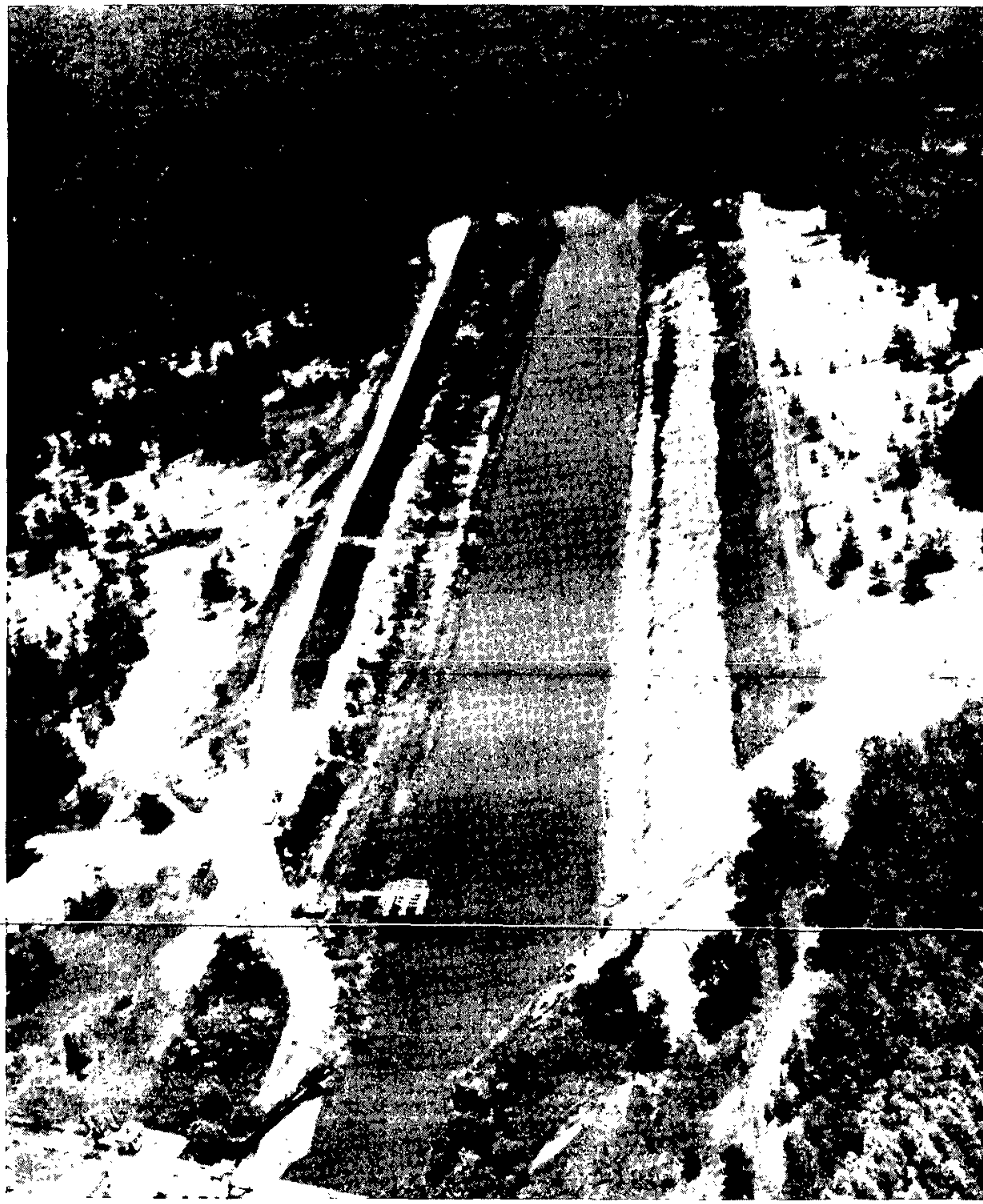


FIGURE 6. Aerial View of the 1G Intake Canal

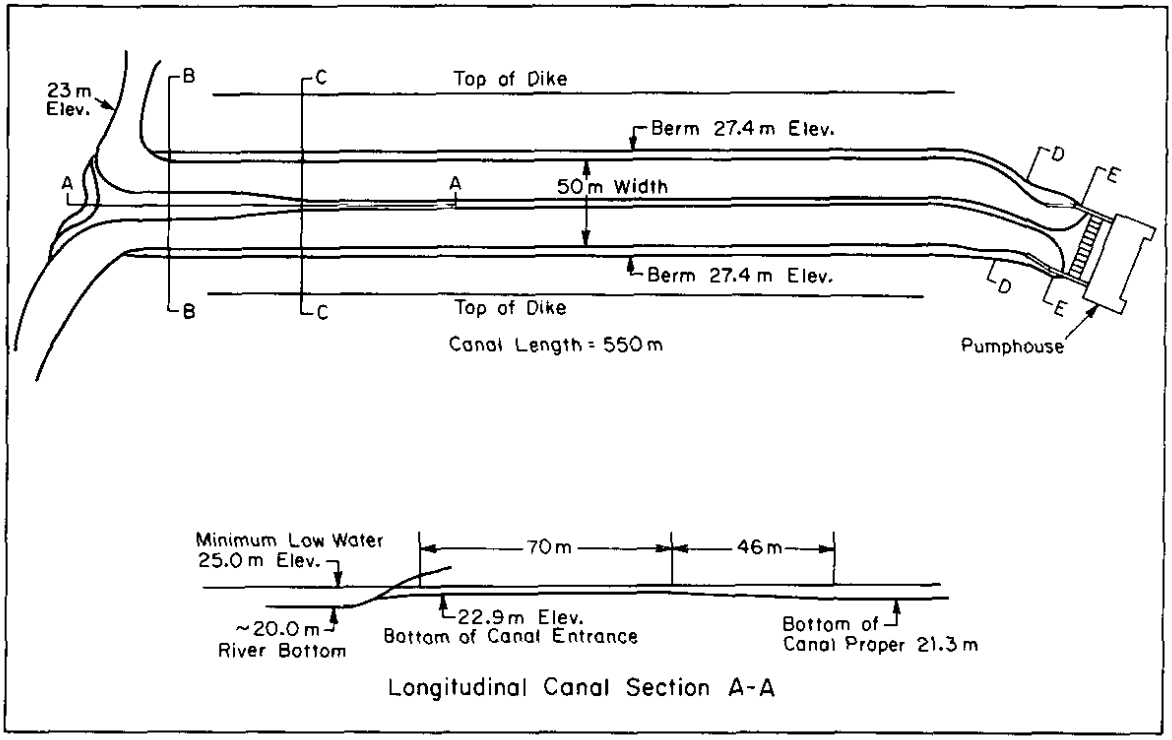


FIGURE 7. Plan View and Longitudinal Section of Entrance of 1G Canal

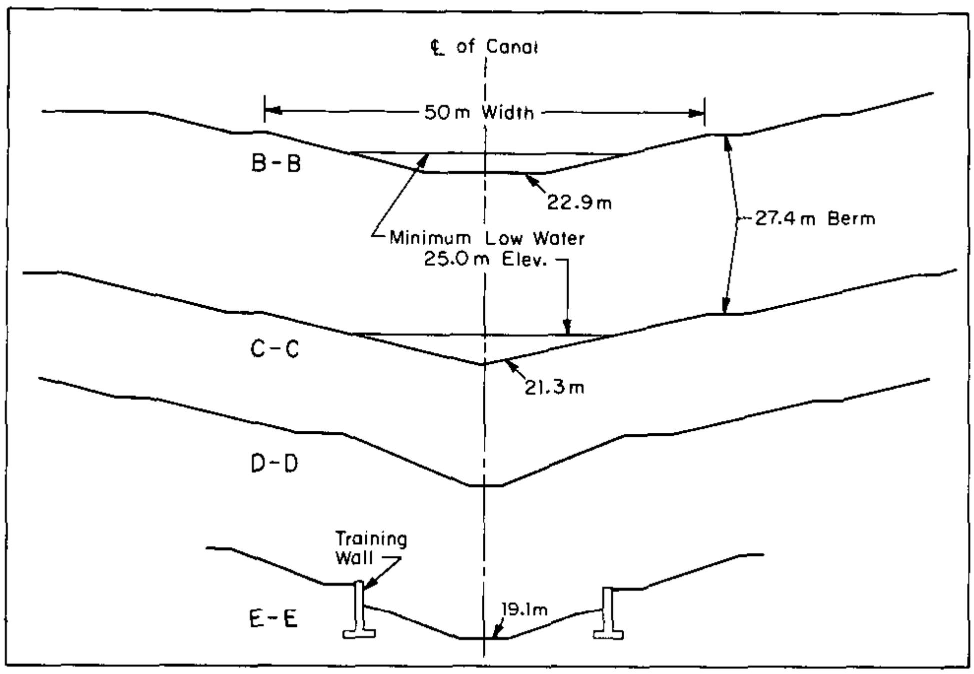


FIGURE 8. Cross Sections of 1G Canal at Points Designated in Figure 7

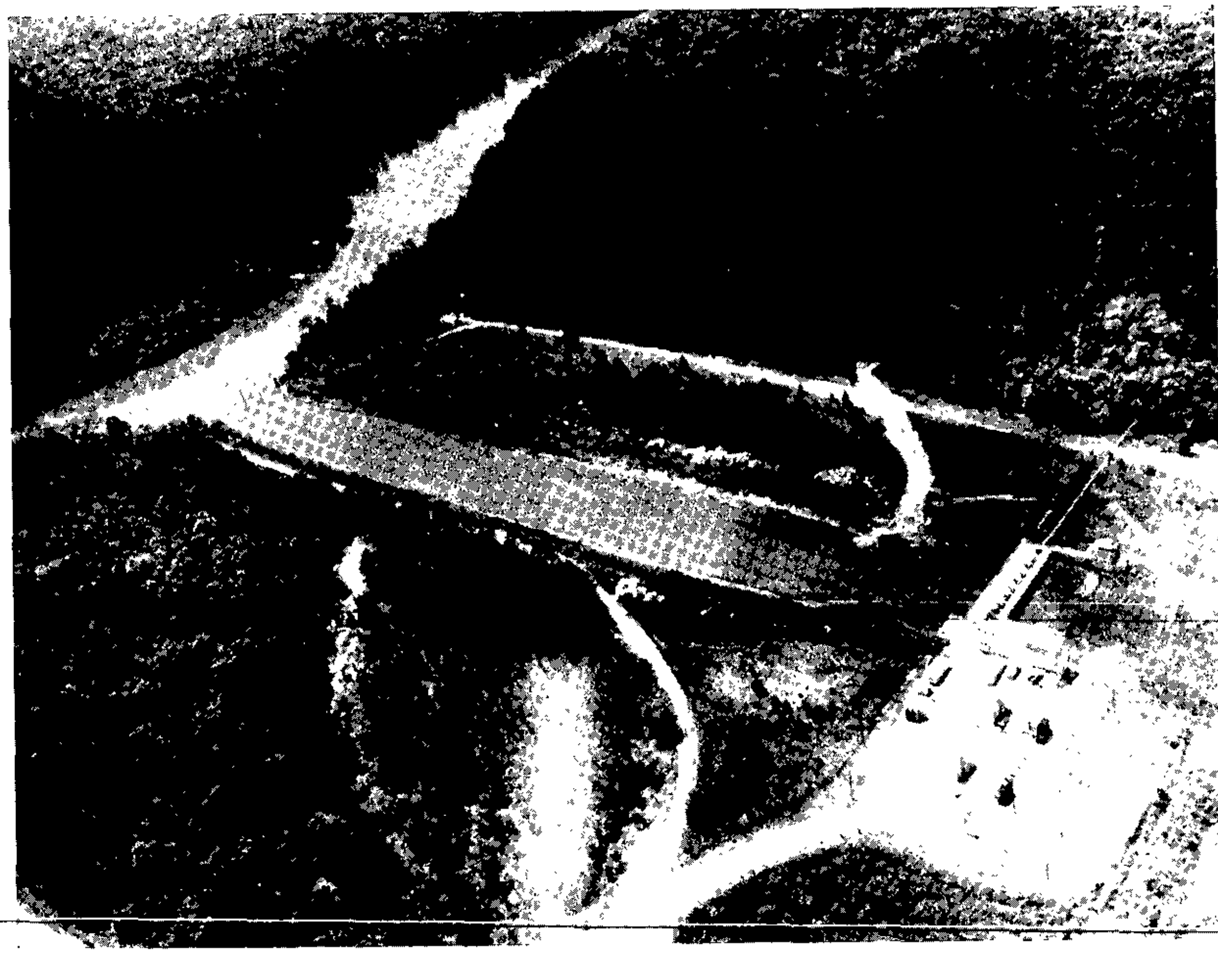


FIGURE 9. Aerial View of the 3G Intake Canal

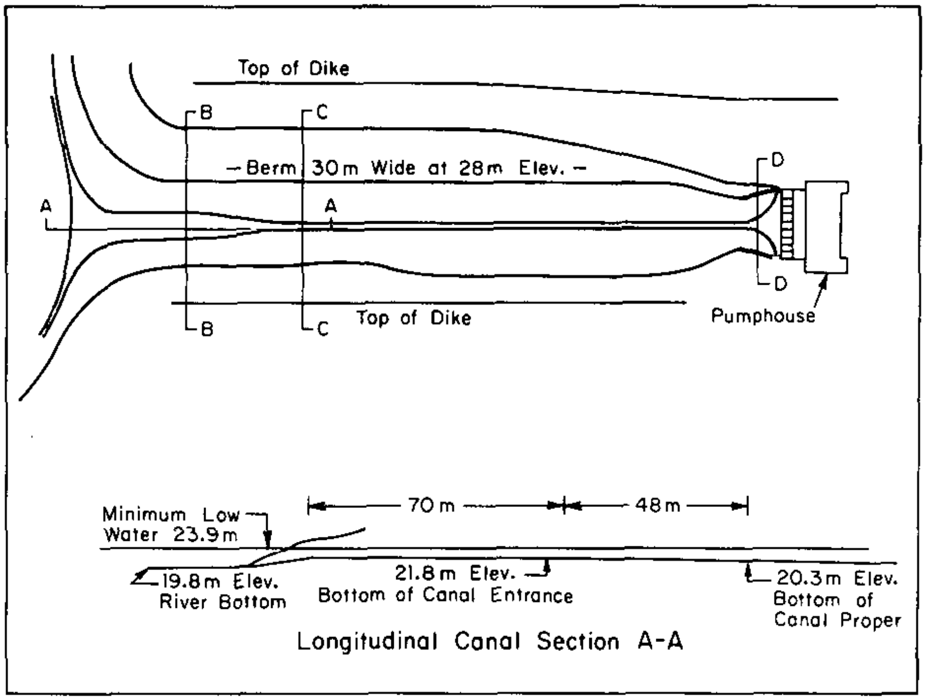


FIGURE 10. Plan View and Longitudinal Section of Entrance of 3G Canal

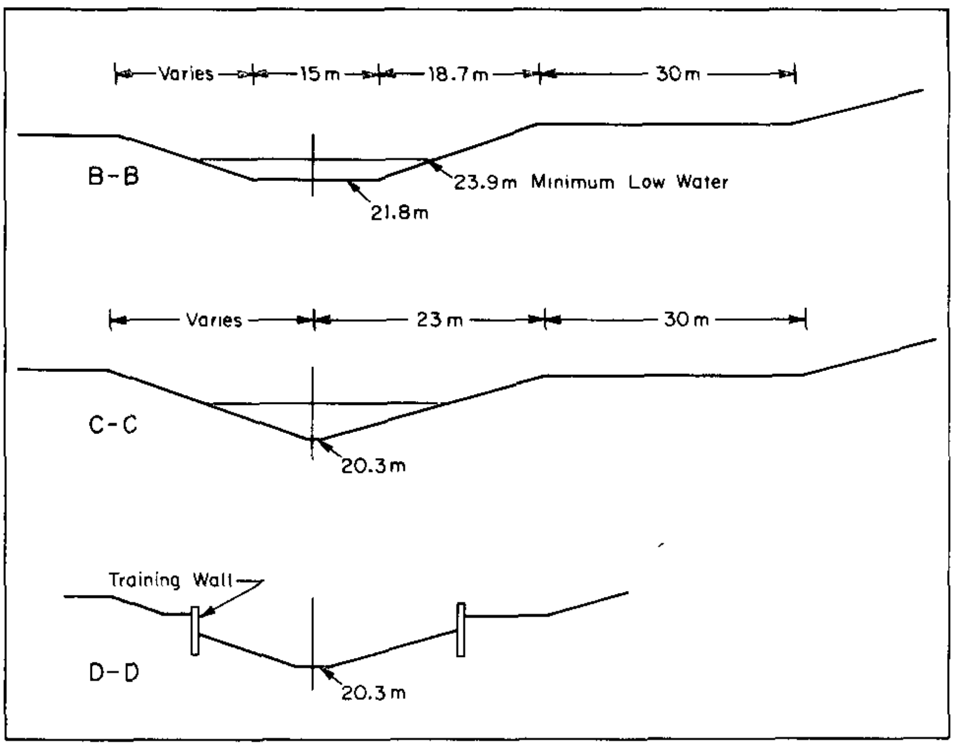


FIGURE 11. Cross Sections of 3G Canal at Points Designated in Figure 10

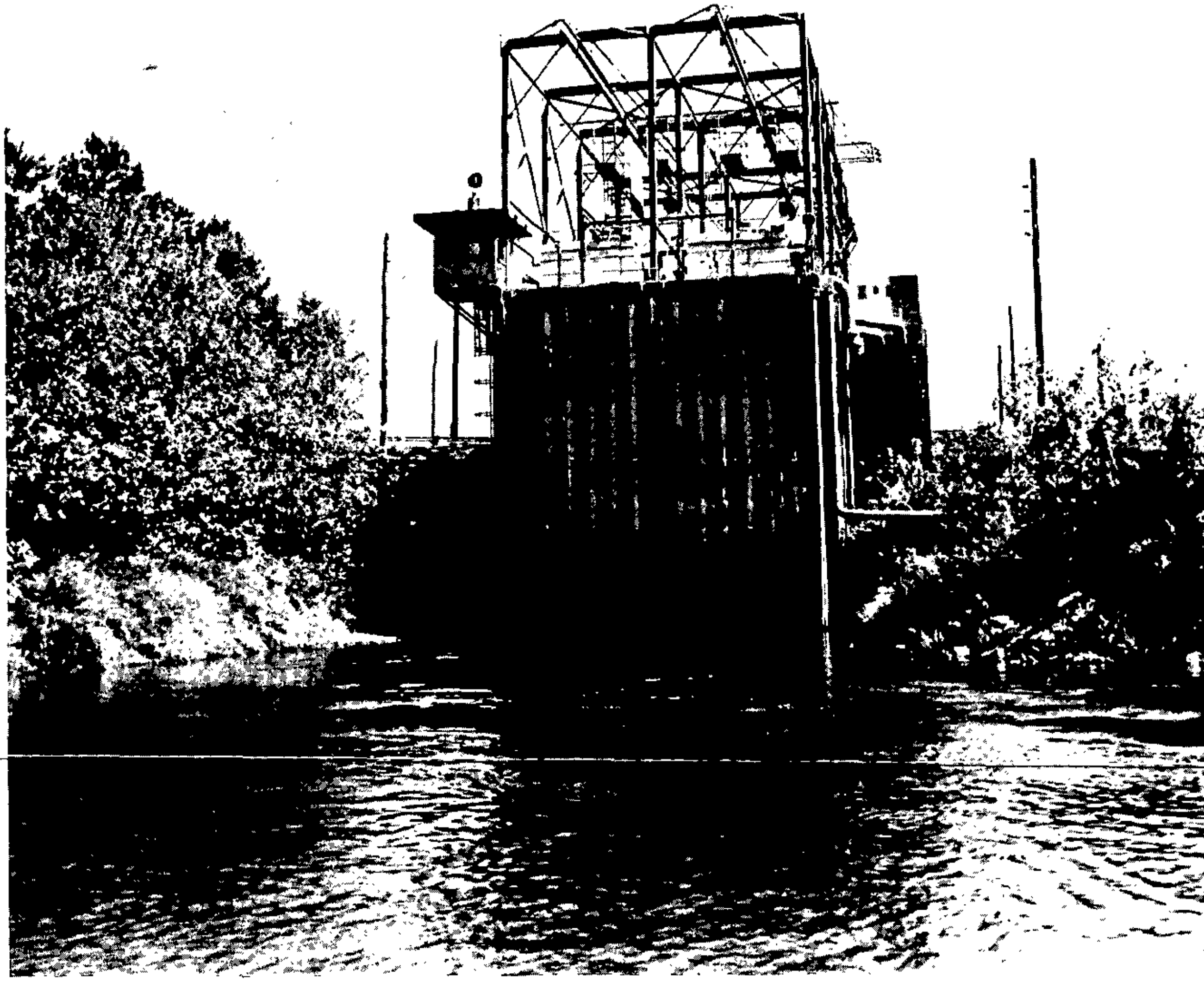


FIGURE 12. The 5G Pumping Station and Intake Cove as Viewed from the River

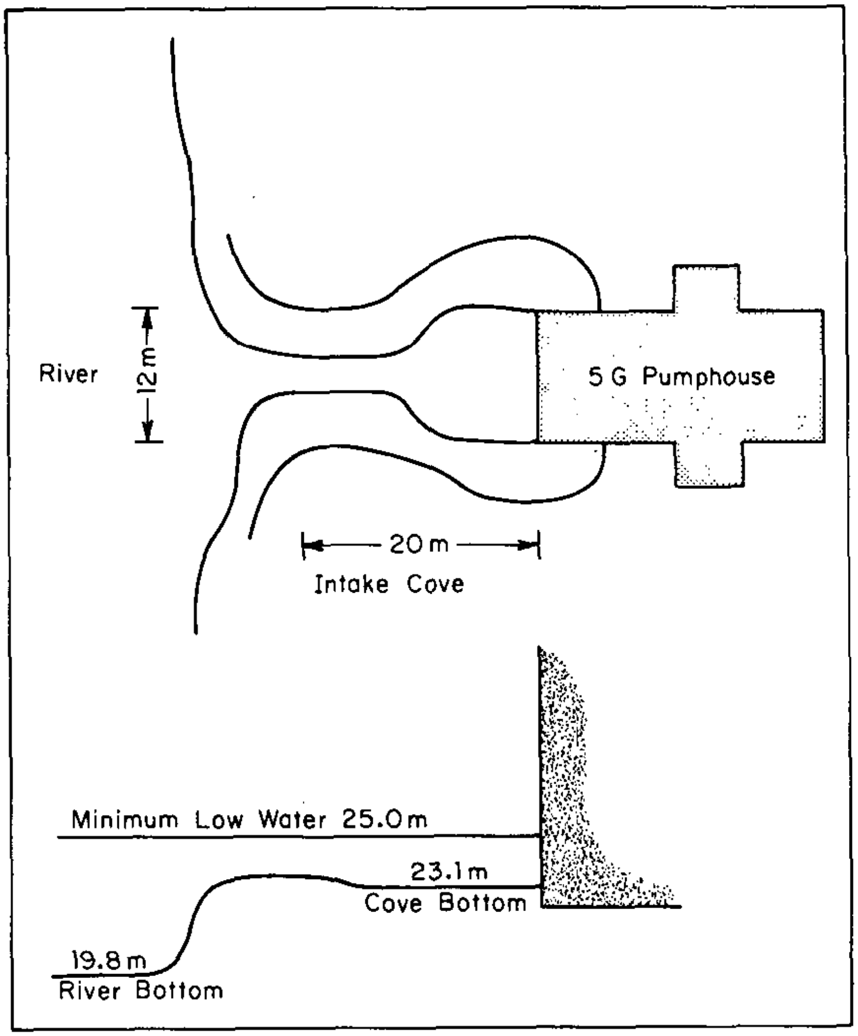


FIGURE 13. Plan View and Profile of 5G Intake Cove

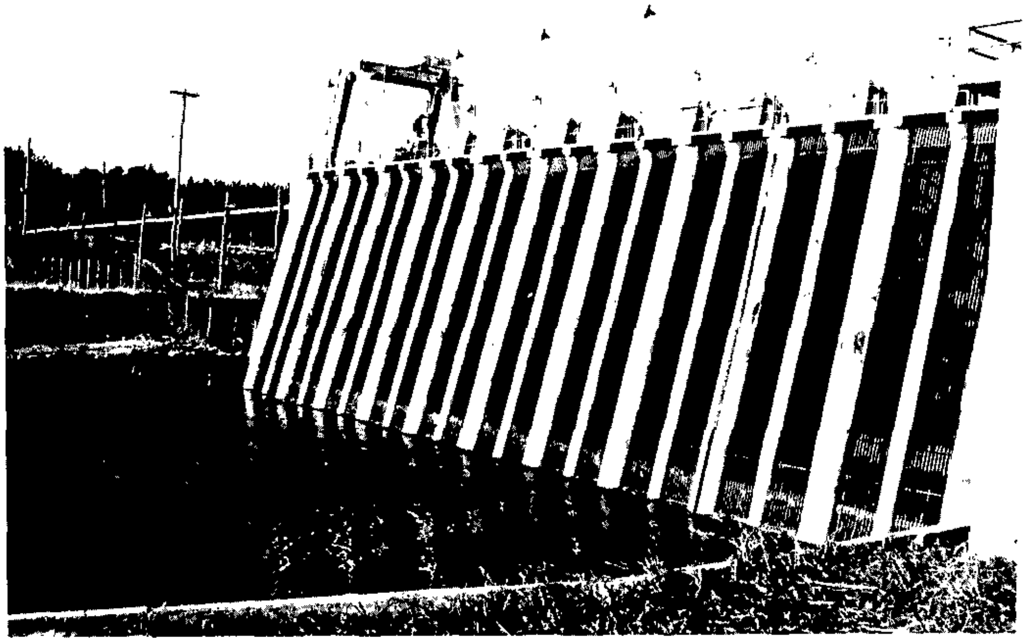


FIGURE 14. The 3G Pumphouse Intake Structure and Trash Disposal Pipeline

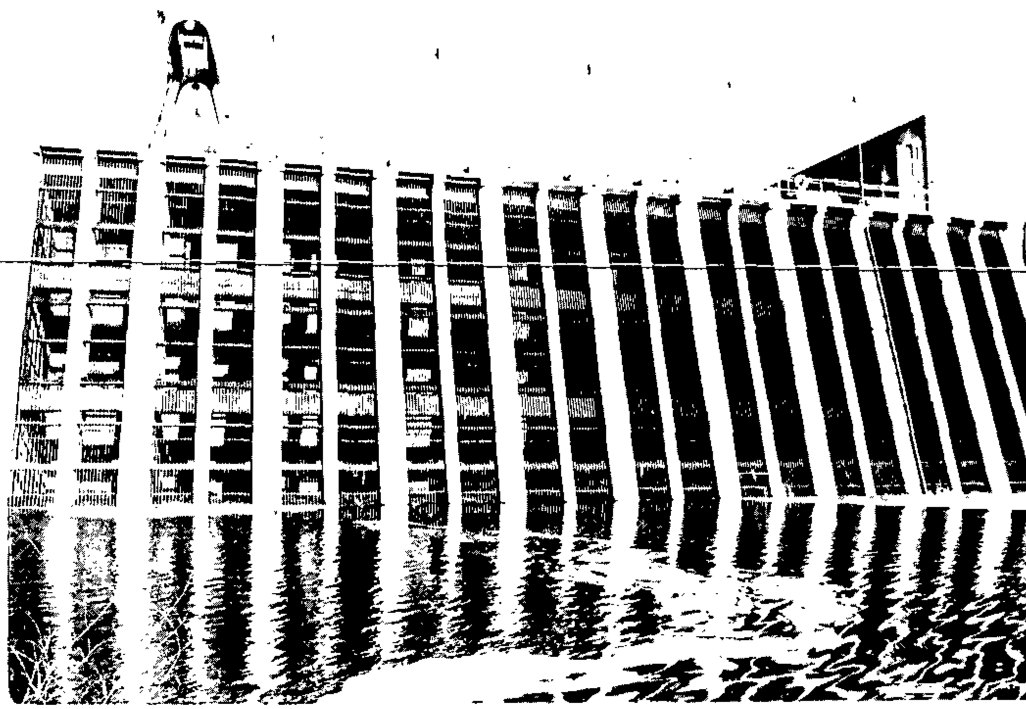


FIGURE 15. The 1G Pumphouse Intake Bays

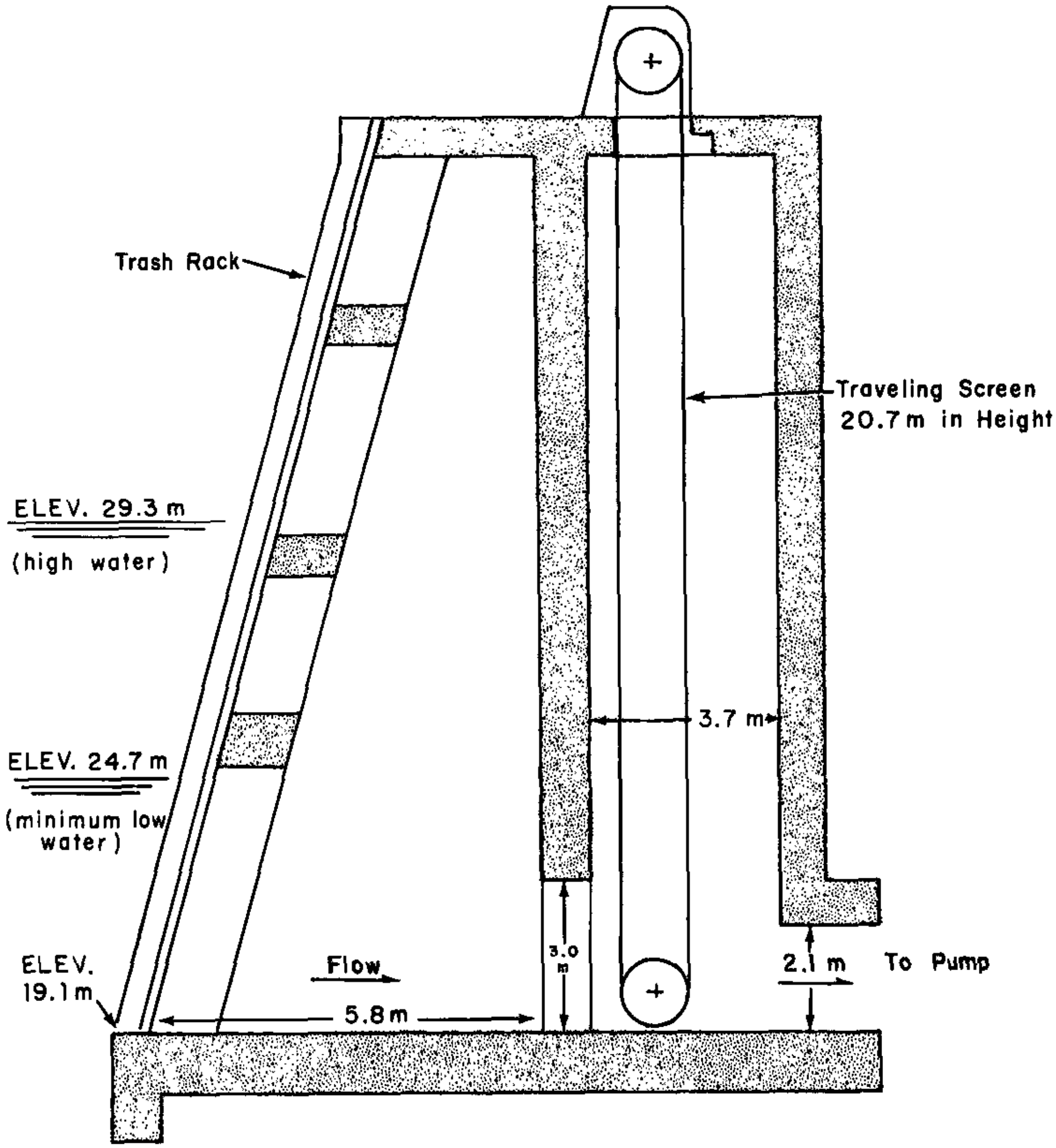


FIGURE 16. Schematic of 1G and 3G Pumphouse Intake, Elevation View

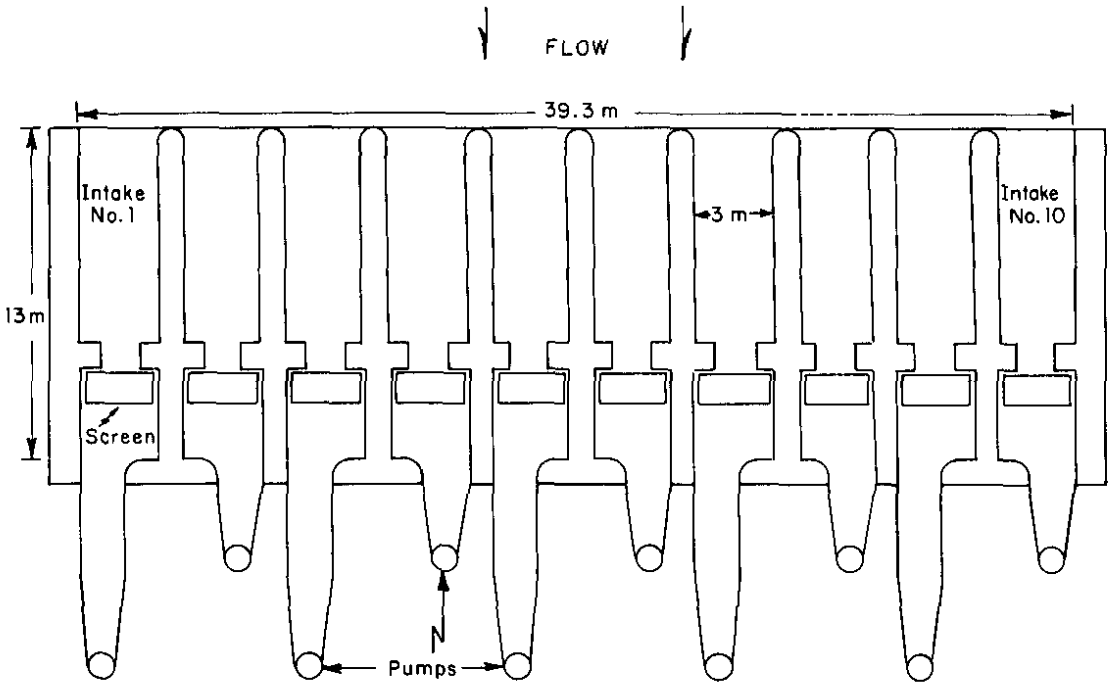


FIGURE 17. Schematic of 1G and 3G Pumphouse Intake, Plan View

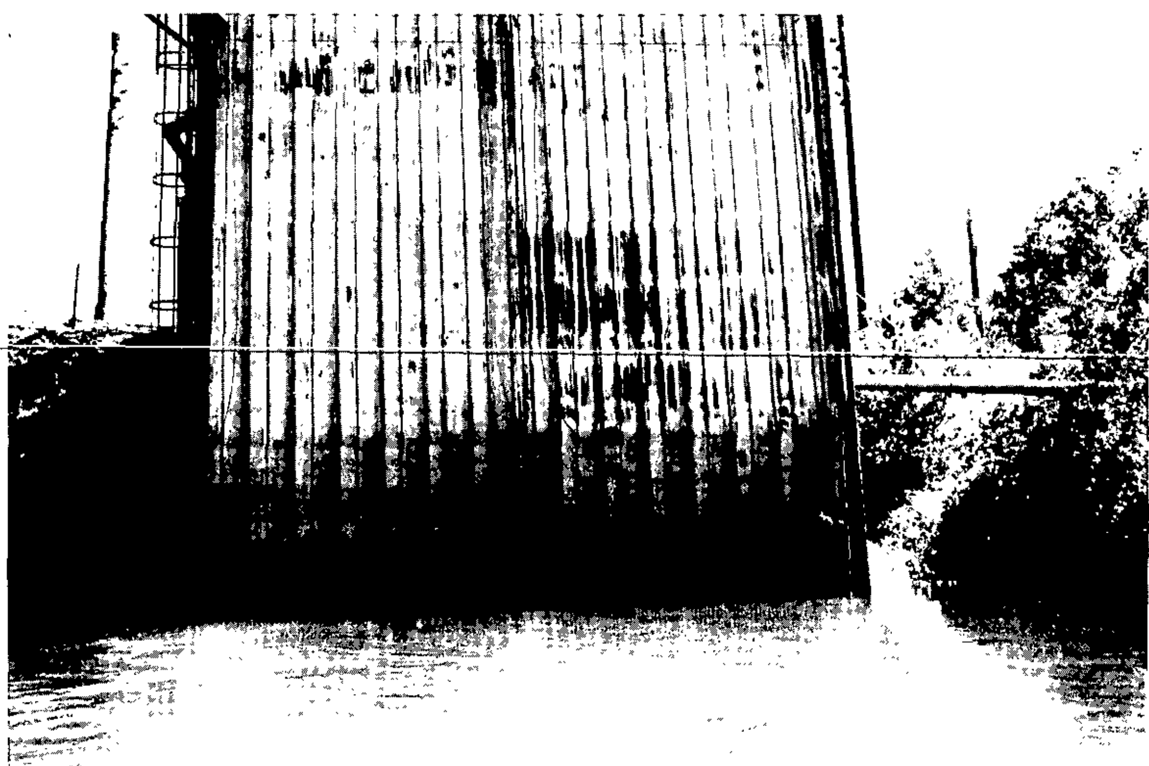
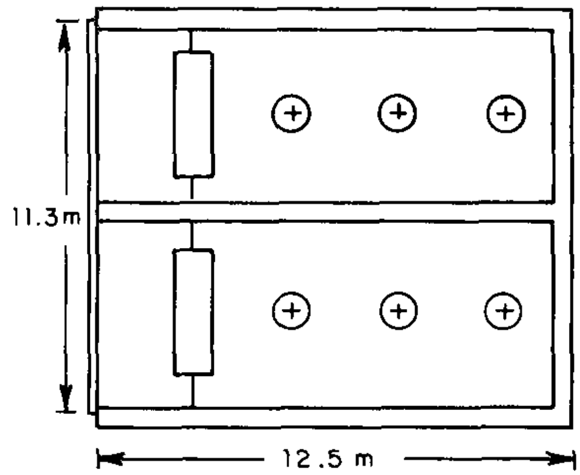
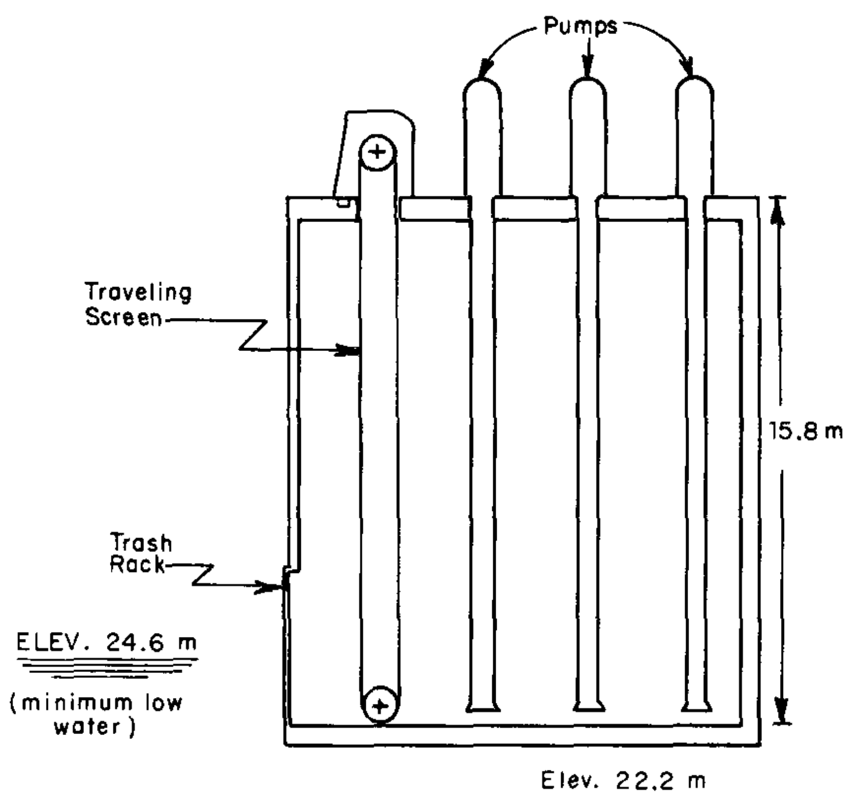


FIGURE 18. The 5G Pumphouse Intakes and Trash Disposal Pipeline



PLAN VIEW



ELEVATION

FIGURE 19. Schematic of 5G Pumphouse Intake

1.3 Screening Devices

All of the SRP pumping stations use vertical traveling screens to remove trash from the cooling water (Figure 20). Each pump at the 1G and 3G stations has a separate traveling screen. One screen suffices for three of the smaller pumps at the 5G station. The screen panels are 1.82 m long, 0.59 m high, with 11 mm-square mesh and a 10 cm-wide trash tray (Figure 21). The relative locations of screens and pumps are shown in Figures 16, 17, 18, and 19.

The screens are normally cleaned once per day, a procedure requiring 15 to 30 minutes. High-pressure water jets wash accumulated trash into a trough and thence to a 0.3-m-diam pipe which empties into a swale some distance away. There is no opportunity for impinged organisms to return to the river.

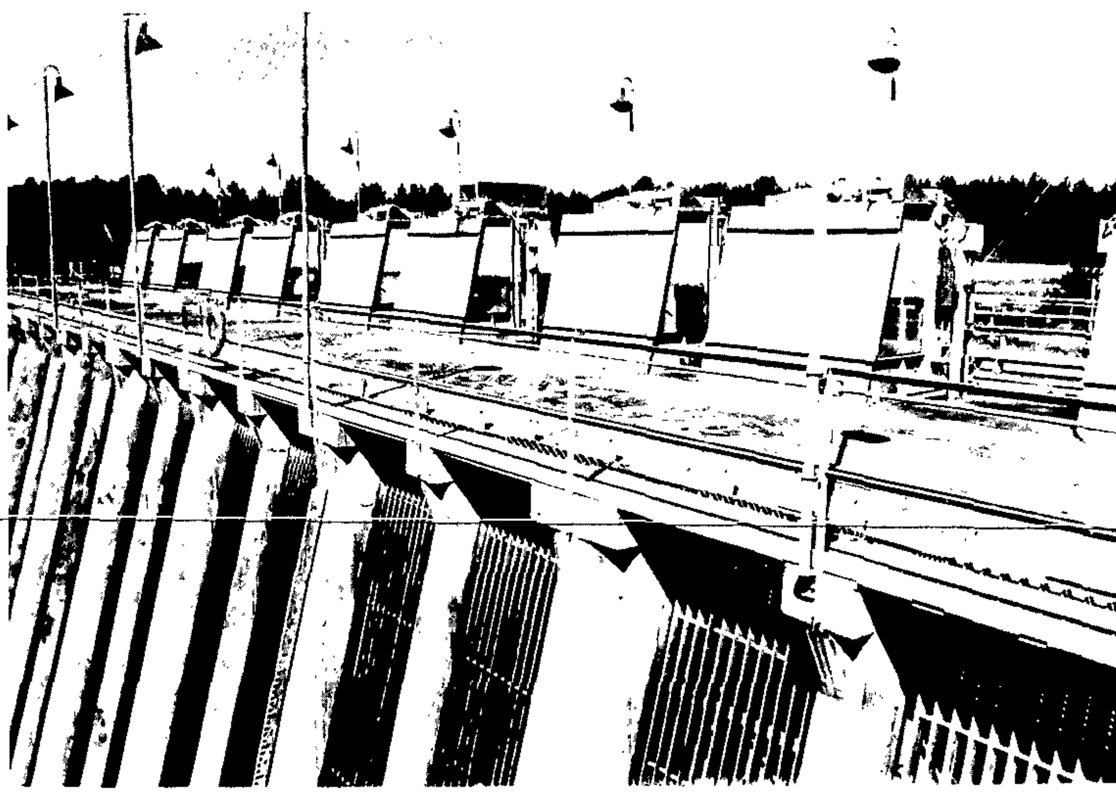


FIGURE 20. Traveling Screen Drive Assemblies at 3G Pumphouse

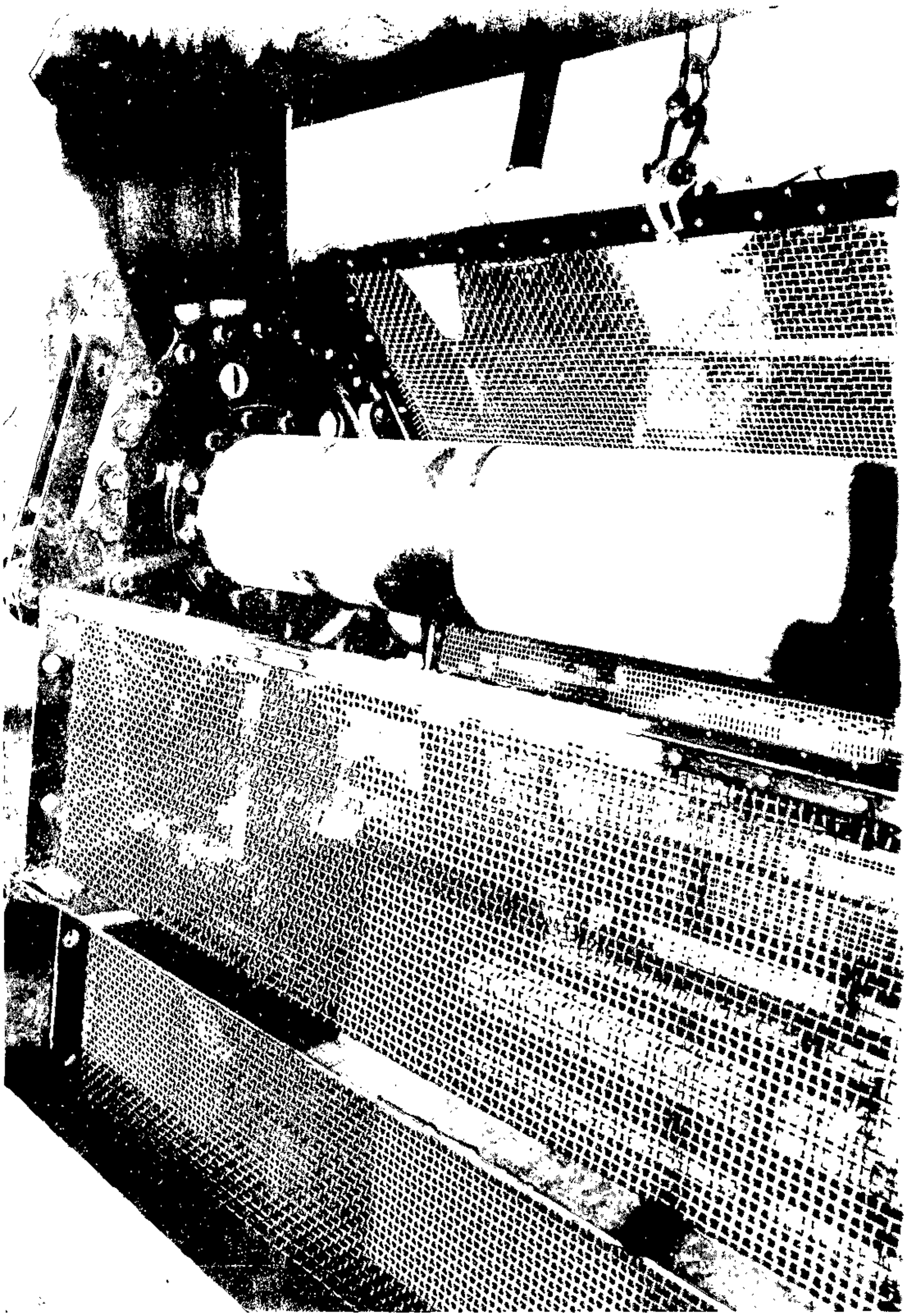


FIGURE 21. Traveling Screen Panel

1.4 Intake Canal Velocities

Intake velocities of both canals were determined at low and high pumping volumes. As velocity is influenced by the number of pumps in operation, the frequency distribution of pump operating levels is shown in Figure 22 for the 12-month period from December 1, 1976 to November 30, 1977. The 1G pumping station operated either three or four pumps on 67% of the days during that period, with no more than six pumps operating at any time. The 3G pumping station operated seven pumps on 39% of the days, eight pumps on 25 days, and nine pumps on but a single day.

Canal velocities were determined with seven pumps operating to represent high flow and two pumps to represent low flow. Velocity profiles were made at three locations on each canal: 100 m downstream from the inlet where unidirectional flow without eddies or backflow could be measured; near the midpoint of the canal; and at the narrowest canal width immediately upstream of the pumphouse intake training walls. The construction design of the 1G and 3G pumping stations precludes measurement of current velocity immediately in front of the traveling screens. The calculated velocity at this point, based upon 2.05 m^3/sec of water passing through a 1.8 × 3.0 m gate in front of the screen, is 0.38 m/sec.

Velocities were determined at low river elevation to maximize velocity at a given pumping volume. Measurements at the 1G canal were made at 25.7 m elevation on June 16, 1977 for high flow and 25.6 m on August 10, 1977 for low flow. Velocities in the 3G canal were determined at 25.5 m on August 22 for high flow and 25.7 m on September 12 for low flow, that same year.

Measurements were made with a Gurley Pygmy flowmeter 0.5 m below the surface and 0.5 m above the bottom at 5 m intervals along a horizontal transect perpendicular to the canal axis. Three consecutive one-minute measurements were made at each point and depth. The variation among the triplicate measurements and between the means of the various location and depth points across the transect are indicated in Table 4. Water movement within the canal is not uniform and fluctuates rapidly for most of the canal length. Flow becomes more uniform as the water mass is constricted at the pumphouse.

The mean high-flow velocities at the three transect locations are given in Table 4. The reduced midcanal velocity reflects the increase in canal depth and width at this point (see Figures 7, 8, 10 and 11). Profiles of intake velocity at high and low flow are shown in Figures 23 and 24.

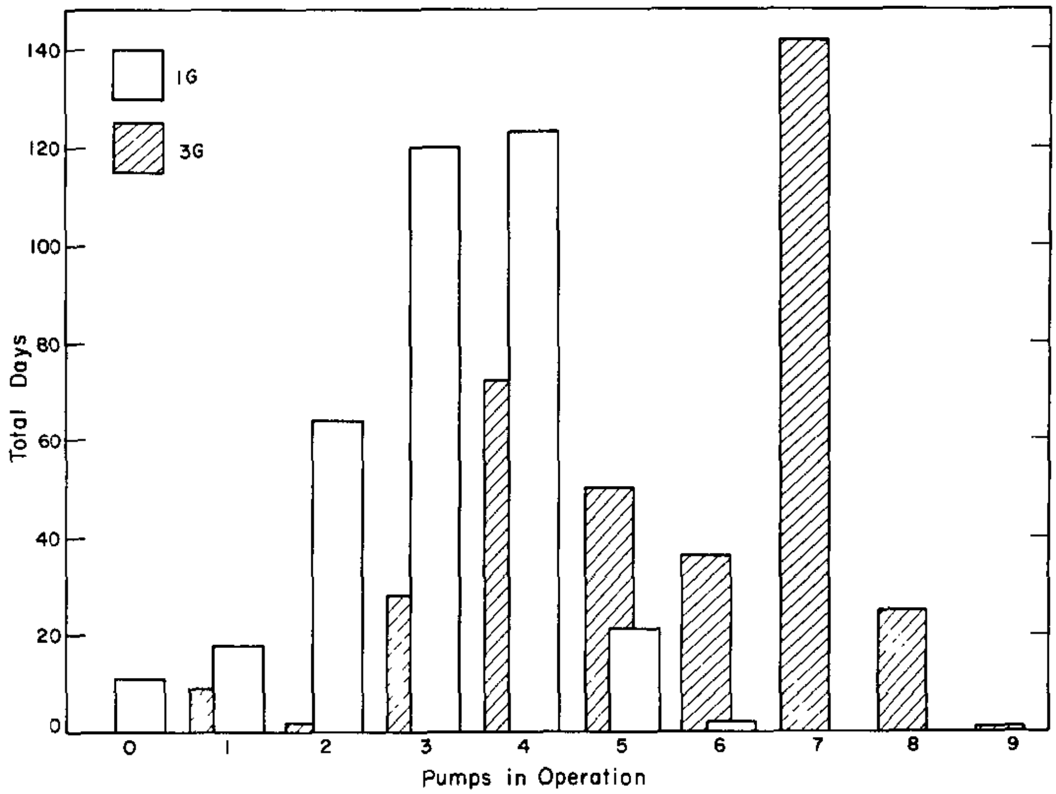


FIGURE 22. Frequency Distribution of Number of Pumps in Operation, December 1, 1976 to November 30, 1977

TABLE 4

Intake Canal High Flow Water Velocity

	Near Inlet		*Midcanal*		*At Pumphouse*	
	mean	*SD*	*mean*	*SD*	*mean*	*SD*
Velocity (m/sec)						
1G	0.17	0.115	0.15	0.078	0.24	0.037
3G	0.22	0.093	0.15	0.026	0.28	0.030
Coefficient of Variation Triplicate Measurements						
1G	29.3		29.9		5.1	
3G	21.9		11.5		4.4	
Transect Points						
1G	67.0		51.4		15.2	
3G	42.3		17.4		10.9	

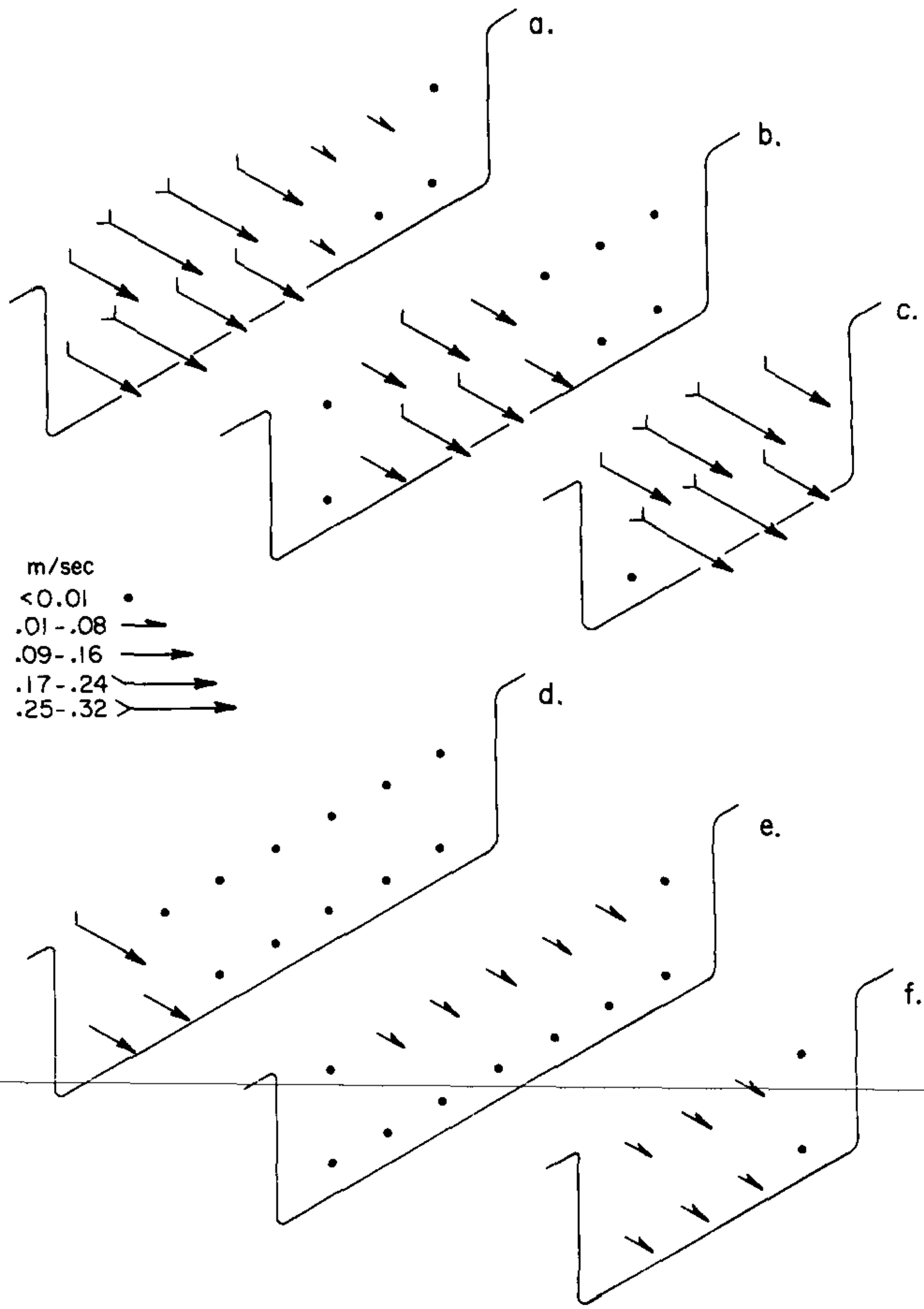


FIGURE 23. Velocity Profile of 1G Canal

Velocity profile of 1G canal at 7 pump, high flow (a-c) and 2 pump, low flow (d-f). Transects were located 100 m downstream from inlet (a, d), near canal midpoint (b, e) and immediately upstream of pumphouse training walls (c, f). Measurements were taken 0.5 m below the surface and 0.5 m above the bottom at 5 m intervals along the transect.

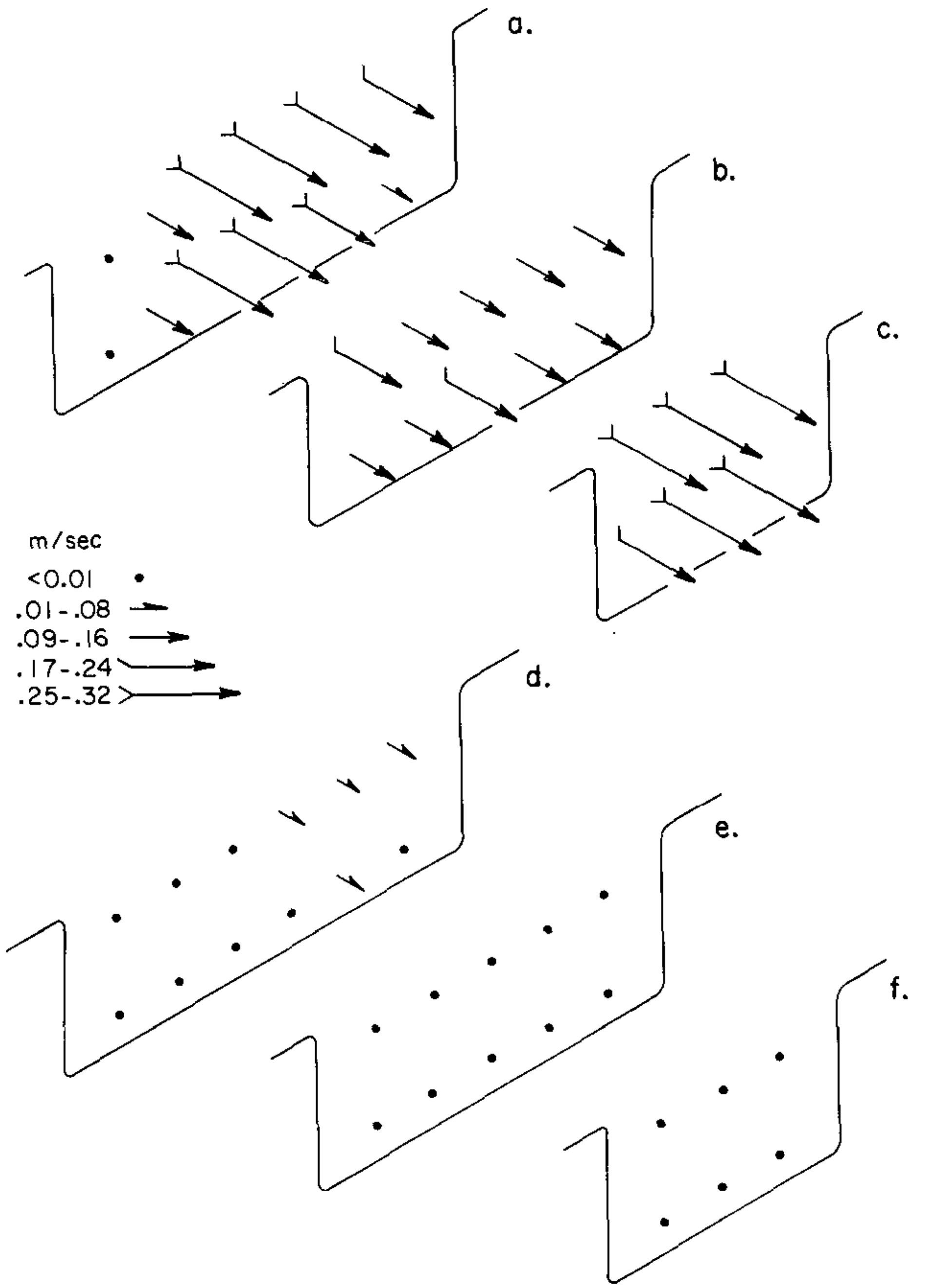


FIGURE 24. Velocity Profile of 3G Canal

Velocity profile of 3G canal at 7 pump, high flow (a-c) and 2 pump, low flow (d-f). Transects were located 100 m downstream from inlet (a-d), near canal midpoint (b, e) and immediately upstream of pumphouse training walls (c, f). Measurements were taken 0.5 m below the surface and 0.5 m above the bottom at 5 m intervals along the transect.

Water enters the 5G pumphouse through two 4.4 m high by 4.8 m wide trash rack openings. Flow patterns in the intake cove are very complex with substantial backflow. Velocity measurements made with four pumps in operation (two in each intake bay) at 25.7 m river elevation on October 13, 1977 were 0.05 m/sec at 0.5 m depth and 0.02 m/sec at 3 m depth, both directly in front of the trash rack.

2. ENVIRONMENTAL DATA

2.1 Savannah River Discharge

U. S. Geological Survey monitoring data of the Savannah River discharge have been used wherever possible in this report. The longest period of record exists for Augusta, Georgia and Clyo, Georgia.[1] River discharge has been greatly influenced by Clark Hill Reservoir since the closing of the dam in 1952. Its principal effects have been to decrease the incidence of both extreme high and low discharge[2] and decrease the average river temperature 3°C. The annual variation in mean daily discharge at Augusta (New Savannah Bluff Lock and Dam, river kilometer 301) and Clyo (near Highway 119, river kilometer 98) for the period 1961-1976 are shown in Figure 25. The 289 m^3/sec mean annual rate of flow for 69 years at Augusta and 342 m^3/sec mean for 43 years at Clyo are also indicated. The seasonal variation of the discharge at Augusta is shown in Figure 26. The lowest flow rates and least variability occur during the summer and fall while peak flow and variability are found in March and April.

Additional data on Savannah River discharge were collected by the U.S. Geological Survey (USGS) at Burtons Ferry Bridge (river kilometer 191) near U.S. Highway 301 from 1939 to 1970. A gauging station was established at the SRP (river kilometer 252) by the USGS in October 1971. Data from this gauge are integrated from punched tape points recorded at 15-minute intervals. Flow data, currently derived from river elevation recorded once daily at 7 a.m., have been collected by SRP personnel since 1954. The characteristics of the river floodplain render data from SRP less useful because it is difficult to estimate flow when the river elevation exceeds the bank height. Therefore, the USGS excludes data for flow rates greater than 566 m^3/s, which is equivalent to 28.8 m river elevation.

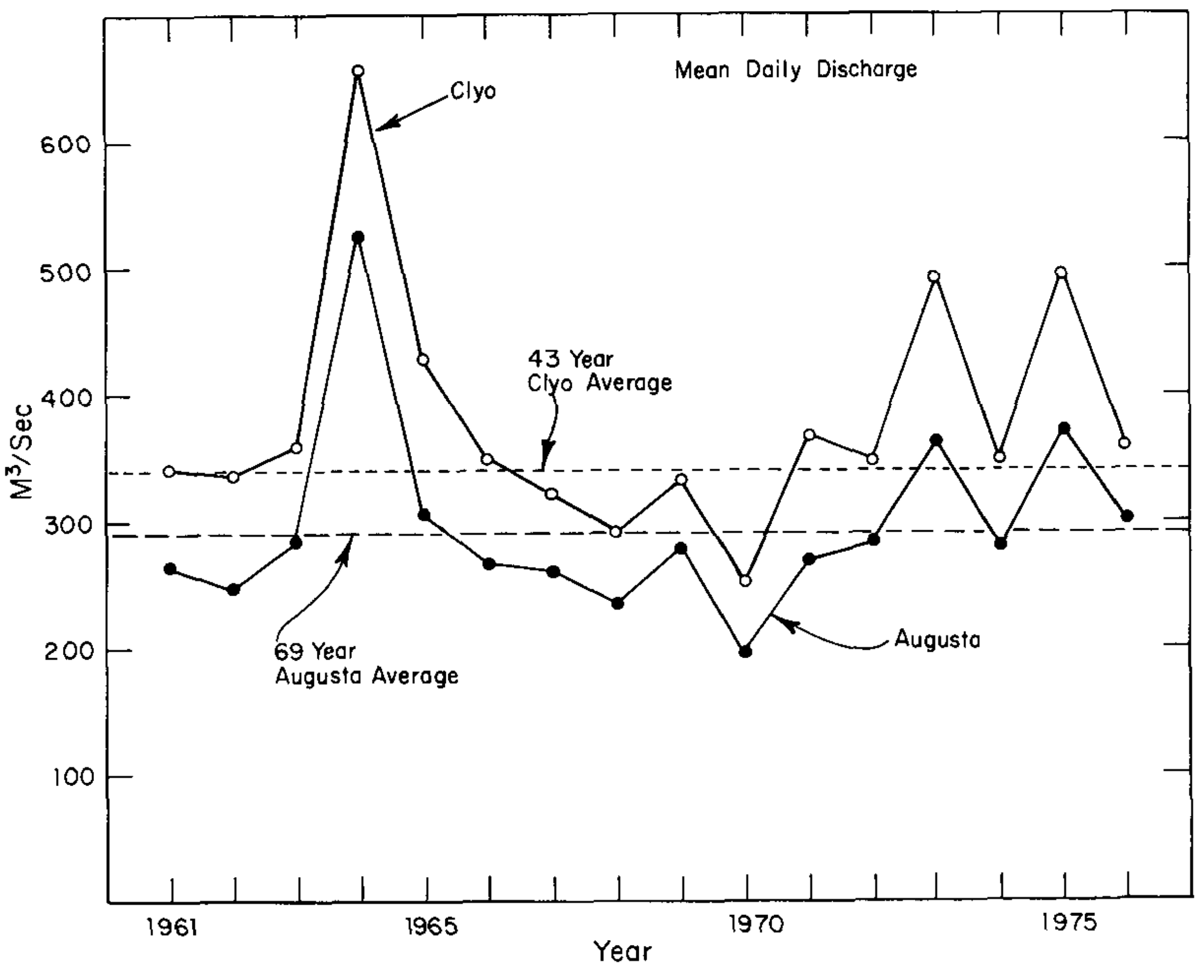


FIGURE 25. Annual Variation in Mean Daily Discharge at Augusta and Clyo

Annual variation in Mean Daily Discharge at Augusta (river km = 301.5) and Clyo (river km = 98.0) for the period 1961-1976.

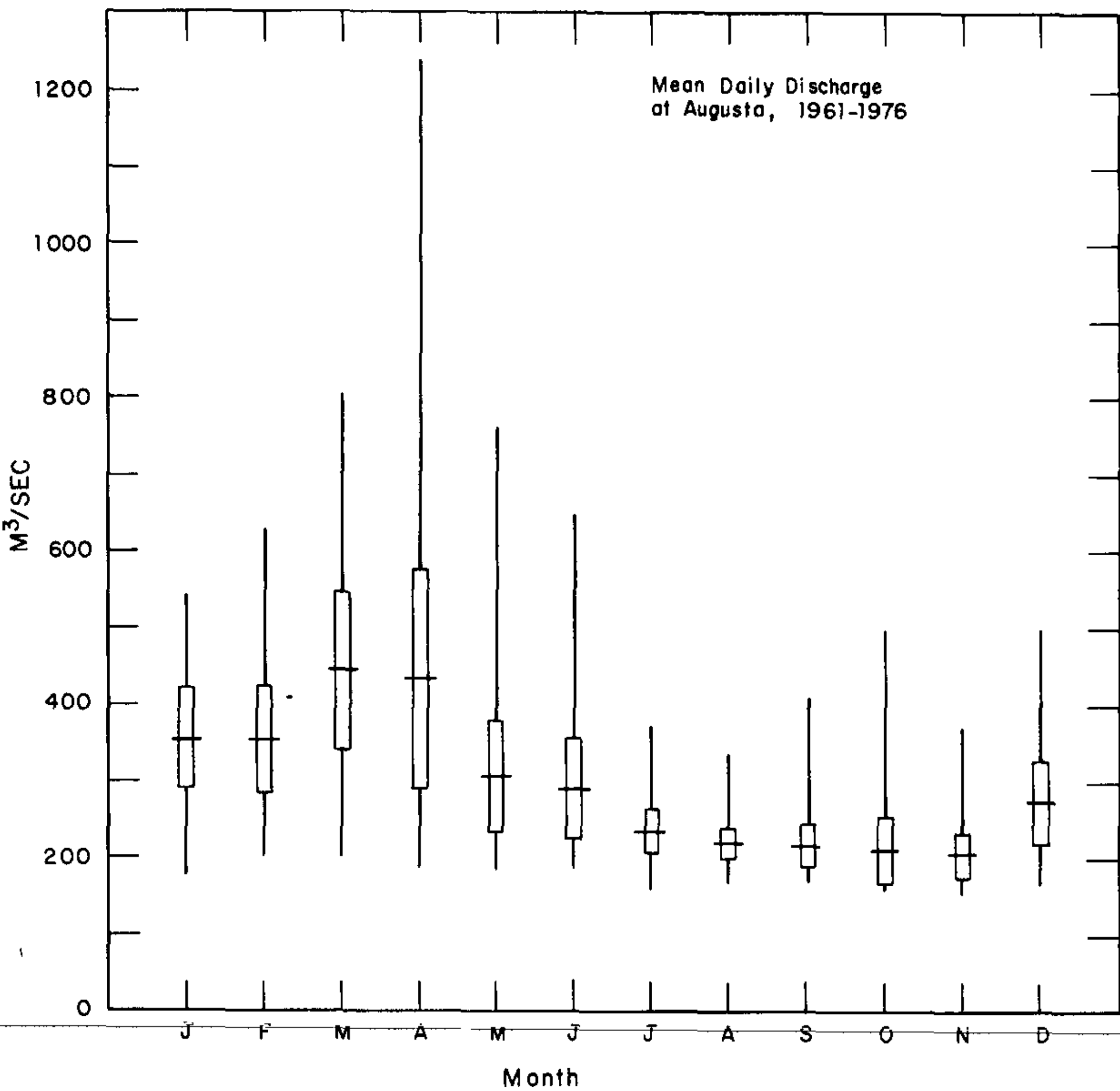


FIGURE 26. Seasonal Variation in Mean Daily Discharge at Augusta

Seasonal variation in mean daily discharge at New Savannah Bluff Lock and Dam, Augusta, for the period 1961-1976. The mean, range, and 95% confidence limits are indicated by the horizontal bar, vertical line, and box, respectively.

The relationship of river discharge at Augusta to subsequent discharge at SRP, Burtons Ferry Bridge, and Clyo is depicted in Table 5. For fully one-half of the fifteen years shown, the estimated discharge at SRP is less than that passing Augusta, and is indicated by a negative difference. The water mass expands out of the channel to form a broad sheet of water up to 3 km wide moving down the floodplain. This non-channel flow is not reflected in the discharge data.

The reliability of Augusta discharge data as a predictor of cumulative downstream discharge and the relationship of river distance to cumulative discharge are shown in Figure 27. The coefficient of determination is lower, although quite respectable, for SRP when compared to Burtons Ferry Bridge and Clyo. The cumulative discharge at Augusta, Burtons Ferry Bridge, and Clyo form a straight line function with distance but SRP does not match this pattern. Calculation of SRP discharge using this distance-versus-discharge regression line (Figure 27 inset, coefficient of determination = 0.9998) estimates mean annual discharge at 315.6 m^3/sec, or 6% greater than the estimate based upon river elevation alone.

The daily variation in river elevation and discharge is quite extensive in response to varying hydroelectric generation requirements, as previously shown in Figure 4.

TABLE 5

The Relationship of Mean Annual Savannah River Discharge (m^3/sec) at Augusta to Discharge at Three Downstream Locations

	Augusta	*SRP*		*Burtons Ferry*		*Clyo*	
	Disch.	*Disch.*	*Percent Diff.*	*Disch.*	*Percent Diff.*	*Disch.*	*Percent Diff.*
1961	264.8	281.8	6.4	309.0	16.7	342.4	29.3
1962	247.7	279.7	12.9	299.6	21.0	336.2	37.7
1963	283.8	288.8	1.8	315.5	11.2	358.2	26.2
1964	524.8	522.4	-0.5	580.6	10.6	656.2	25.0
1965	305.9	340.1	11.2	361.9	18.3	427.3	39.7
1966	266.2	263.9	-0.9	316.3	18.8	348.9	31.1
1967	259.2	248.3	-4.2	299.3	15.5	321.1	23.9
1968	234.5	244.1	4.1	272.6	16.2	290.3	23.8
1969	278.1	260.9	-6.2	309.8	11.4	332.2	19.5
1970	197.3	195.7	-0.8			249.7	26.6
1971	268.4	278.4	3.7			365.9	36.3
1972	282.0	270.9	-3.9			346.4	22.8
1973	360.8	345.8	-4.2			491.1	36.1
1974	278.7	281.1	0.9			348.1	24.9
1975	370.7	364.3	-1.7			494.5	33.4
Mean	294.9	297.7	2.1	340.5	15.5	380.6	29.1
Std. Dev.	74.39	72.70	6.31	87.71	3.49	97.25	6.03

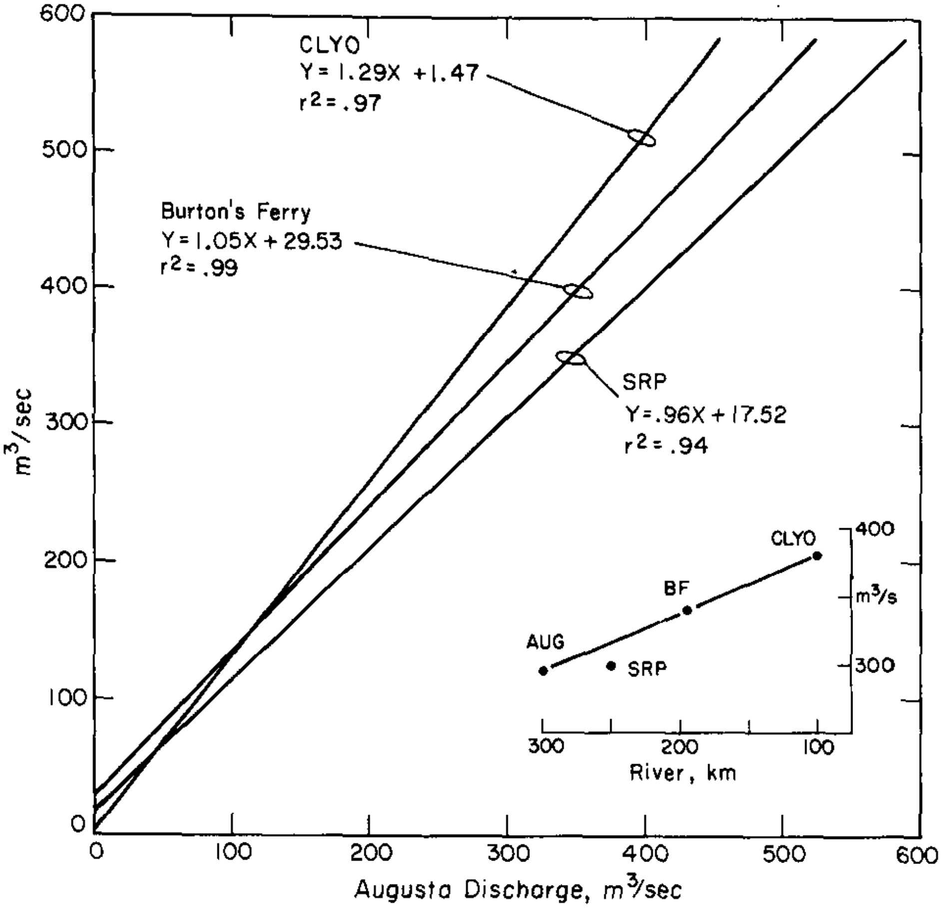


FIGURE 27. Savannah River Discharge at Augusta as a Predictor of Downstream Flow

Inset shows the relationship of river distance to cumulative discharge.

2.2 Minimum Flow

The USGS has determined the 7-day, 10-year minimum flow for the Savannah River during the period 1953-1964 to be 119.2 m^3/sec at Augusta and 137.4 m^3/sec at Burtons Ferry Bridge. The interpolated figure for SRP, based upon river distance, is 128.3 m^3/sec. Examination of river discharge figures for SRP since 1961 reveals that the lowest 7-day value of 147.5 m^3/sec was reached on February 15 through 21, 1962.

2.3 Stream Velocity

Stream velocities were estimated on ten dates from April to August 1977. A digital flowmeter mounted in the mouth of a plankton net provided duplicate measurements from both top meter and bottom meter of the water column at three transect positions. The average of these twelve measurements and their 95% confidence limits for ten sampling dates are shown in Figure 28. The resultant linear regression line is statistically significant at the 95% confidence level with a relatively low correlation coefficient (r = 0.61). The regression indicates that current velocity is approximately 0.74 m/sec at mean annual discharge and 0.65 m/sec at 7-day, 10-year low flow.

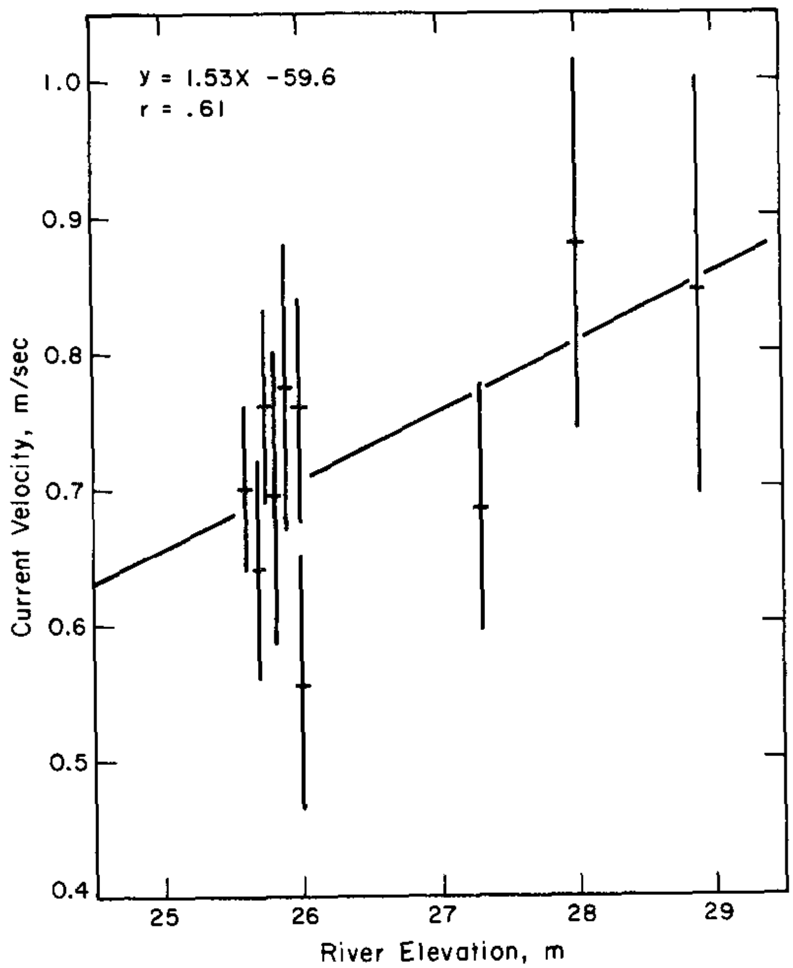


FIGURE 28. Relationship Between River Elevation and Current Velocity

2.4 Depth of Water Removal

The design of the 1G and 3G intake canals dictates that cooling water is withdrawn from the upper layers of the river (Figures 7 and 10). Water is removed from the upper third of the water column at low river elevation and the upper two-thirds at high elevation. The proximity of Upper Three Runs (Figure 5) results in 45 to 95% of the creek discharge being drawn into the 1G canal, depending on flow rates.

The restricted intake orifice of the 5G pumphouse results in withdrawal of surface water at low river elevations but mid-water withdrawal at high elevations (Figures 13 and 19).

3. BIOLOGICAL DATA

3.1 The Fish Fauna

Fish of the Savannah River have been studied at regular intervals since 1951 by the Academy of Natural Sciences of Philadelphia (ANSP) under contract with the Savannah River Plant. The list of 69 species known to occur in riverine habitats of the Savannah River Plant presented in Table 6 is thus based upon considerable data collected over a 25-year period. Species of fishes restricted to tributaries of the river, and not found in the river or the intake canals, have been omitted from this report even though they occur in nearby habitats. The relative occurrence of the riverine species (subjectively classified as abundant, common, uncommon, or rare) indicated in Table 6 is based upon fish collections made during this study, ANSP reports, or other publications.[3,4,5]

The present status and relative abundance of riverine fishes in the vicinity of SRP pumping stations were determined by extensive collecting during this study. Representative habitats along the river and each of the intake canals have been electrofished nocturnally at monthly intervals. Fish traps have been operated continuously in each of the intake canals. Traps placed in the river and at the 5G pumphouse were removed after frequent poaching rendered the data collected unreliable. Irregular collecting with gill, trammel nets, dip nets, and haul seines was conducted wherever feasible or necessary to verify other data. More than 5000 fish of 59 species have been examined (Table 6).

Five species have been added to the list of SRP riverine fishes during this study. Occasionally, local fishermen observe Atlantic sturgeon – particularly when the sturgeon become enmeshed in shad nets; and one larval specimen was collected in

TABLE 6

The Fish Fauna of the Savannah River in the Vicinity of the Savannah River Plant, and Their Distribution and Relative Abundance in Recent Collections

Species	*Status*[1]	*Distribution*				*Number Captured*
		River	*1G*	*3G*	*5G*	
Atlantic Sturgeon, *Acipenser oxyrhynchus*	R					
Longnose Gar, *Lepisosteus osseus*	C	+	+	+		61
Florida Gar, *Lepisosteus platyrhincus*	R	+				1
Bowfin, *Amia calva*	C	+	+	+	+	48
American Eel, *Anguilla rostrata*	A	+	+	+		117
Blueback Herring, *Alosa aestivalis*	A	+	+	+		124
Hickory Shad, *Alosa mediocris*	R					
American Shad, *Alosa sapidissima*	A	+	+	+	+	190
Gizzard Shad, *Dorosoma cepedianum*	C	+	+	+		70
Threadfin Shad, *Dorosoma petenense*	U	+	+	+	+	22
Eastern Mudminnow, *Umbra pygmaea*	R		+			1
Redfin Pickerel, *Esox americanus*	C	+	+	+	+	35
Chain Pickerel, *Esox niger*	C	+	+	+		54
Carp, *Cyprinus carpio*	U	+	+	+		14
Silvery Minnow, *Hybognathus nuchalis*	A	+	+	+	+	339
Rosyface Chub, *Hybopsis rubrifrons*	U	+	+	+		31
Blueface Chub, *Nocomis leptocephalus*	R					
Golden Shiner, *Notemigonus crysoleucas*	U	+	+	+	+	30
Ironcolor Shiner, *Notropis chalybaeus*	R			+		1
Dusky Shiner, *Notropis cummingsae*	R					
Pugnose Minnow, *Notropis emiliae*	R	+	+	+		3
Spottail Shiner, *Notropis hudsonius*	A	+	+	+	+	866
Ohoopee Shiner, *Notropis leedsi*	U	+		+		28
Taillight Shiner, *Notropis maculatus*	R	+	+			5
Whitefin Shiner, *Notropis niveus*	U	+	+			25
Coastal Shiner, *Notropis petersoni*	U	+	+	+		55
Quillback, *Carpiodes cyprinus*	R	+				1
Creek Chubsucker, *Erimyzon oblongus*	R			+		1
Lake Chubsucker, *Erimyzon sucetta*	R		+	+		4
Spotted Sucker, *Minytrema melanops*	A	+	+	+		354
Silver Redhorse, *Moxostoma anisurum*	U	+	+	+		60
Snail Bullhead, *Ictalurus brunneus*	R	+	+	+		8
White Catfish, *Ictalurus catus*	R	+	+	+		11
Yellow Bullhead, *Ictalurus natalis*	R	+		+		3
Brown Bullhead, *Ictalurus nebulosus*	R					
Flat Bullhead, *Ictalurus platycephalus*	C	+	+	+	+	141
Channel Catfish, *Ictalurus punctatus*	C	+	+	+		96
Tadpole Madtom, *Noturus gyrinus*	R					
Speckled Madtom, *Noturus leptacanthus*	R		+			1
Swampfish, *Chologaster cornuta*	R					
Pirate Perch, *Aphredoderus sayanus*	R	+	+	+		11
Atlantic Needlefish, *Strongylura marina*	R		+			2
Starhead Topminnow, *Fundulus lineolatus*	R			+		1
Mosquitofish, *Gambusia affinis*	C	+	+	+		10
Brook Silverside, *Labidesthes sicculus*	C	+	+	+		68
White Bass, *Morone chrysops*	R		+			1
Striped Bass, *Morone saxatilis*	R					
Mud Sunfish, *Acantharchus pomotis*	R		+	+		2
Flier, *Centrarchus macropterus*	R	+	+	+		13
Banded Pygmy Sunfish, *Elassoma zonatum*	R					
Bluespotted Sunfish, *Enneacanthus gloriosus*	R		+	+	+	35
Redbreast Sunfish, *Lepomis auritus*	A	+	+	+	+	862
Green Sunfish, *Lepomis cyanellus*	R					
Pumpkinseed, *Lepomis gibbosus*	U	+	+	+	+	52
Warmouth, *Lepomis gulosus*	C	+	+	+	+	140
Bluegill, *Lepomis macrochirus*	A	+	+	+		702
Dollar Sunfish, *Lepomis marginatus*	R			+		2
Redear Sunfish, *Lepomis microlophus*	C	+	+	+		150
Spotted Sunfish, *Lepomis punctatus*	U	+	+	+	+	61
Largemouth Bass, *Micropterus salmoides*	C	+	+	+	+	92
White Crappie, *Pomoxis annularis*	R		+			1
Black Crappie, *Pomoxis nigromaculatus*	C	+	+	+		113
Swamp Darter, *Etheostoma fusiforme*	R				+	1
Christmas Darter, *Etheostoma hopkinsi*	R				+	1
Tessellated Darter, *Etheostoma olmstedi*	R		+	+	+	5
Yellow Perch, *Perca flavescens*	C	+	+	+	+	164
Blackbanded Darter, *Percina nigrofasciata*	R	+				1
Striped Mullet, *Mugil cephalus*	U	+	+	+		32
Hogchoker, *Trinectes maculatus*	U	+	+	+		12
Total Species	69	44	48	47	18	59
Total Fish						5357

A - abundant:	very likely to be collected in large numbers every time its habitat is sampled at the proper season.
C - common:	may be collected most of the time or in smaller numbers under the same circumstances.
U - uncommon:	may be collected quite regularly in small numbers in the appropriate habitat and season.
R - rare:	seldom encountered at any locality.

our ichthyoplankton samples. The striped mullet was repeatedly captured by electrofishing or traps. The white bass has been introduced as a sport fish in upstream reservoirs and one was trapped in a canal. The mud sunfish and Christmas darter are more characteristic of SRP streams[6] than the river, but both were impinged during this study.

Nine of the 64 species reported by the ANSP were not collected during this study. The blueface chub, dusky shiner, tadpole madtom, and banded pygmy sunfish are all more characteristic of SRP streams[6] than the river. The swampfish is rare and unlikely to be collected by our techniques. A striped bass was observed but not captured while electrofishing. The inclusion of green sunfish in the SRP fauna is questionable. The absence of hickory shad and brown bullhead from our collection is notable.

A comparison of the fishes found in the river with those known to inhabit the intake canals is pertinent to this study. A single specimen each of the Florida gar, quillback, and black-banded darter were collected in the river but not the intake canals. Thirteen species were found only in the canals, with all but the threadfin shad represented by four or fewer specimens. The swamp and Christmas darters were collected only by impingement from the 5G intake cove. All fishes in the canals obviously must have entered from the river, and this study has demonstrated that virtually all fishes found in the river can be expected to also occur in the intake canals.

The relative fish diversity of the river and intake canals is presented in Table 7. The greater number of species and individuals collected in the canals reflects the inclusion of impingement and trapping data. Community diversity and the equitability of each species' abundance are commonly (albeit, controversially) calculated by use of several indices. In this report diversity is expressed as the Shannon index H' and equitability as Pielou's evenness index J'.[8] The three localities are very similar in diversity and the equitability of relative distribution between species. The relative abundance of species in the river and canals is shown in Figure 29. The canals are dominated by sunfishes. Minnows are prominent in the river. Suckers are somewhat more prevalent in the canals than in the river, but there is no significant difference in top carnivores in the river.

Canal fishes were tagged and released throughout this study to determine the extent of fish movement between the study habitats. Seventy of the 680 fishes of 22 species tagged were recovered. Only two fish were recaptured in an area other than the tagging locality. A redbreast sunfish tagged in 3G was recaptured in 1G 12 days later. A mullet tagged in 3G was recovered in the river immediately upstream from 3G 42 days later. Fishes were recovered in their original canals at intervals as long as six months after tagging. Several fish were recaptured twice. Recapture rates for bluegills, redbreast sunfish, and redear sunfish were 12, 15, and 20 percent, respectively.

In summary, the resident fish community of the intake canals is similar in species composition but distinct in relative species abundance from the riverine community. The dominant sunfishes tend to reside in the canals for long periods and there is little interchange between canals.

TABLE 7

The Diversity and Equitability of Distribution of River and Canal Fish Communities

	Sample Size	*Number of Species*	*Diversity H'*	*Evenness J'*
River	1467	42	2.65	0.709
1G Canal	2082	46	2.77	0.724
3G Canal	1830	46	2.84	0.742

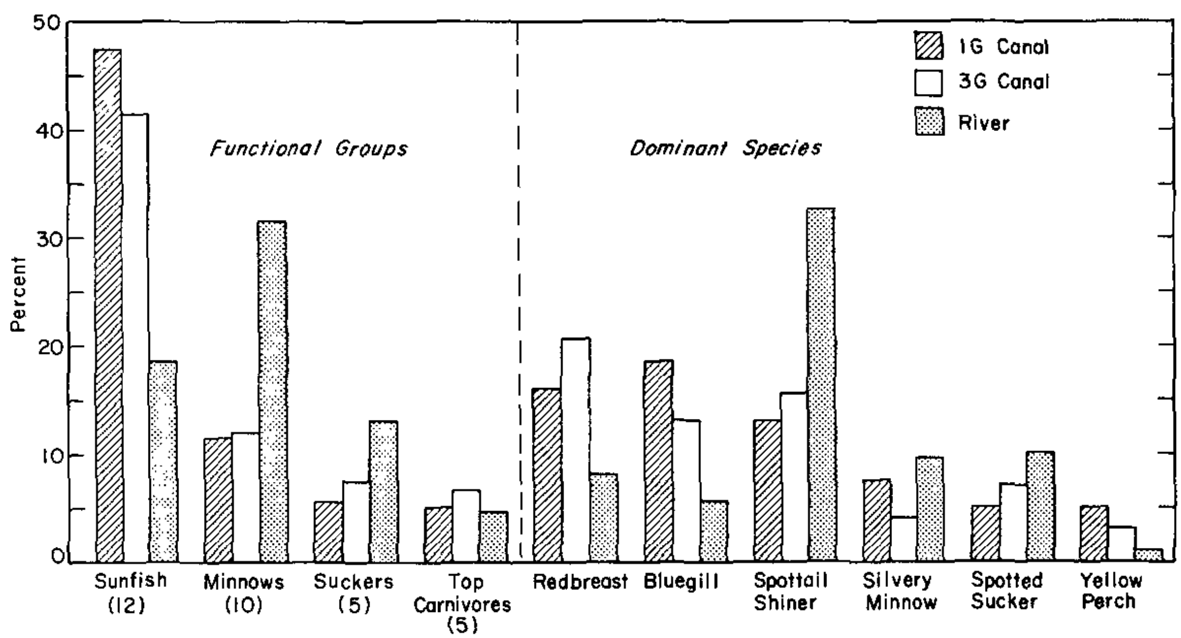


FIGURE 29. Relative Abundance of Fishes in the Savannah River and SRP Intake Canals

3.2 Fish Impingement

Fish impingement samples were obtained by intercepting the material washed from the traveling screens before it entered the disposal pipe (1G and 3G pumping stations) or as it exited the pipe (5G pumping station). Samples representing a 24-hour accumulation of screened material were obtained biweekly. All fishes were identified, weighed and measured. Dead fish were occasionally observed floating in the river and canals throughout the year and such fish were subsequently screened from the intake water. All fish which were decomposed and obviously dead for some time were tabulated but excluded from the data presented in this report. Inclusion of these fish would inflate the number and weight tallies by less than ten percent.

A summary of fish impingement is presented in Table 8. Total impingement for a ten-month period was 347 fishes of 35 species. The average of 7.3 fish per day would extrapolate to 2680 fish per year. The relative abundance and size of the impinged fish are presented in Table 9. Twelve of the 35 species were represented by either one or two individuals. No species comprised more than ten percent of the sample. The most common species were bluespotted

TABLE 8

Summary of Fish Impingement March to December 1977

	1G	*3G*	*5G*	*Total*
Number of Days Sampled	36	41	41	
Sample Days with Fish Impingement				
Number	30	38	24	
Percent	83.3	92.7	58.5	
Number of Species Impinged	25	30	19	35
Number of Fish Impinged	98	188	61	347
Weight of Fish Impinged (kg)	11.78	18.61	2.05	32.44
Maximum Number of Fish Per Day	13	25	11	30
Average Number of Fish Per Day	2.44	3.75	1.15	7.34
Estimated Annual Impingement	891	1369	420	2680

TABLE 9

Relative Abundance and Size of Impinged Fishes

Species	*Number*	*Average Length (Range), mm*	*Average Weight (Range), g*	*Total Weight, kg*
Bowfin	4	423 (345-458)	790 (517-1042)	3.162
American Eel	1	515	325	.325
American Shad	18	172 (70-477)	161 (3-915)	2.895
Gizzard Shad	17	214 (67-419)	177 (2-707)	3.015
Threadfin Shad	18	78 (40-145)	5 (1-22)	.098
Redfin Pickerel	11	200 (130-353)	75 (16-288)	.830
Chain Pickerel	4	202 (71-293)	75 (2-168)	.300
Silvery Minnow	4	79 (66-95)	5 (2-9)	.020
Golden Shiner	8	155 (95-190)	43 (9-89)	.304
Spottail Shiner	9	112 (76-127)	14 (5-22)	.125
Lake Chubsucker	2	135 (124-146)	34 (25-43)	.068
Spotted Sucker	2	317 (233-401)	399 (148-650)	.798
White Catfish	2	118 (80-155)	25 (4-45)	.049
Yellow Bullhead	1	180	75	.075
Flat Bullhead	14	187 (80-305)	115 (6-380)	1.613
Channel Catfish	29	196 (89-393)	70 (4-369)	1.968
Speckled Madtom	1	92	8	.008
Pirate Perch	5	64 (33-100)	7 (1-14)	.035
Mud Sunfish	2	150 (140-160)	68 (58-77)	.135
Flier	11	137 (70-185)	64 (7-122)	.704
Bluespotted Sunfish	34	63 (39-77)	6 (3-10)	.205
Redbreast Sunfish	19	157 (39-270)	122 (1-328)	2.319
Pumpkinseed	2	118 (110-125)	31 (24-38)	.062
Warmouth	32	150 (69-241)	89 (5-298)	2.850
Bluegill	8	149 (55-212)	87 (3-201)	.698
Dollar Sunfish	1	138	48	.048
Redear Sunfish	11	212 (61-278)	265 (4-386)	2.916
Spotted Sunfish	18	96 (63-160)	27 (4-29)	.572
Large Mouth Bass	5	281 (142-440)	277 (36-476)	1.385
Black Crappie	14	146 (2-172)	42 (2-172)	.589
Swamp Darter	1	49	1	.001
Christmas Darter	1	67	3	.003
Tessellated Darter	1	61	2	.002
Yellow Perch	25	159 (11-335)	83 (6-386)	2.138
Hogchoker	7	93 (82-105)	21 (15-31)	.148

sunfish (9.9%), warmouth (9.3%), channel catfish (8.2%), and yellow perch (7.6%). Redbreast sunfish, spotted sunfish, and American, gizzard, and threadfin shad each accounted for five percent of the total sample. All twelve centrarchid species (sunfish, crappie, and bass) together formed 46%, the five catfishes 13%, and the three shad 15% of the sample. Thus, while the 35 species are not impinged equally, there is no single species which predominates. Three impinged species — the swamp and Christmas darters, and speckled madtom — were not collected by any other technique during this study.

Impingement was determined biweekly. From March until June, samples were taken for several consecutive days to determine the daily variance (Table 10). The monthly variation for each pumphouse and the total sample are shown in Figure 30.

Comparison of the relative abundance of species in the canal fish community, as determined by electrofishing and trapping, with their relative abundance in the impingement samples reveals considerable variation in susceptibility to impingement. The dominant species of the canal fish community do not constitute a corresponding fraction of the impingement samples (Figure 31). For example, bluegill, redbreast sunfish, and spottail shiners together constitute one-half of the canal fish communities but only 13% or less of the total impingement samples. In contrast, the warmouth sunfish, similar in size to redbreast and bluegills, ranks high among impinged species but low in the canal. The channel catfish is the most frequently impinged species at both canals although comprising only 1 to 1.5% of the canal community. Another catfish, the flat bullhead, is more abundant in the canals but less prominent in impingement samples.

Fifteen species which frequent the canals have not been recovered in the impingement samples. Five impinged species were absent from the canal samples. Most of these fishes were infrequent in their respective collections.

A recent survey of fish impingement at 33 power plants on inland waters[7] indicates that the SRP impingement of 220 fish per month is very low. Impingement at these power plants ranged from 0.5 fish to 2.2 million fish per month. Only two of the 33 plants had lower impingement than the Savannah River Plant.

TABLE 10

Variation in Number of Fish Impinged

		Days Sampled	*Avg. Number of Fish*	*Standard Deviation*	*Standard Error*
March	1G	2	2.5	2.12	1.50
	3G	7	6.7	3.20	1.21
	5G	8	1.1	1.46	0.52
April	1G	6	2.3	3.39	1.38
	3G	6	4.3	4.41	1.80
	5G	7	5.6	3.46	1.31
May	1G	7	5.6	3.51	1.32
	3G	7	8.3	8.18	3.05
	5G	6	0.5	0.55	0.39
June	1G	8	4.0	4.04	1.43
	3G	8	3.5	2.45	0.87
	5G	7	0.1	0.38	0.14
July	1G	2	2.0	2.83	2.00
	3G	2	4.5	4.95	3.50
	5G	2	1.0	0.00	0.00
August	1G	2	3.5	2.12	1.50
	3G	2	1.0	1.41	1.00
	5G	2	1.0	0.00	0.00
September	1G	2	1.5	2.12	1.50
	3G	2	0.5	0.71	0.50
	5G	2	1.0	1.41	1.00
October	1G	3	1.0	1.00	0.58
	3G	3	0.7	0.58	0.33
	5G	3	0.7	1.15	0.67
November	1G	2	1.0	1.41	1.00
	3G	2	1.5	0.71	0.50
	5G	2	0.0	0.00	0.00
December	1G	2	1.0	1.41	1.00
	3G	2	6.5	0.71	0.50
	5G	2	0.5	0.71	0.50
Average	1G		2.44	1.44	0.46
	3G		3.75	2.65	0.84
	5G		1.15	1.61	1.53

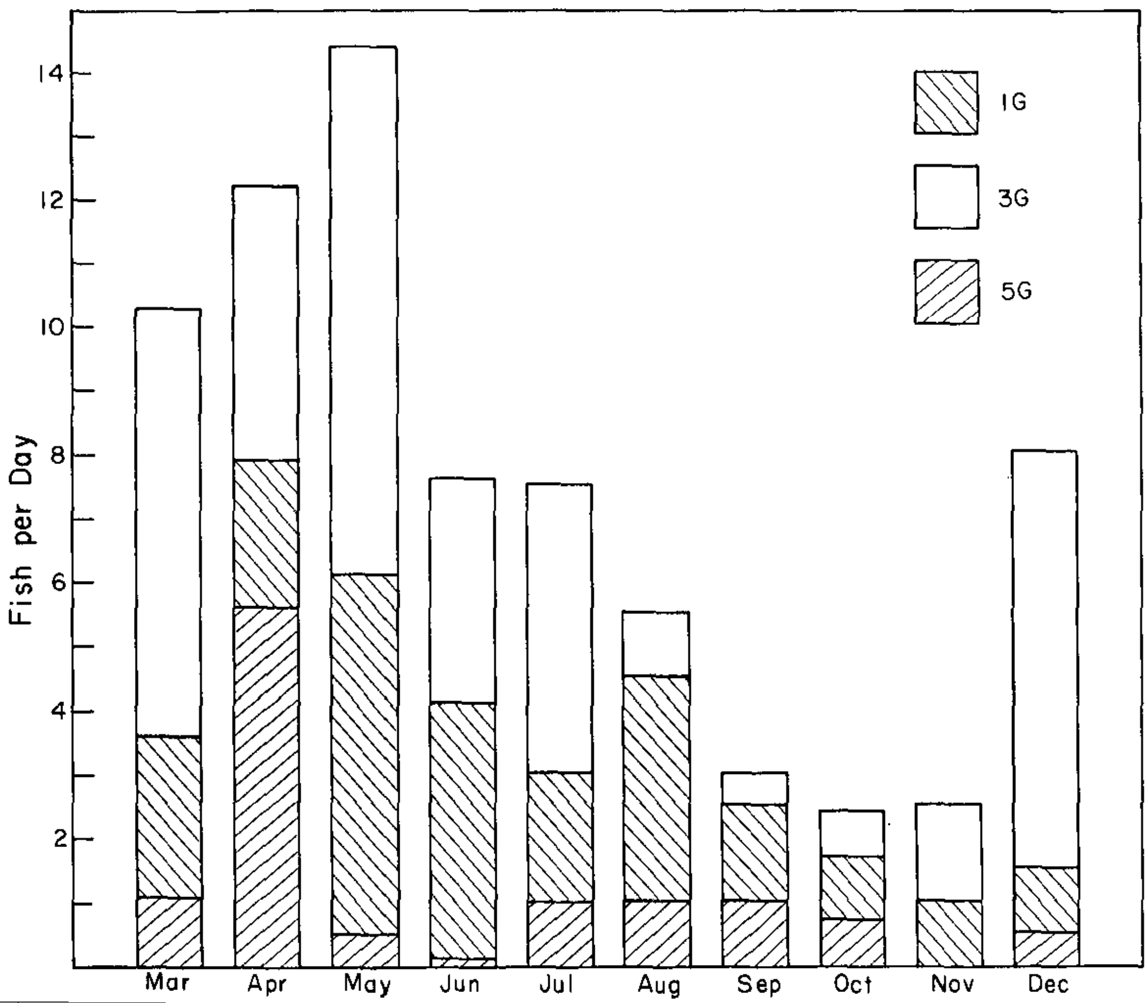
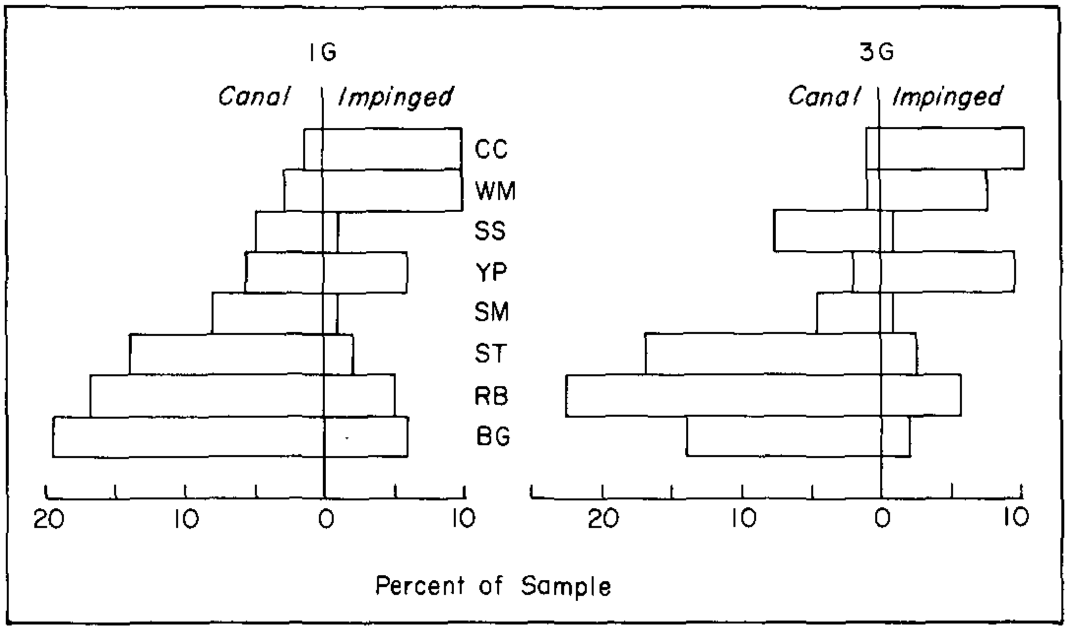


FIGURE 30. Monthly Variation in Number of Fish Impinged per Day



CC - Channel Catfish
WM - Warmouth
SS - Spotted Sucker
YP - Yellow Perch
SM - Silvery Minnow
ST - Spottail Shiner
RB - Redbreast
BG - Bluegill

FIGURE 31. Differential Impingement of Selected Dominant Species of Canal Fish Communities and Impingement Samples

3.3 Entrainment

3.3.1 Plankton Collection Methods

The river ichthyoplankton was sampled with 760 micron plankton nets 0.5 m in diameter and 1.5 m long, with a digital flowmeter mounted in the mouth of the net. The river debris content of the water limited sampling time to ten minutes, during which 50 to 100 cubic meters of water was typically filtered. At the upriver and downriver sampling stations (see Figure 2) paired samples were collected from the top and bottom meter of the water column at three transect points across the river, yielding 12 samples per locality. One side of the transect at the downriver station was too shallow at low river elevations to distinguish top and bottom sampling so only ten samples were obtained on those dates.

The 1G and 3G canals were sampled by towing the plankton net the length of the canal. Paired replicates were obtained from surface and bottom waters, a total of four samples per sampling date.

Canal velocities were insufficient to permit anchored sampling. The nature of water flow past the outer trash racks rendered plankton sampling difficult at that point. A substantial mat of twigs and debris has accumulated on the trash racks. This mat is 10-20 cm thick and sufficiently dense at some intake bays to cause the pumps to draw the water down below the canal level at low river elevations. The mat produces a slow, diffuse flow of water past the trash racks at velocities below the lower limit (0.3 m/sec) of the flowmeters used with the plankton nets.

The 5G intake cove is too small to permit net towing. The low current velocity and complex current patterns within the cove make reliable sampling very difficult. The use of a low velocity rotor on the current meter permitted sampling directly in front of the intake grates but the substantial lateral flow of water parallel to the grates reduces the reliability of these estimates.

Upper Three Runs Creek was sampled while at anchor approximately 200 m upstream of its juncture with the river. The inlet and outlet of the oxbow channel adjacent to the 1G canal were also sampled when river elevation was sufficiently high.

3.3.2 Density Calculations

Ichthyoplankton samples were obtained biweekly from March 17 to August 1, 1977. It has previously been shown[9,10] that the best estimate of plankton density is obtained by simply dividing the total number of organisms collected at a station by the total volume of water sampled. This method provides the best estimate of density but gives no indication of the variance associated with that estimate. This study compares the calculated variance for the average of the replicate samples, the average of unpaired samples, and the composite upriver versus downriver samples.

The velocity of the river current is highly variable, both vertically and laterally. Since no reliable estimate of the amount of water sampled could be obtained on board the boat while the plankton net was in operation, the samples were standardized to time. Each sample represents ten minutes of filtering but different amounts of water sampled, thus the results are expressed as density (that is, the number of eggs or larvae per cubic meter of water filtered).

3.3.3 Fish Egg Entrainment

The seasonal pattern and density for the 357 fish eggs collected at six sampling stations during this study are given in Table 11. Eggs of the American shad comprised 96.4% of all fish

TABLE 11

Fish Eggs Recovered from Ichthyoplankton Samples

		Eggs per Cubic Meter					
Date	*Total Eggs Recovered*	*Upriver Station*	*Upper Three Runs*	*1G Canal*	*3G Canal*	*5G Intake*	*Downriver Station*
Mar. 17	4	-	-	-	-	-	.004
Mar. 28-30	15	.006	0	0	0	-	.010
Apr. 11-12	6	.004	0	.002	0	-	.001
Apr. 25-26	44	.031	0	0	.004	-	.017
May 9-10	117	.105	0	0	.007	-	.081
May 23-25	116	.064	0	0	0	.038	.058
June 6-8	45	.023	0	0	0	.024	.021
June 20-22	7	.003	0	0	0	0	.004
July 5-7	1	0	0	0	0	0	.001
July 21	1	0	0	0	0	0	.001
Aug. 1	1	0	0	0	0	0	.001

eggs collected. The changes in egg density at the upriver and downriver stations with time are shown in the upper graph of Figure 32. Although some spawning commenced in March, only 6% of the total eggs collected were acquired by April 12. The primary spawning activity began in late April and both the peak in egg density and 50% of spawning were achieved by May 10. Spawning continued for another month and was 85% complete by May 25 and 98% complete by June 8.

The variance associated with these samples is given in Table 12. The composite sample density is derived by dividing the total number of eggs collected by the total volume of water sampled. As all eggs are thus considered as comprising a single sample, no estimate of variance is possible. The mean density is the average of the 12 sample densities and generally is greater than the corresponding composite density. Variance is estimated two ways: considering the 12 samples as independent estimates, or considering them as six paired samples. Both methods yield similar results and an analysis of variance comparing variance between the pairs to variance within the entire group demonstrates the difference to be significant only once among the ten collections. However, these variance estimates are very high and the standard deviation exceeds the mean in 9 of the 10 collections.

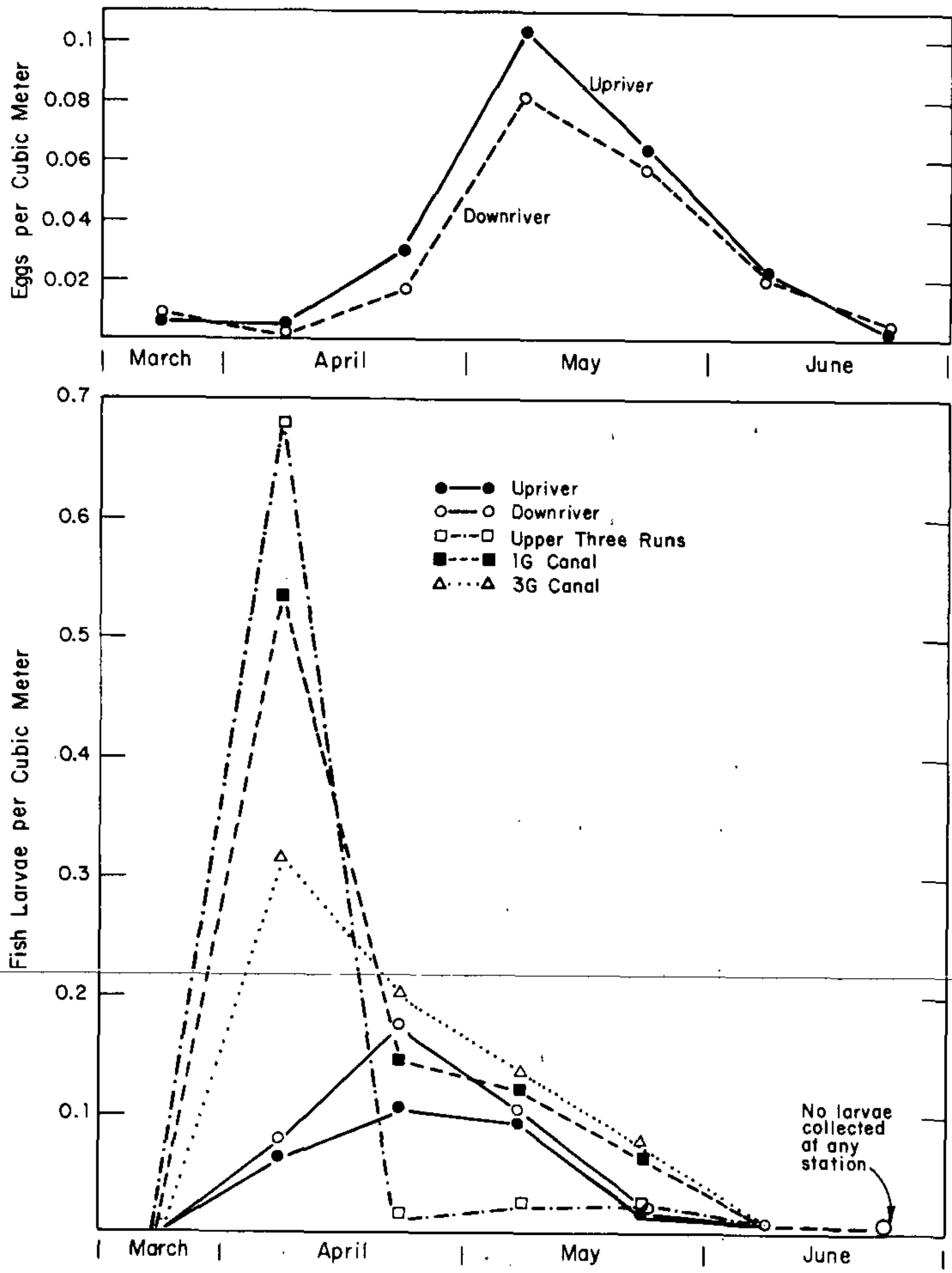


FIGURE 32. Seasonal Trends in Density of Fish Eggs (Above) and Larval Fish (Below)

TABLE 12

Variance of Fish Egg Samples

Date	*Composite Sample Density*	*Mean Density*	*Std. Dev.*	*Variation*	*Mean Var. of Paired Samples*	*F[a] Ratio*
UPRIVER	n = 1	n = 12	n = 12	n = 12	n = 6	
April 11	.005	.005	.007	.00005	.00001	5.00[b]
April 25	.031	.035	.054	.00292	.00325	1.11
May 9	.105	.145	.229	.05244	.05476	1.04
May 23	.064	.068	.079	.00624	.00680	1.09
June 6	.023	.027	.040	.00160	.00159	1.01
DOWNRIVER	n = 1	n = 10	n = 10	n = 10	n = 5	
April 11	.002	.002	.006	.00004	.00001	4.00
April 25	.017	.016	.018	.00032	.00031	1.03
May 9	.081	.104	.128	.01638	.01638	1.00
May 23	.058	.066	.023	.00656	.00529	1.24
June 6	.021	.022	.040	.00160	.00178	1.11

PAIRED UPRIVER-DOWNRIVER COMPOSITE SAMPLES n = 2

	Mean	Std. Dev.	Variance
April 11	.004	.002	.000005
April 25	.024	.010	.00010
May 9	.093	.017	.00029
May 23	.061	.004	.00002
June 6	.022	.001	.000002

a. Analysis of variance comparing variance between the paired replicates to variance within the entire group.

b. Significant at 0.95 level.

Comparison of the upriver and downriver collections provides an estimate of the variance associated with the composite sample densities (Table 12). The estimate is much lower than that calculated using mean densities. The usefulness of upriver plankton densities as predictors of downriver densities is shown in Figure 33, with high correlation possible (see also Figure 32).

Several aspects of the egg data merit further discussion. No eggs were collected from Upper Three Runs and, in the absence of information of any nature to the contrary, it is concluded that this creek is not used as a spawning site by anadromous fishes.

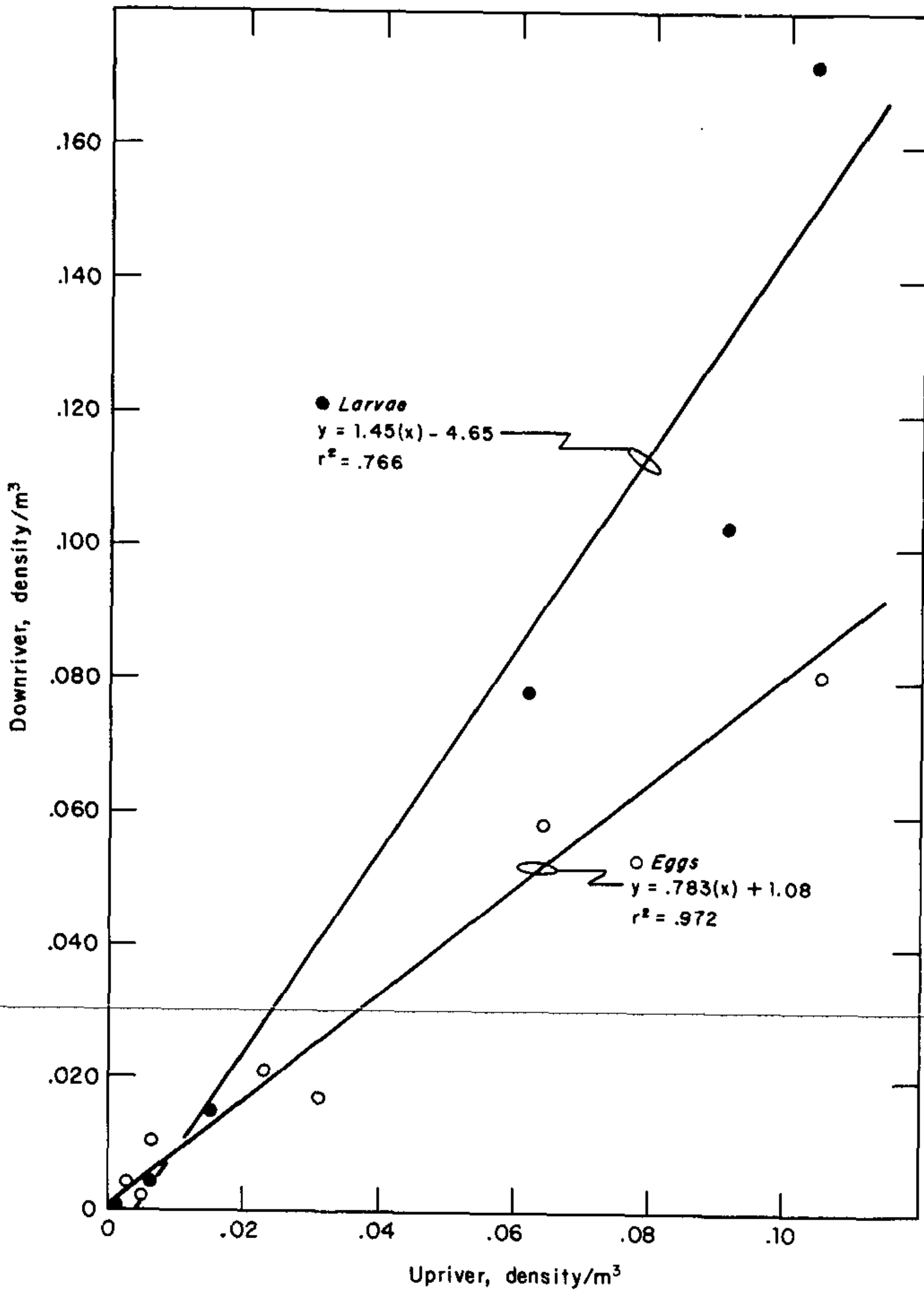


FIGURE 33. Upriver Densities as a Predictor of Fish Egg and Larval Fish Densities Downriver

Only four eggs were collected from the 1G and 3G canals. This conspicuous absence can apparently be attributed to the semibuoyant nature of shad eggs which require river turbulence to maintain them in the water column. Eggs ~~that~~ drift into zones of little or no current and turbulence soon settle to the bottom. The trend in vertical distribution for shad eggs is given in Table 13. The data represent composites of all surface samples compared to bottom samples, providing best estimates of egg density and demonstrating the tendency for greater egg densities near the bottom. Ichthyoplankton are usually patchily distributed in a water mass and samples without organisms were not uncommon in our collections. The variance resulting from inclusion of these zero density samples prevents the demonstration of statistical significance between surface and bottom densities.

TABLE 13

Vertical Distribution of American Shad Eggs Based on Composite Data from Six Upriver and Four Downriver Samples at Each Depth

	Surface Water			*Bottom Water*		
Date	*Number of Eggs*	*m^3 Sampled*	*Eggs/m^3*	*Number of Eggs*	*m^3 Sampled*	*Eggs/m^3*
April 25	11	919	0.012	30	729	0.041
May 9	36	739	0.049	77	413	0.186
May 23	50	929	0.054	56	709	0.079
June 6	3	939	0.003	38	774	0.049

Since the bottom of the river channel is three meters below the bottom of the intake canal entrances (see Figures 7, 10, and 13), those eggs suspended in the lower water column are not susceptible to entrainment. However, the "worst possible case" estimates (which disregard differences in vertical distribution) are calculated using average egg densities at the upriver station.

The curve described by the 8 upriver collection data points (see Figure 32) was used to estimate that 72.3 million shad eggs were transported past the intake canals and were susceptible to impact during April, May, and June (Table 14). There are no data available concerning the fecundity of American shad in the Savannah River but the fecundity of this species in the Altamaha River in Georgia is 365,000 ova per female.[11] This implies that a minimum of 200 female shad spawned in the Savannah River above the SRP, a figure that seems conservatively low. Based upon the amount of cooling water withdrawn during this period and the estimated density of shad eggs in the river, 6.8 million eggs could have been drawn into the intake canals where they either settled to the bottom and were lost or they were directly entrained into the pumphouse. This figure is equivalent to the reproductive output of 19 females and 9.5% of the eggs transported past the intake canals.

TABLE 14

Estimated "Worst Case" Fish Egg Entrainment (Millions of Eggs)

Date	*Upriver Population*	*Entrained*				*Percent of Upriver Population*
		1G Canal	*3G Canal*	*5G Intake*	*Total*	
April	23.117	0.341	0.651	0.062	1.054	4.6
May	41.810	1.756	2.898	0.340	4.994	11.9
June	7.398	0.262	0.461	0.070	0.793	10.7
Total	72.325	2.359	4.010	0.472	6.841	9.5

3.3.4 Larval Fish Entrainment

More than 1700 larval fish were collected and identified to species or the lowest taxonomic level possible. Fish larvae frequently can only be identified to the generic or family level for two reasons:

- Larvae which are only several days old often lack the definitive characteristics that distinguish them from closely related species
- Damage incurred during collection often obscures the pertinent morphological features

A minimum of 22 species are represented in the larvae collection (Table 15). Several additional species, particularly minnows and sunfishes, are undoubtedly present but unrecognized. Single specimens of two species are notable. The Atlantic sturgeon is a rare anadromous fish and the Atlantic needlefish is an estuarine species not known to spawn in this area. The blueback herring, spotted sucker, and black crappie were the most common species. Nearly half of all larvae collected were clupeids, primarily blueback herring.

TABLE 15

Relative Abundance of Fish Larvae

	Number	Percent
Acipenseridae Atlantic sturgeon	1	
Lepisosteidae Longnose gar	1	
Clupeidae American shad Blueback herring *Dorosoma* sp.	830	48.1
Cyprinidae Carp Golden shiner *Notropis* sp.	172	10.0
Catastomidae Spotted sucker one other species	193	11.2
Ictaluridae Channel catfish two bullhead sp.	96	5.6
Aphredoderidae Pirate perch	11	
Belonidae Needlefish	1	
Atherinidae Brook silverside	2	
Centrarchidae Black crappie Largemouth bass two *Lepomis* sp.	367	21.3
Percidae Yellow perch another percid	50	2.9
Total	1724	

The seasonal pattern and density for 1307 larvae collected at six sampling stations are given in Table 16. The variance associated with the upriver and downriver samples is presented in Table 17. Two distinct trends demonstrated by these data are more graphically emphasized in Figure 32. The abundance curve for larvae precedes that for eggs by approximately two weeks. The peak in larval density and 78% of the larvae were collected by April 25. This reflects species differences in that 96% of the eggs, but an insignificant fraction of the larvae, were American shad. Also, the greatest densities of larvae occurred in Upper Three Runs, 1G Canal, and 3G Canal, respectively. This was caused by a large emission of blueback herring larvae which were swept out of the forested floodplain into the river at the mouth of Upper Three Runs and thence into the intake canals.

TABLE 16

Larval Fish Recovered from Ichthyoplankton Samples

Date	*Total Larvae Recovered*	*Larvae Per Cubic Meter*					
		Upriver Station	*Upper Three Runs*	*1G Canal*	*3G Canal*	*5G Intake*	*Downriver Station*
Mar. 17	12	-	-	-	-	-	.012
Mar. 28-30	3	.001	.007	0	.004	-	0
Apr. 11-12	668	.065	.679	.532	.316	-	.080
Apr. 25-26	331	.104	.011	.146	.200	-	.172
May 9-10	198	.091	.020	.121	.134	-	.103
May 23-25	83	.015	.019	.062	.077	.010	.015
June 6-8	11	.006	0	0	0	.012	.004
June 20-22	0	0	0	0	0	0	0
July 5-7	1	0	-	0	0	0	.001
July 21	0	0	0	0	0	0	0
Aug. 1	0	0	-	0	0	0	0

TABLE 17

Variance of Fish Larvae Samples

Date	*Composite Sample Density*	*Mean Density*	*Std. Dev.*	*Variance*	*Mean Var. of Paired Samples*	*F*[a] *Ratio*
UPRIVER	n = 1	n = 12	n = 12	n = 12	n = 6	
April 11	.065	.074	.046	.00212	.00067	3.16
April 25	.104	.107	.060	.00365	.00214	1.71
May 9	.091	.105	.122	.01485	.00771	1.93
May 23	.015	.016	.013	.00018	.00008	2.25
June 6	.006	.006	.008	.00006	.00005	1.20
DOWNRIVER	n = 1	n = 10	n = 10	n = 10	n = 5	
April 11	.080	.087	.063	.00397	.00136	2.92
April 25	.172	.168	.101	.01020	.00390	2.62
May 9	.103	.126	.126	.01588	.00182	8.73[b]
May 23	.015	.015	.015	.00023	.00037	1.61
June 6	.004	.003	.010	.00010	.00300	30.00[c]

PAIRED UPRIVER-DOWNRIVER COMPOSITE SAMPLES n = 2

	Mean	Std. Dev.	Variance
April 11	.072	.008	.00007
April 25	.138	.048	.00231
May 9	.097	.008	.00007
May 23	.015	0	0
June 6	.005	.001	.000002

a. Analysis of variance comparing variance between the paired replicates to variance within the entire group.

b. Significant at .95 level.

c. Significant at .99 level.

The role of the submerged floodplain as a spawning zone and nursery is shown by Table 18. High water had submerged the floodplain forest behind the natural river dikes during the first half of April (see Figure 4). Samples collected at this time (April 11-12) revealed the density of larvae at the mouth of Upper Three Runs to be an order of magnitude greater than at the upriver sampling station (Figure 34). The density of larvae collected in the 1G and 3G canals was also much higher (but only 1G significantly different at the 0.95 level) than either upriver or downriver densities. A similar increase (significant at the 0.95 level) was also noted between the inlet and outlet of the oxbow channel adjacent to Upper Three Runs and the 1G intake canal (see Figure 2). This reflects the influx of larvae from the submerged floodplain on the opposite bank of the river. Two weeks later (April 25-26) the river level was falling precipitously (see Figure 4), the floodplain was no longer submerged, and the density of larvae leaving Upper Three Runs was approaching zero. Larval densities at the various sample stations did not differ significantly from one another. When these data are plotted as a function of distance downstream (Figure 35) it is apparent that the larvae entrained in the intake canals on April 11-12 reflect the dilution of the larvae injected into the river from Upper Three Runs.

Blueback herring constituted 94% of the identifiable clupeids entering the river from the submerged floodplain on April 11-12. They were distinctly outnumbered by the *Dorosoma* species in later collections.

TABLE 18

The Relative Densities of Fish Larvae on Two Selected Dates

	April 11-12	*April 25-26*	*Distance (km)*
River elevation	29 m, steady	27 m, falling	
Floodplain	submerged	exposed	
LARVAE PER CUBIC METER			
Upriver	.065	.104	0.0
Upper Three Runs	.679	.011	2.0
1G canal	.532	.146	2.2
3G canal	.316	.200	5.0
Downriver	.080	.172	6.6
Oxbow inlet	.036	.112	0.0
Oxbow outlet	.136	.137	0.9

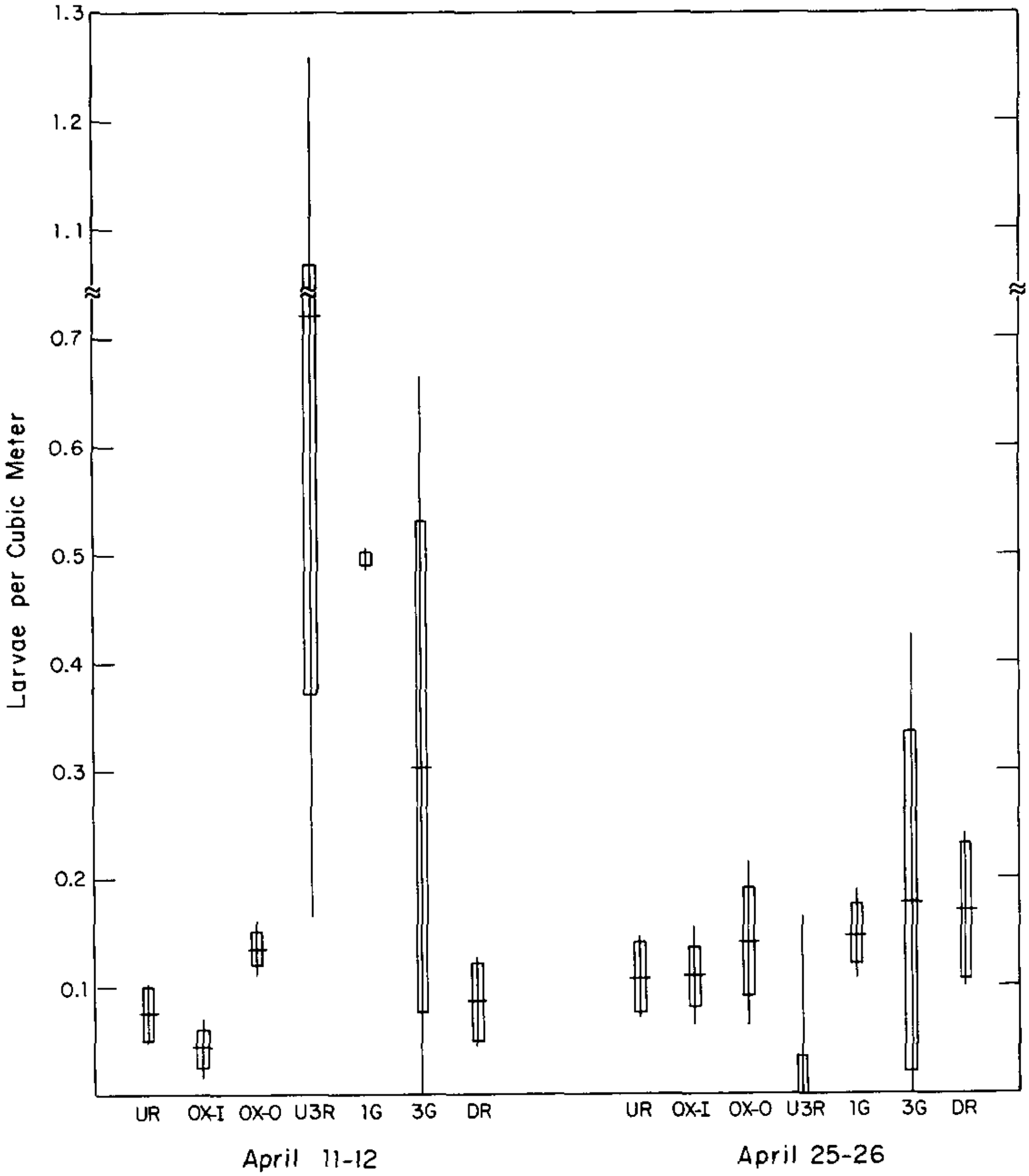


FIGURE 34. The Input of Larval Fish from Submerged Floodplain

The mean, 95% confidence limits, and ±2 std. errors are indicated by the horizontal bar, vertical line, and rectangle, respectively. Sampling stations designated by: UR -- upriver, OX-I -- oxbow inlet, OX-O -- oxbow outlet, U3R -- upper three runs, 1G -- 1G canal, 3G -- 3G canal, and DR -- downriver.

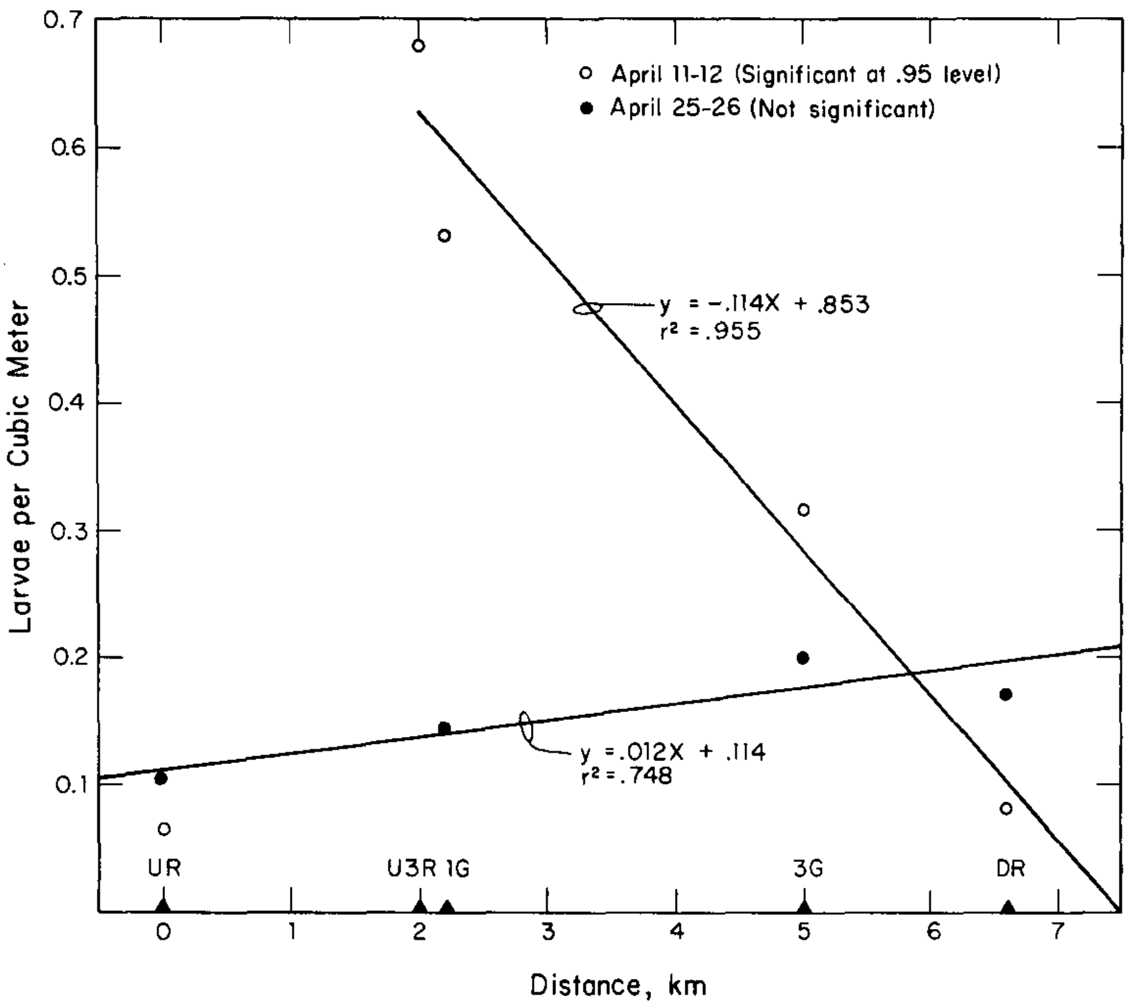


FIGURE 35. The Relationship Between River Distance and Larval Densities

An estimate of the number of larval fish entrained at each pumping station during April and May is presented in Table 19. The values were derived from the curves generated for each of the collecting localities and dates (see Figure 32). The total entrainment of 19.6 million larval fish represents 9.1% of the 216 million larvae susceptible to entrainment. It is estimated that 75 million larval fish were added to the river along the 6.6 km passage between the upriver and downriver sampling stations, and the entrained larvae represent the equivalent of 26% of this input. This influx of larvae is reflected in the lowered reliability of upriver density as a predictor of downriver density (see Figure 33), as compared to the predictability of downriver egg densities. It is known that the floodplain above Upper Three Runs contributes a substantial number of larvae to the river and this subsequently

TABLE 19

Estimated Larval Fish Entrainment (As Millions of Larvae)

	Upriver	*Downriver*	*Entrained* *1G*	*3G*	*5G*	*Total*
April	109.89	158.50	4.952	7.688	0.317	12.957
May	31.00	38.03	2.152	4.243	0.275	6.670
Total	140.89	196.53	7.104	11.931	0.592	19.627

Total Larvae Downriver	196.53	196.53
Total Larvae Upriver	-140.89	
	55.64	
Total Larvae Entrained	+ 19.63	19.63
Total Larvae Gained in river segment	75.27	
Total Larvae Population		216.16

Entrained Larvae = 9.1% of Total Larvae

increases entrainment at the pumping stations. The absence of any data regarding the amount of water re-entering the river at the mouth of Upper Three Runs precludes any estimate of the total number of larvae contributed to the river at this point. In addition, no data exists regarding the contribution of other portions of the river floodplain to the larval fish population. This floodplain ranges up to 3 km wide for much of the length of the Savannah River, including the entire 30 km of SRP river frontage.

Herring and shad dominated the larval fish collections. One-fourth of these fish could not be identified beyond the family (Clupeidae) level (Table 20). The two resident species, gizzard and threadfin shad, were not separable among the larvae collected. Jointly they comprised 19% of the clupeids identifiable to the generic level. Only four of the 507 anadromous *Alosa* identified were American shad, the remainder being blueback herring. It is unlikely that a significant portion of the unidentifiable clupeids were American shad for 99% were less than 5.7 mm total length, the minimum size known for American shad, the larger species.

The paradox presented by American shad contributing 96% of the fish eggs collected but virtually none of the larval fish is less perplexing under closer examination of their reproductive ecology and behavior. Shad eggs are spawned in the open river

TABLE 20

Relative Abundance of Clupeid Larvae Collected

	Number	*Percent*
Blueback herring	503	60.6
American shad	4	0.5
Dorosoma sp.	120	14.5
unidentifiable clupeid	203	24.5

and normally hatch in approximately 72 hours. All of the eggs recovered during this study were in early stages of development and few had progressed beyond the formation of the embryonic axis. The three dams in the Augusta area prevent shad from migrating more than 50 to 80 km further upstream from SRP. It is apparent that eggs spawned above the SRP are carried downstream past the SRP before they hatch.

The reverse circumstances exhibited by blueback herring, which contributed few eggs but dominated the larval samples, also reflect their specific reproductive habits. This species spawns adhesive eggs over flooded vegetation where the eggs adhere to the underbrush until they hatch.[12,13,14]

4. SUMMARY AND CONCLUSIONS

4.1 Species of Special Concern

The only endangered species of fish known from the Savannah River is the shortnose sturgeon. This fish is restricted to tidewater regions and has never been reported near the SRP. The only commercial species of significance are the American shad and the channel catfish. These species are exploited to a very limited degree by nonprofessional local fishermen. Sportfishermen are the principal consumers of river fishes, primarily pursuing sunfishes and crappie. The striped bass is a favorite quarry of fishermen in the Augusta area.

4.1.1 The American Shad

This anadromous species ascends the Savannah River as far as the several dams permit and spawns above and near the SRP. The semi-buoyant eggs are carried past the SRP and are susceptible to either direct entrainment or loss by sinking to the bottom sediments upon reduction of current velocity in the intake canals. Assumption of "worst possible case" conditions indicates a potential loss of 9.5% of the eggs susceptible to impact.

Few shad larvae hatch near SRP. Most eggs are swept downstream in the early stages of development. Juveniles apparently migrate back up the river and they appear in plankton and electrofishing samples in late June. The juvenile shad are attracted to the intake canals where they are particularly conspicuous while feeding upon insects at dusk. In spite of their abundance in the canals, they are rarely impinged. A few adult fish are impinged late in the spawning season. These fish are always emaciated and appear unlikely to survive their spawning effort. American shad commonly die following their once-in-a-lifetime spawning in southern rivers.

The impact of SRP upon the American shad is limited to the entrainment of shad eggs for a three-month period. High fecundity and natural mortality rates are characteristic of this species. The egg-to-adult survival rate required to maintain population levels in the Connecticut River is 0.00056%.[15] The 9.5% egg loss assumed to be inflicted by SRP is probably negligible under these circumstances. The tendency for shad eggs to remain near the bottom, and the shallow entrances to the intake canals most likely result in substantially lower egg loss.

4.1.2 The Channel Catfish

This fish is exploited to a very limited degree by local fishermen. Most of the specimens collected during this study were small. Catfish spawn in constructed nests and guard their eggs and young. No eggs appear to be entrained and less than 5% of the larvae collected were this species. It does constitute 10% of the fishes impinged but the numbers are too few to contribute substantially to its natural mortality. Juvenile catfishes are commonly consumed by larger piscivorous fishes.

4.1.3 The Striped Bass

A recent study has revealed that the Savannah River population of this species has unique spawning habits.[16] Some individuals spend most of the year in upstream waters and then migrate downstream to spawn, the reverse of the typical habits in northern rivers. All spawning is restricted to a portion of a channel above Savannah. Striped bass in the Augusta area congregate near the outfalls of the Augusta canal and the New Savannah Bluff Lock and Dam. During this study no eggs, larvae, juveniles, or adults were collected in any manner. One adult was observed while electrofishing. Two adults were collected by hook and line some distance upstream in Upper Three Runs by SRP personnel. The SRP is judged to have no impact upon this species.

4.1.4 The Blueback Herring

This forage fish has no commercial or sportfishing value in the Savannah River and is essentially unexploited. It ascends the river to spawn but is not among those species impinged. Its adhesive eggs are not subject to entrainment. Substantial entrainment of larval fish is the primary mode of SRP impact as it is the most commonly entrained species. Juveniles are abundant in the intake canals from June until December but are not subject to impingement in spite of their frequent capture by electrofishing between the training walls of the pumphouses.

4.2 Impingement

The low fish impingement rate associated with SRP cooling water withdrawal renders analysis of the causative factors difficult. The small sample sizes and high variability associated with a particular pumping station greatly reduce the potential to demonstrate statistical significance.

The combination of an approach channel intake, individual intake bays, and conventional vertical traveling screens is generally considered to be an unfavorable intake design.[17] Fishes following the shoreline are led directly to the intake structure where they may become entrapped by eddy currents, turbulence and intake velocity. Several environmental factors may contribute to impingement rate as well.

Low water temperatures are known to immobilize certain species of fishes and reduce their ability to escape intake currents. The threadfin shad — not native to the Savannah River — is adversely affected by water temperatures below 10°C. Impingement of this species at SRP occurs only during winter when the river temperature is 10° or less. No other species appears to be affected in this manner at SRP.

The effect of river elevation is uncertain. Impingement is lowest during the summer when the river is low for extended periods. The accumulated layer of debris across the trash racks below the low water level is sufficiently dense that flow is inhibited and the pumps at certain intake bays can lower the water level within the bay 10 to 30 cm below the canal level (see Section 3.1.1). This layer obviously will inhibit the passage of fish into the intake bay, at least below the low water level. Higher canal elevations permit the unimpeded movement of fishes over this barrier but the forces acting to draw the fish into the pump are subsequently reduced. A distinct vortex is visible above the intake opening at low water levels. This vortex is nearly imperceptible at high water levels and the amount of surface debris collected on the trash screens is reduced. The bluespotted sunfish may be more susceptible to impingement at high water, particularly at the 5G pumping station. Here the floodplain is submerged on both sides of the pumphouses and fishes exploiting the temporary food resources of the floodplain may be attracted to the intervening intake cove.

Water velocities rarely exceed 0.3 m/sec at low water levels and decrease even more as the river rises. The virtual absence among the impingement samples of small fishes commonly encountered in the intake canals, such as mosquitofish, brook silverside, and several minnows, indicate that many small, resident fishes have little problem in avoiding impingement. Shoreline currents are very low or imperceptible (see Figures 23 and 24).

The differential impingement rates shown in Figure 31 indicate that the selected microhabitat and behavior of certain species can affect their susceptibility to impingement. These factors remain unidentified and their magnitude unknown.

4.3 Entrainment

The estimated entrainment of fish eggs was based upon "worst possible case" conditions (entrainment at river densities) because no eggs were collected in canal plankton samples. Larval fish entrainment was based upon canal collection data. Several operant factors will tend to depress both types of mortality.

Fish eggs were rarely found in canal plankton samples. The losses are assumed to occur when eggs suspended in the turbulent water column of the river are swept into the canal and sink to the bottom where they are covered with sediment. The eggs tend to be more numerous in the lower portions of the water column and those near the bottom will pass by the intake canals without being entrained into the canal entrance above.

Fish larvae are planktonic for the first several days of life and are transported primarily by the water mass. As they grow they become more capable of directed movement and swimming against a current. Thus, the assumption that all larvae carried into an intake canal will subsequently be entrained into the pumps is not necessarily valid. The persistence of minnows, sunfish, and larval and juvenile silversides in the canals lends credence to this mitigating factor. The sunfish are known to spawn in the intake canals and their domination of the canal fauna throughout the year is evidence that their larvae are not totally consumed by entrainment.

Entrainment losses principally affect two species, with estimated maximum loss of 9.5% of American shad eggs and 9.1% of blueback herring larvae. Both species feature enormous fecundity—averaging 365,000 eggs per female shad, and 244,000 eggs per female herring[13] — in the Altamaha River. Both suffer tremendous natural mortality, the American shad requiring the production of 2,000 eggs to ensure the return of a single adult to spawn (in the Connecticut River).

In the absence of information regarding the number of shad and herring which spawn in the Savannah River, it is difficult to assess the impact of a ten percent loss of eggs and larvae. There are no historical data to indicate whether their populations have decreased, remained constant, or increased during the 25 years they have been subjected to the impact of SRP cooling water withdrawal.

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