Effects of Intermittently Chlorinated Cooling Tower Blowdown on Fish and Invertebrates

Kenneth L. Dickson,* Albert C. Hendricks, John S. Crossman,[1] and John Cairns, Jr.

Biology Department and Center for Environmental Studies, Viriginia Polytechnic Institute and State University, Blacksburg, Va. 24061

■ An in situ bioassay was conducted to evaluate the effects of intermittently chlorinated cooling tower blowdown from Appalachian Power Co.'s Carbo, Va., plant on bluegill sunfish (*Lepomis macrochirus* Raf.) and a snail (*Anculosa* sp.). Cooling towers at the plant were treated for slime control with 0.75 mg/l. of chlorine for 30 min four times a day. The cooling tower blowdown was discharged to the Clinch River. Caged fish and invertebrates were placed at various distances downstream from the blowdown discharge and observed for 96 hr. Amperometric determinators for both free and total chlorine were made at 10-min intervals at selected stations throughout the study period. No fish deaths occurred which could be attributed to the blowdown discharges. However the blowdown was acutely toxic in 72 hr to 50% of the snails exposed to less than 0.04 ppm total residual chlorine for less than 2 hr/day and to 80 μg/l. copper plus other blowdown constituents. Nevertheless the impact of the cooling tower blowdown on the total ecology of the Clinch River was probably of no importance since the observed mortalities were restricted to an area extended not over 20 ft from the left bank and 800 ft downstream.

Despite the widespread distribution of power plants and many years of operation there is very little evidence on the effects of intermittently chlorinated cooling tower blowdown from power plants on aquatic organisms. Brook (*1*) described the effect of such chlorination practices on the photosynthesis and respiration of algae and reported a definite reduction in both photosynthesis and respiration immediately after chlorination. Brungs (2) suggests that 0.1 mg/l. not to exceed 30 min/day or 0.05 mg/l. not to exceed 2 hr/day should not result in significant kills of aquatic organisms or adversely affect the aquatic ecology. However, as Brungs (2) states, the recommendations for discontinuous total residual chlorine in fresh water are not founded on solid ground. Field studies by Basch (3) conducted with caged fish below a sewage outfall where chlorinated and nonchlorinated effluents were discharged found toxic conditions existing for rainbow trout (*Salmo gairdneri*) 0.8 mile below the outfall. Tsai (*4, 5*) found a reduction in number and species of fish below plants discharging chlorinated sewage. Both Basch and Tsai attributed the toxic conditions to the chlorinated effluents. Sprague and Drury (6) demonstrated an avoidance by rainbow trout of 0.001 mg/l. free chlorine. Brungs (2) in a personal communication with Truchan and Basch reported that "Fifty percent of brown trout placed in cages in a power plant discharge died within four days when chlorination occurred for only 30 minutes per day. The mean total residual chlorine concentration during the chlorination periods was 0.06 mg/l."

Brungs (7) in a review article evaluating the effects of residual chlorine on aquatic life suggested that an interim criteria for intermittent chlorination should be that the total residual chlorine not exceed 0.04 mg/l. for a period of 2 hr/day to protect most species of fish. However, if a high percentage of residual chlorine exists as free chlorine then the total residual chlorine should not exceed 0.01 mg/l. for a period of 30 min/day to protect sensitive species such as trout and salmon. Brungs indicates that no similar criteria for warm water fish could be made because of lack of data.

The purpose of this paper is to report the results of a study initiated at the Appalachian Power Co.'s Clinch River plant, Carbo, Va., on September 11, 1972, to determine the effect of chlorinated cooling tower blowdown on organisms placed in the river. The in situ tests were performed utilizing bluegill sunfish (*Lepomis macrochirus* Raf.) and an operculate snail (*Anculosa* sp.).

Location and Description of Stations. Six stations, each divided into three substations, were established in the vicinity of the Clinch River Power Plant (Figure 1). The substations were designated left (L), middle (M), and right (R) and were positioned more by the flow characteristics of the system than proximity to a bank. Substations L were nearest the left bank when the observer was facing downstream. Substations M were located somewhat farther from the left bank than substations L, except at station 1 where substation M was at midchannel. Substations R were at midchannel except at station 1 where the substation was close to the right bank. At all stations below the outfall, substations L and M were in the outfall's plume area. The plume area was determined by placing rhodamine dye in the cooling water blowdown discharge and observing its diffusion pattern. Thus one could approximate the outer limits of the plume. All stations were similar in substrate composition, water depth, and other habitat characteristics. River flow was rather constant during the study ranging from 400–600 cfs. Flow velocities ranged from 0.47 ft/sec to 2.0 ft/sec at the various stations.

Chlorination Regimen in Cooling Towers. Appalachian Power Co.'s Carbo plant has three cooling units with towers 1 and 2 in unit #1, towers 3 and 4 in unit #2, and tower 5 in unit #3. All three units are cooled by closed-cycle, evaporative systems equipped with mechanical draft-cooling towers. Makeup water is untreated water from the Clinch River. The cooling water is treated only by feeding sulfuric acid for control of pH, and by intermittent chlorination for control of slime on the condenser tube surfaces and of algae and other aquatic growths in the cooling towers. Units 1 and 2 were chlorinated at 10:00 a.m., 4:00 p.m., 10:00 p.m., and 4:00 a.m. with an average of 0.75 mg/l. of chlorine for 30 min. Unit 3 was chlorinated at 7:00 a.m., 1:00 p.m., 7:00 p.m., and 1:00 a.m. with an average of 0.75 mg/l. of chlorine for 30 min. The water from units 1 and 2 were combined with water from unit 3 and then discharged into the river. Flow-through times in the towers were approximately 14 min.

Materials and Methods

Chemical Analyses. Water was collected for routine chemical analyses (Table I has a list of characteristics determined) at all stations. The samples were sent to the

[1] Present address, Teledyne Brown Engineering, Research Park, Mail Stop 5, Huntsville, Ala.

American Electric Power Service Corp. General Laboratbry at Huntington, W.Va. Chlorine determinations (both free and total) were made with a Wallace & Tiernan amperometric titrator in the field. Chemicals and procedures outlined in the Wallace & Tiernan amperometric titrator manual were utilized. Chlorine tests were run before the

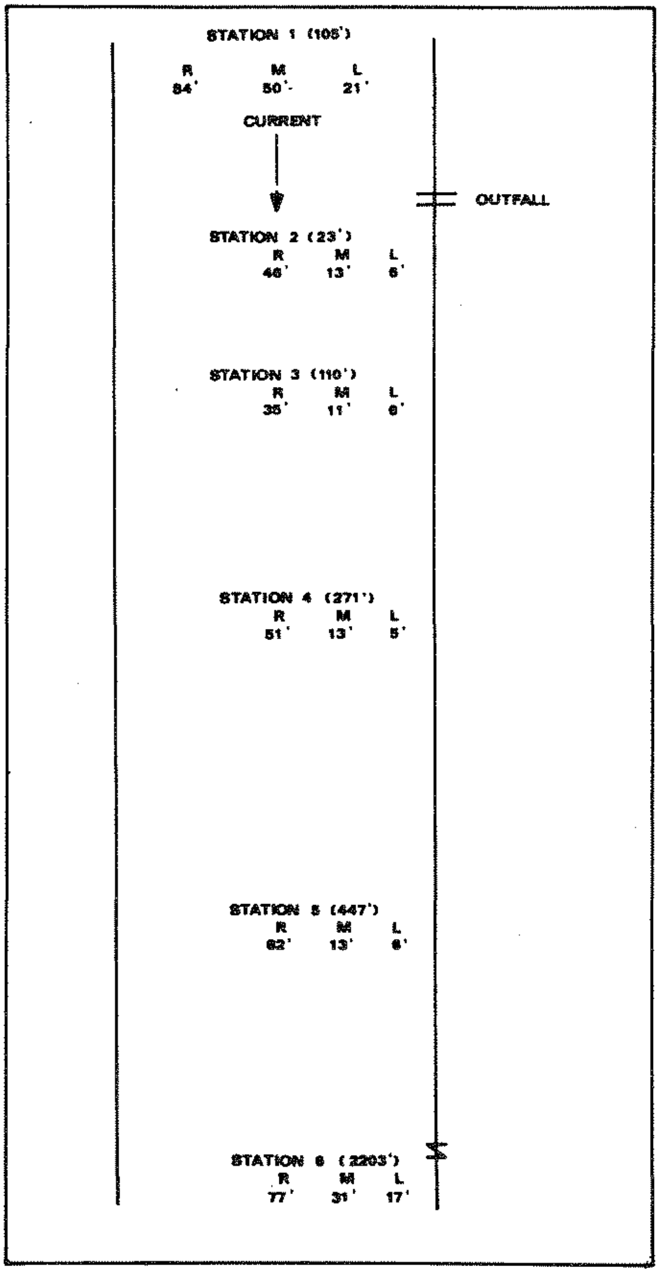

Figure 1. Diagrammatic sketch of river showing distances between the outfall and the sampling stations and distances of subsamples from left bank

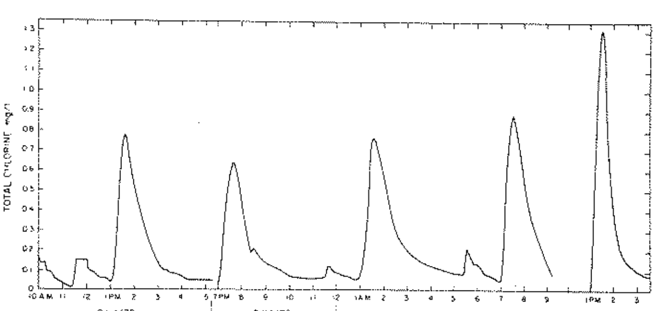

Figure 2. Total residual chlorine levels of blowdown water before going into Clinch River, September 14, 1972

cooling water entered the river and at stations 2, 3, 4, and 5. The chlorine determinations were initiated at 1:45 p.m. on September 11 and continued 24 hr a day until 4:15 p.m. September 14. The samples were taken at 5–10-min intervals and at varying distances from the left bank. This permitted determination of the times when the peak loads of chlorine appeared in the river and the duration of the chlorine contact time at the various stations. The chlorine tests were performed at a particular station through one or more chlorination cycles. In this way the minimum chlorine concentrations in the river before and after chlorine dosing and the maximum value during dosing were determined. A number of the stations were tested more than once during the study period.

Test Organisms. Bluegill sunfish (*Lepomis macrochirus* Raf.) and a snail (*Anculosa* sp.) were utilized as the test organisms because they represent indigenous species. The fish were caged in the river in nylon live bags (20 × 30 in.), and the snails were caged in plastic screen cones equipped with draw strings to prevent the animals from escaping. Ten fish and 10 snails were exposed at each substation in cages attached to iron rods driven into the river bed. The fish were transported from the Aquatic Ecology Laboratory at Virginia Polytechnic Institute and State University to the Clinch River for acclimation to river conditions six days before the tests began. During the acclimation period they were caged in the river approximately 500 yd above the plant's outfall. The snails were collected from a riffle approximately 100 yd upstream from the power plant outfall the day that testing began.

The test organisms were placed into the river at 4:00 p.m. September 11, 1972. Animals were inspected and dead organisms removed at 8:00 a.m., 2:00 p.m., and 8:00 p.m. each day. On the 12th of September 1972 the animals were also checked at 2:00 a.m.. These hours were chosen since they occur approximately 1 hr after chlorination of unit #3. Mortality of the fish was determined by observing the animals. The snails were considered dead when no movement could be detected after repeatedly touching the soft parts of the organisms with a probe.

Results and Discussion

Figure 2 is a graph of the total residual chlorine concentrations before the water entered the Clinch River. The water was collected in a water box before discharge to the river. There was a marked chlorine peak approximately 30–40 min after the chlorination of unit #3 (unit #3 was chlorinated at 1:00 and 7:00—i.e., four times a day). During the five dosing periods of the study the maximum total residual chlorine levels ranged from 1.31–0.64 mg/l. in unit #3. The free chlorine concentration ranged from 0.0–88.0% of the total residual chlorine with a mean percentage of 17.3%. The concentration of free chlorine in the discharge ranged from 0.0–0.35 mg/l. with a mean concentration of 0.08 mg/l. Figures 3, 4, and 5 were generated from chlorine data collected at stations 2, 3, and 4, respectively. As might be expected, the highest total residual chlorine values in the river were found at station 2 some 23 ft below the point of discharge (0.55 mg/l.). However, the difference between the maximum values recorded at stations 3 and 4 was not anticipated. There was a drop of approximately 0.40–0.35 mg/l. of total residual chlorine between stations 2 and 3, a distance of 80 ft, while no appreciable drop occurred between stations 3 and 4, a distance of 170 ft. This suggests that much of the chlorine entering the river was reduced within the first 100 ft.

The ammonia concentration in the Clinch River at the time of the study had a range of 0.15–0.25 mg/l. with a mean concentration of 0.20 mg/l. The presence of this

Table I. Chemical Analyses of Clinch River Water Collected on 9-15-73

	Station					
Analyses	1	2	3	4	5	6
Calcium, mg/l.	35.0	125.0	107.5	97.5	71.3	57.5
Magnesium	10.8	35.0	30.5	27.0	22.3	16.0
Sodium	18.5	85.0	85.0	85.0	43.8	43.8
Bicarbonate	152.2	142.9	144.6	144.2	146.7	147.9
Sulfate	14.4	282.3	229.6	183.5	116.1	54.3
Chloride	5.5	28.5	22.0	18.6	14.2	8.5
Dissolved solids	177.2	722.5	633.3	337.6	396.5	285.0
Hardness ($CaCO_3$)	131.9	456.2	394.0	354.6	269.9	209.5
Net ignition loss	13.2	83.2	75.2	66.8	52.0	27.6
Organic matter[a]	1.51	4.76	5.00	3.91	3.36	2.47
pH	7.5	6.9	6.9	7.2	7.1	7.3
Specific conductivity	283.0	821.0	732.0	653.0	506.0	377.0
Chromium[b]	4.23	12.42	10.82	9.25	6.61	4.23
Copper[b]	1.6	240.0	160.0	140.0	80.0	32.8
Lead[b]	5.81	11.36	9.25	5.28	6.87	7.93
Mercury[b]	0.93	0.03	0.03	0.03	0.03	0.03
Nickel[b]	3.43	8.72	5.55	5.02	3.43	2.38
Zinc[b]	5.55	80.00	60.0	50.00	22.19	10.04

[a] $KMnO_4$ consumed as O_2. [b] Expressed in ppb.

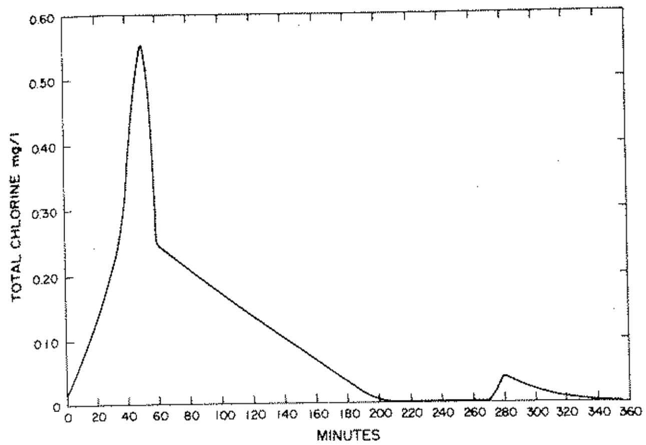

Figure 3. Maximum total residual chlorine in discharge plume at point in river 23 ft downstream from Unit 3. Time 0 is 1300 hr on September 12, 1972

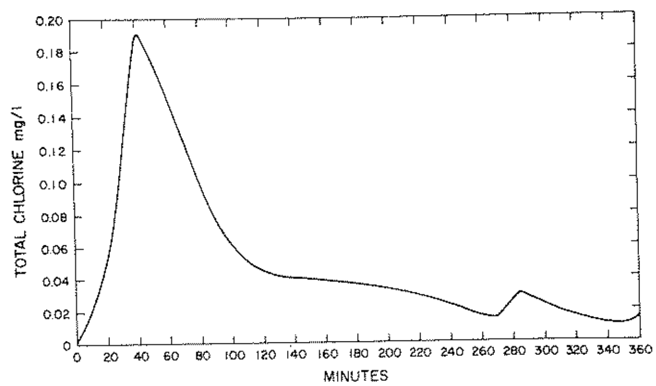

Figure 4. Maximum total residual chlorine in discharge plume at point in river 100 ft downstream from Unit 3. Time 0 is 1900 hr on September 13, 1972

ammonia plus possibly other reduced compounds probably accounts for the levels of free chlorine being lower at all sampling stations (range equaled 0.0–0.07 mg/l., mean equaled 0.02 mg/l.) than in the discharge to the river (range equaled 0.0–0.35 mg/l., mean equaled 0.08 mg/l.). Table II summarizes the maximum total residual chlorine found at the various stations plus the farthest distance from the left bank that any residual was found and the longest length of time that any residual remained.

Table I is a compilation of the other chemical analyses performed on the river water collected along the left bank at the various stations. Such attributes as hardness, conductivity, and dissolved solids increased below the discharge of blowdown water. Also, there was an increase of all the heavy metals analyzed in the plume, except mercury.

In these in situ studies, it is impossible to separate the effects of chlorine from the effects of other constituents in the blowdown. However the concentration of heavy metals with the possible exception of copper do not appear to be high enough to produce acute lethality.

Fish mortality results indicate that none of the deaths observed were due to chlorine or other materials in the blowdown plume (Table III). At station 1 three fish died, one at each substation. These fish were not exposed to the

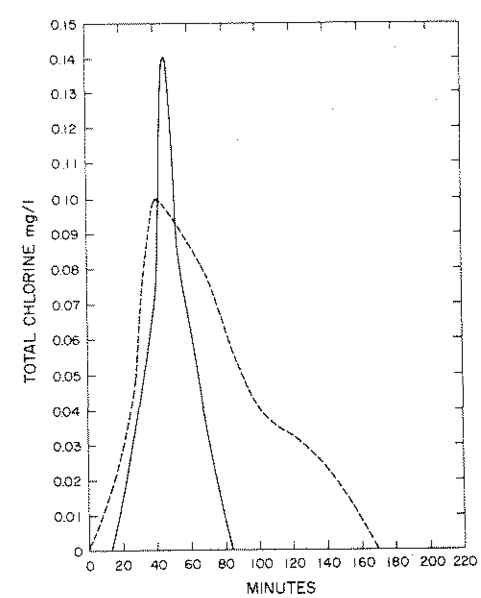

Figure 5. Maximum total residual chlorine in discharge plume at point in river 270 ft downstream from Unit 3 discharge. Time 0 is 0100 hr for broken line and time 0 is 1300 hr for solid line on September 14, 1972

blowdown discharge and certainly died from other causes. However, station 1 provided adequate controls since 90% of the fish survived. No deaths occurred at station 2, even though 20 fish were maintained in the plume area 23 ft below the outfall. Only one death occurred at station 3 (substation 3M). This fish appeared to have physical abrasions (loss of scales, frayed fins) and probably died as a consequence of being trapped in a portion of the nylon net. At stations 4 and 6 all of the deaths appeared to be due to similar physical factors. At substations 4M, 4R, and 6R the fish that died also showed physical abrasions from fouled nets. Since no chlorine reached the organisms at substation 6M, (Table III), the deaths there were due to factors other than the chlorine. Only one death occurred at station 5, and this death was outside the area affected by the blowdown discharge.

Snail mortality data are shown in Table III. No snail deaths occurred at stations 1 and 6, and no deaths occurred at the R substations at stations 2, 3, 4, and 5. This indicates that the controls were quite adequate throughout the study. Snail deaths were recorded at substations 2L, 2M, 3L, 3M, 4L, and 5L. All of these deaths appeared to be associated with the blowdown water since all of the substations were in the plume as verified by the chemical data.

If one plots the snail mortality data against time (Figure 6) a rather interesting picture emerges. The length of time required to kill 50% of the snails at the various substations are: 2L = 27.5 hr, 2M = 32.0 hr, 3L = 36.0 hr, 4L = 31.0 hr, and 5L = 72.0 hr. It appears that the data from substation 4L is somewhat out of line. However, if one inspects the chlorine data (Table II), one finds that the chlorine concentrations were almost as high at substation 4L (0.14 ppm) as they were at substation 3L (0.19 ppm). Also of interest is the observation that the snail survival rate increased as the distance from the left bank increased. This also agrees with the chlorine data since higher concentrations were always found near the left bank and then decreased toward the outer limits of the plume.

The literature does not reveal any work that has been done on bluegill sunfish and chlorine under in situ conditions. However, it would seem to be worthwhile to compare our findings with the interim criteria for freshwater aquatic life suggested by Brungs (7). He suggested that for intermittent chlorination that more resistant species of fish (i.e., not trout and salmon) would not be protected if the total residual chlorine exceeded 0.2 mg/l. for a period of 2 hr/day. From Figure 3 it can be determined that the total residual chlorine stayed about 0.2 mg/l. for approximately 50 min for that one fourth of the daily chlorination cycle. For four chlorination periods a day it would appear that the fish caged at station 2 were exposed to at least 0.2 mg/l. for more than 3 hr/day. Also, they were exposed to 0.4 mg/l. for approximately 1 hr/day. These preliminary data tend to indicate that the Brungs (7) criterion of 0.2 mg/l. for a period of 2 hr/day will probably be adequate to protect more resistant warm water fish such as the bluegill.

The snail mortality suggests that the chlorine was eliciting a response from the organisms particularly the snail deaths that occurred at station 5. It should be pointed out that the snails possibly were responding to the heavy metals in the effluent; however, all of these ions were rather low except for copper (Table I). The copper was low (80 μg/l.) at station 5 where we did get snail mortality. It is difficult to determine from the literature what the response of this particular snail might be to the range of copper concentration encountered in the plume area. A study by Wurtz and Bridges (1961) gave an LC_{50} value of 0.27 mg/l. of $CuSO_4$ for 96 hr for *Physa heterostropha*. This was in laboratory-prepared water and highly controlled conditions, and on a snail of a different family (family Physidae) than the snails we utilized (*Anculosa* sp.) family Pleuroceidae). In the Wurtz and Bridges publication the LC_{50} values were for $CuSO_4$ and not Cu^{2+}; however, the

Table II. Chlorine Residuals in Clinch River

Station no.	Distance from Outfall, ft	Highest total residual chlorine, mg/l.	Highest free chlorine residual, mg/l.	Distance from left bank that any chlorine residual was found, ft	Longest length of time that any chlorine residual remained, min
2	23	0.55	0.07	13–17	300
3	100	0.19	0.04	N.D.	>360[a]
4	270	0.14	N.D.	12–14	210
5	447	0.04	N.D.	4	767 < 115
6	2203	0.00	N.D.	—	—

[a] Residual did not fall before following chlorination period. N.D. = not determined.

Table III. Fish and Snail Mortality Results from Clinch River—Chlorine Studies[a]

Date	Time	Duration, hr	Station #1 L	Station #1 M	Station #1 R	Station #2 L	Station #2 M	Station #2 R	Station #3 L[b]	Station #3 M	Station #3 R	Station #4 L	Station #4 M	Station #4 R	Station #5 L	Station #5 M	Station #5 R	Station #6 L	Station #6 M	Station #6 R
9-11-72	8 p.m.	3.5	—[d]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9-12-72	2 a.m.	9.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	8 a.m.	15.5	—	—	1/0	—	0/1	—	0/1	—	—	—	—	9/0	—	—	—	—	1/0	1/0
	2 p.m.	21.5	—	—	—	—	—	—	—	—	—	—	—	1/0	0/1	—	—	—	1/0	2/0
	8 p.m.	27.5	1/0	—	—	0/5	—	—	0/2	—	—	0/4	1/0	X[e]	—	—	—	—	—	5/0
9-13-72	8 a.m.	39.5	—	—	—	0/3	0/5	—	0/3	1/0	—	—	—	—	—	—	—	—	1/0	1/0
	2 p.m.	45.5	—	—	—	0/2	0/1	—	0/3	—	—	0/4	—	—	0/1	—	—	—	—	—
	8 p.m.	51.5	—	—	—	—	0/1	—	—	0/2	—	0/1	—	—	—	—	—	—	—	—
9-14-72	8 a.m.	63.5	—	—	—	—	0/1	—	—	—	—	0/1	—	—	—	—	—	—	—	—
	2 p.m.	69.5	—	—	—	—	0/1	—	—	0/1	—	—	—	—	—	—	—	—	—	—
	8 p.m.	75.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1/0
9-15-72	8 a.m.	87.5	—	—	—	—	—	—	—	—	—	—	—	0/4	—	—	—	—	—	—
	4:30 p.m.	96.0	—	1/0	—	—	—	—	—	—	—	—	—	0/1	—	—	1/0	—	—	—

[a] Number to left of slash equals number of observed fish mortalities. Number to right of slash equals the number of snail mortalities. [b] Began bioassays at 4:30 p.m., 9-11-72. [c] Three snails were lost from bag. [d] No fish or snail mortality. [e] X one snail was lost from bag.

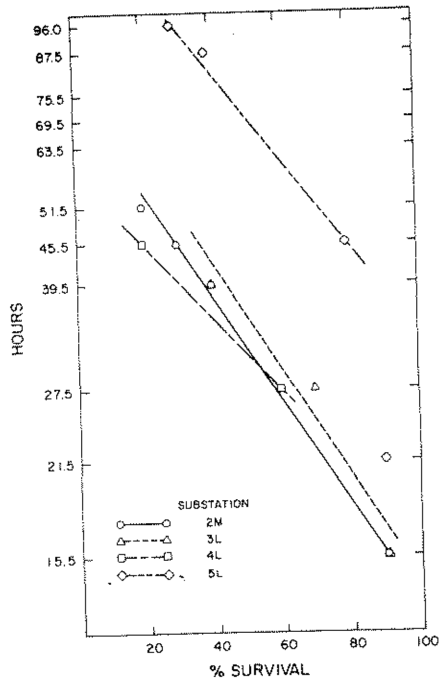

Figure 6. Time until death for 50% of snails at various substations

value we obtained at station 5 for Cu^{2+} was less than the amount of Cu^{2+} Wurtz and Bridges had in solution—i.e., 80 μg/l. Table I vs. 108 μg/l.

The information in Brungs (7) is of little or no value when trying to interpret the snail mortality data. For intermittent chlorination, Brungs only considers species of fish. He does mention in his summary, however, that warm water fish, snails and crayfish are less sensitive to chlorine than trout, salmon, and some fish-food organisms. As can be seen in Figures 4 and 5, the chlorine levels never exceeded 0.2 mg/l. at stations 3 and 4 but still the snail mortality rate was high for these stations. Again it might be suggested that copper was acting independently or synergistically to cause this lethality.

Nevertheless, it is significant that at station 5 (447 ft below outfall) the maximum recorded total residual chlorine concentration was 0.04 mg/l. and that a 50% mortality of snails was observed in 72 hr. While it is not possible to determine from the data how long the test organisms were exposed to 0.04 mg/l. total residual chlorine, these data show that there were some significant responses—i.e., mortality of snails. Extrapolation of the data in Figure 5 (270 ft below the outfall) shows that the total chlorine residual probably exceeded 0.04 ppm for approximately 160 min in 24 hr. Due to the rate of dissipation of chlorine as it proceeds downstream (shown in Figures 2–4) it is highly unlikely that the test organisms at station 5 (447 ft below the outfall) were exposed to 0.04 ppm total residual chlorine for 2 hr/day. While the data on snail mortality indicate that toxic conditions exist due to the blowdown it is not possible to explicitly identify the cause of the toxicity. However the analytical data indicate that the probable cause of the toxicity was chlorine and/or copper either independently or acting synergistically. Additional work is needed to allocate the toxic effects of the various constituents of the blowdown.

It appears, however, that the total impact of the chlorine and other blowdown constituents of the discharge plume at the Clinch River plant was quite negligible on the total ecology of the stream. The chlorine plume extends into the river approximately 20 ft; therefore, any organisms moving up- or downstream would be able to avoid the chlorine. Also the chlorine dissipated rather quickly (none found at 800 ft and no mortality at 2203 ft below the outfall); therefore, a very minor area of the left side of the river was under stress from the blowdown discharge. Fish were observed in the vicinity of the discharge plume during the study. However, previous studies at the plant have identified a "shadow" effect on the macrobenthos extending 2.5 mi below the plant particularly along the left bank of the river (9).

Summary

Even though a few fish deaths occurred during the study, none of these could be directly linked to the chlorine residuals in the river. Of the deaths, 87% occurred outside the area influenced by chlorine.

The snail deaths appeared to be directly related to the blowdown discharge, and the snail survival rate increased as the distance away from the outfall increased. Also, snail survival rates increased as the distance from the left bank increased.

The snails demonstrated a higher sensitivity to the blowdown discharge than the fish.

Since the chlorine dissipates rather rapidly (none detected at 800 ft and no snail mortalities at 2203 ft) and since the plume stayed close to the left bank, we feel that the portion of the river affected by the cooling water blowdown discharge will have little if any impact on the total ecology of the Clinch River.

Our preliminary data indicate that Brung's 1973 recommended criteria for total residual chlorine (0.2 mg/l. not to exceed 2 hr per day) will probably be adequate to protect more resistant warm water fish such as the bluegill.

However, our study also indicates that more work is needed to understand the toxicity of intermittently chlorinated cooling tower blowdown since we observed significant snail mortality at lower concentrations of chlorine with less exposure time than Brung's 1973 recommended criteria of 0.04 mg/l. not to exceed 2 hr/day. It appears from our data that the toxicity observed may not be a function of chlorine toxicity alone but may involve copper toxicity either independently or synergistically with chlorine.

Acknowledgments

We would like to thank G. E. Campbell, G. Crawford, D. Jonas, and G. Munsey of American Electric Power Service Corp. for their aid and assistance.

Literature Cited

(1) Brook, A. J., Baker, A. L., *Science*, **176** (4042), 1414–15 (1972).
(2) Brungs, W. A., "Water quality criteria recommendations for total residual chlorine in fresh surface waters," Memorandum to F. T. Mayo, Regional Administrator EPA, Region V, 1971.
(3) Basch, R. E., "In situ investigation of the toxicity of chlorinated municipal wastewater treatment plant effluents to rainbow trout (*Salmo gairdneri*) and fathead minnows (*Pimephales promelas*)," 50 pp, Bureau of Water Management, Michigan Department of Natural Resources, Lansing, Mich., 1971.
(4) Tsai, C., *Chesapeake Sci.*, **9** (2), 83–93 (1968).
(5) *Ibid.*, **11** (1), 34–41 (1970).
(6) Sprague, J. B., Drury, D. E., 1969. "Avoidance reactions of salmonid fish to representative pollutants," in S. H. Jenkins (Ed.), "Advances in water pollution research," pp 169–79, *Proc. 4th Int. Conf.*, Prague, Pergamon Press, New York, N.Y., and Oxford, England.
(7) Brungs, W. A., *JWPCFA*, **45** (10), 2180–93 (1973).
(8) Wurtz, C. B., Bridges, C. H., *Proc. Pa. Acad. Sci.*, **35**, 51–6 (1961).
(9) Cairns, John, Jr., Crossman, John S., Dickson, Kenneth L., Purdue Univ. *Engrg. Bull.* **137** (1), 182–92 (1972).

Received for review October 9, 1973. Accepted June 17, 1974. Work supported by American Electric Power Service Corp.