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TOXICITY OF CHLORINATED POWER PLANT CONDENSER COOLING WATERS TO FISH

Environmental Research Laboratory
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by

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ABSTRACT

Studies were conducted during 1972 at five Michigan power plants in which caged brown trout (Salmo trutta) and fathead minnows (Pimephales promelas) were held for 96 hr in the intake and condenser cooling water discharge channels. Caged fish were also held in condenser cooling water dechlorinated with sodium thiosulfate at the same time that fish held in the discharge channel were subjected to 30-min chlorination periods. The 48-hr total residual chlorine intermittent concentrations lethal to 50 percent (ILC-50) of the caged brown trout ranged from 0.14 to 0.17 and 0.18 to 0.19 mg/liter for fish exposed to two and four 30-min chlorinations, respectively. The 96-hr ILC-50 total residual chlorine values at two plants ranged from 0.02 to 0.05 and 0.17 to 0.18 mg/liter for fish exposed to three and six 30-min chlorinations, respectively. Fathead minnow deaths in all studies could not be attributed to the total residual chlorine because of excessive numbers of deaths among control fish.

Resident fish were observed in distress at two plants during 1972. These behavioral symptoms were noted at maximum total residual chlorine concentrations ranging from 0.2 to 0.5 mg/liter.

Studies were repeated in 1973 at one plant with brown trout and other salmonid species. These fish were subjected to similar chlorine concentrations as the 1972 studies at this plant. No deaths of test fish occurred during these tests that could be attributed to chlorine concentrations. The inconsistent results may be related to interactions between chlorine, temperature, and dissolved oxygen saturation in the discharge channel.

A laboratory bioassay was conducted during 1973 in which brown trout were held for 96 hr at 17 C (63 F) and 21 C (70 F) after being subjected to one 30-min chlorine dosage. Increase in lethality was greater than 50 percent with the 4 C (7 F) temperature increase. The ILC-50's were 1.19 mg/liter and 0.56 mg/liter for fish held at 17 C (63 F) and 21 C (70 F), respectively.

This report was submitted in fulfillment of Project Number R800700 by the Michigan Water Resources Commission, Bureau of Water Management, under the (partial) sponsorship of the Environmental Protection Agency. Work was completed in September 1974.

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ACKNOWLEDGMENTS

Environmental and operating personnel from the Consumers Power and Detroit Edison Companies provided valuable assistance in conducting this project, and special thanks are due them.

Various members of the Bureau of Water Management staff participated in this project, and their support is greatly appreciated. Special thanks are due Ronald Fobes, William Stone, Willard Quandt, and William Watt, who contributed valuable suggestions, criticisms, and hard work throughout this project. Special thanks are also due to Esther Clickner who typed many revisions of this document.

The Michigan Department of Natural Resources, Fisheries Division, provided fish throughout the project, and their assistance is appreciated.

The Environmental Protection Agency project officer was John Arthur, whose assistance and patience are also gratefully acknowledged.

SECTION I

CONCLUSIONS

1. Chlorinated power plant cooling waters in the discharge channels of two plants caused aberrant behavior of resident adult salmonid fish.

2. Chlorinated power plant cooling waters were lethal to caged brown trout but not to fathead minnows, brown bullheads, or various centrarchid species held in many of the discharge channels.

3. The 48-hr total residual chlorine intermittent concentrations lethal to 50 percent (ILC-50) of the caged brown trout ranged from 0.14 to 0.17 and 0.18 to 0.19 mg/liter for fish exposed to two and four 30-min chlorinations, respectively. The 96-hr ILC-50 total residual chlorine values at two plants ranged from 0.02 to 0.05 and 0.17 to 0.18 mg/liter for fish exposed to three and six 30-min chlorinations, respectively.

4. Water temperature and gas saturation levels can interact to markedly change the concentrations of chlorine lethal to fish.

SECTION II

RECOMMENDATIONS

Chlorine dosages needed to prevent fouling of power plant condensers are poorly defined. Frequency of chlorine application has been based largely on judgment and experience of the plant operating personnel. It is recommended that research be conducted to determine minimal levels and frequency of chlorine application necessary to prevent biofouling. This research should result in reduced chlorine concentrations and frequency of use which will help to minimize the impact on aquatic organisms in the discharge waters.

In high water-quality areas where sensitive fish species occur it may be necessary to reduce the concentrations of chlorine to levels near the limit of detectability. It is recommended in these instances that the plants either neutralize the chlorine before discharge or use an alternative condenser cleaning technique. In this regard it is recommended that research be increased on chlorine neutralization and alternative condenser cleaning techniques.

Since free chlorine measurements were inaccurate it is also recommended that total residual chlorine be monitored by amperometric titration procedures.

SECTION III

INTRODUCTION

Several investigators have reviewed the literature on toxicity to fish of continuous exposure to chlorine (Doudoroff and Katz 1950; McKee and Wolf 1963; Isom 1971; Zillich 1972). Brungs (1973) recently completed a comprehensive review of literature dealing with the toxicity to fish of both continuous and intermittent exposures to chlorine.

Electric generating plants intermittently chlorinate their condenser cooling water for short time periods to remove algal and bacterial slimes growing on the condenser tubes. These growths interfere with heat transfer across the condenser and cause loss of turbine efficiency. In the fall of 1971 the possible lethality of this type of chlorine application was investigated. Chlorine-monitoring surveys by the Michigan Water Resources Commission (MWRC) at two Michigan plants indicated that under normal plant chlorination procedures the intermittent doses of chlorine could be lethal to fish in the discharge channels (Basch 1971; Basch and Truchan 1971; Truchan and Basch 1971).

Based on this preliminary field work, the MWRC staff in January 1972 recommended interim restrictions for industrial dischargers of chlorine. They proposed that, where chlorine application is on a continuous basis, total residual chlorine (TRC) concentrations in the effluent should not exceed 0.05 mg/liter. For intermittent chlorine application, total residual chlorine concentrations in the effluent should not exceed 0.5 mg/l, with such application limited to 30 min during any 2-hr period. Brungs (1973) also suggested concentrations for intermittent chlorine dosages that would protect fish. He recommended that limiting residual chlorine concentrations to 0.04 mg/liter for 2 hr per day should protect most species of fish. He also recommended that, if high concentrations of free chlorine persist, the level should not exceed 0.01 mg/liter for the same time period.

This project was conducted to assess, under field conditions, the effect of chlorinated cooling waters from power plant condensers on coldwater and warmwater fish. A further objective was to evaluate seasonal differences in lethality of these chlorinated waters.

SECTION IV

1972 FIELD STUDIES

METHODS

Study sites for this project were selected with the cooperation of the Consumers Power and Detroit Edison Companies. Plant personnel provided close control over chlorine application rates and in-plant monitoring of chlorine concentrations. The plant staff also supplied the following operational data for their respective plants: intake and discharge temperatures, chemical sampling results, cooling water volumes, number of units in operation, chlorination schedules, dosage rates, and in-plant chlorine-monitoring results.

Nine bioassays with caged fish were conducted in 1972 at five power plants. Separate bioassays were conducted at all five plants during the summer and repeated at four of the five plants during the fall or winter. Fish were held in cages in the discharge channels and exposed to free and combined chlorine present in the condenser cooling water. Control fish were held in the intake water and in cooling water that had been dechlorinated.

Fish held in the intake were subjected to the same water quality as fish held in the discharge except for the elevated water temperatures and the periodic chlorinations. A device was employed in which fish were held in dechlorinated discharge channel water to monitor the effect of the elevated temperatures. Since the fish at the test stations in the discharge channel and the dechlorinated control stations were subjected to the same temperature and water-quality conditions, differences in survival were assumed to be due to the chlorinated compounds present in the cooling water. Any deaths among the intake control fish could indicate stress from the experimental design, fish handling, intake water quality, disease, or any combination of these factors. The general procedures employed during each of the 1972 bioassays are given below. Exceptions to these general methods will be noted in the discussion of the results for each bioassay.

Rhodamine B dye was used to determine the location of the plant's discharge plume. Four to six stations were then positioned at various

distances down the discharge channel and in the receiving water within the discharge plume. Three wooden cages were used for fish exposure at each station (Basch et al. 1971). Two of the cages contained brown trout, and one cage contained fathead minnows. The fathead minnow cages were partitioned into two equal sections. At the discharge channel stations the three cages were bolted to one end of a 2.4-m (8-ft) wooden board (4.1 cm X 9.2 cm, commonly called a 2 X 4); a second 2 X 4 was attached to the opposite end (Fig. 1). The total apparatus, referred to as the boom, was suspended by U-bolts from a 2.1-m (7-ft) steel fence post driven into the channel bottom. A rope was attached to the outer end of the boom and secured to a second fence post positioned approximately 3.1 m (10 ft) upstream. This rope and boom arrangement allowed the cages to be checked for fish mortality by swinging the boom toward shore. The U-bolt suspension also allowed vertical movement of the cages with changes in the channel depth. A 13.6-kg (30-lb) concrete weight was attached to the outer end of the boom along with a 1-gal plastic bottle. The weight and bottle kept the cages submerged just beneath the surface. At the lake stations and intake stations the cages were attached to a 1.2-m (4-ft) 2 X 4 and were weighted to float just beneath the water's surface.

A device was constructed to acclimate the fish to condenser cooling water that had been dechlorinated. This dechlorination device was mounted on a flat-bed snowmobile trailer (Fig. 2). Two 208.3-liter (55-gal) drums held an aqueous sodium thiosulfate ($Na_2S_2O_3$) solution at a concentration of approximately 2,400 mg/liter. This solution was continuously pumped at about 80 ml/min with a ministaltic pump into the bottom of a baffled box and mixed with condenser cooling water pumped from the discharge channel. The discharge channel water was pumped at approximately 0.5 m^3/sec (8-9 gpm) with a 1-hp centrifugal pump to the mixing box. The resulting mixture in the box had approximately 6.5 mg/liter of sodium thiosulfate. The dechlorinated cooling water overflowed from the mixing box into a 545.5-liter (144-gal) metal tank. Fish were acclimated in this metal tank before each test. In addition, caged fish were held in this tank during each test. Water overflowed from the tank back to the discharge channel.

The two species of test fish, brown trout ranging in length from 6.4 to 10.2 cm (2.5-4.0 inches) and fathead minnows ranging from 5.1 to 7.6 cm (2-3 inches), were obtained from the Michigan Department of Natural Resources (MDNR) Wolf Lake State Fish Hatchery. Approximately

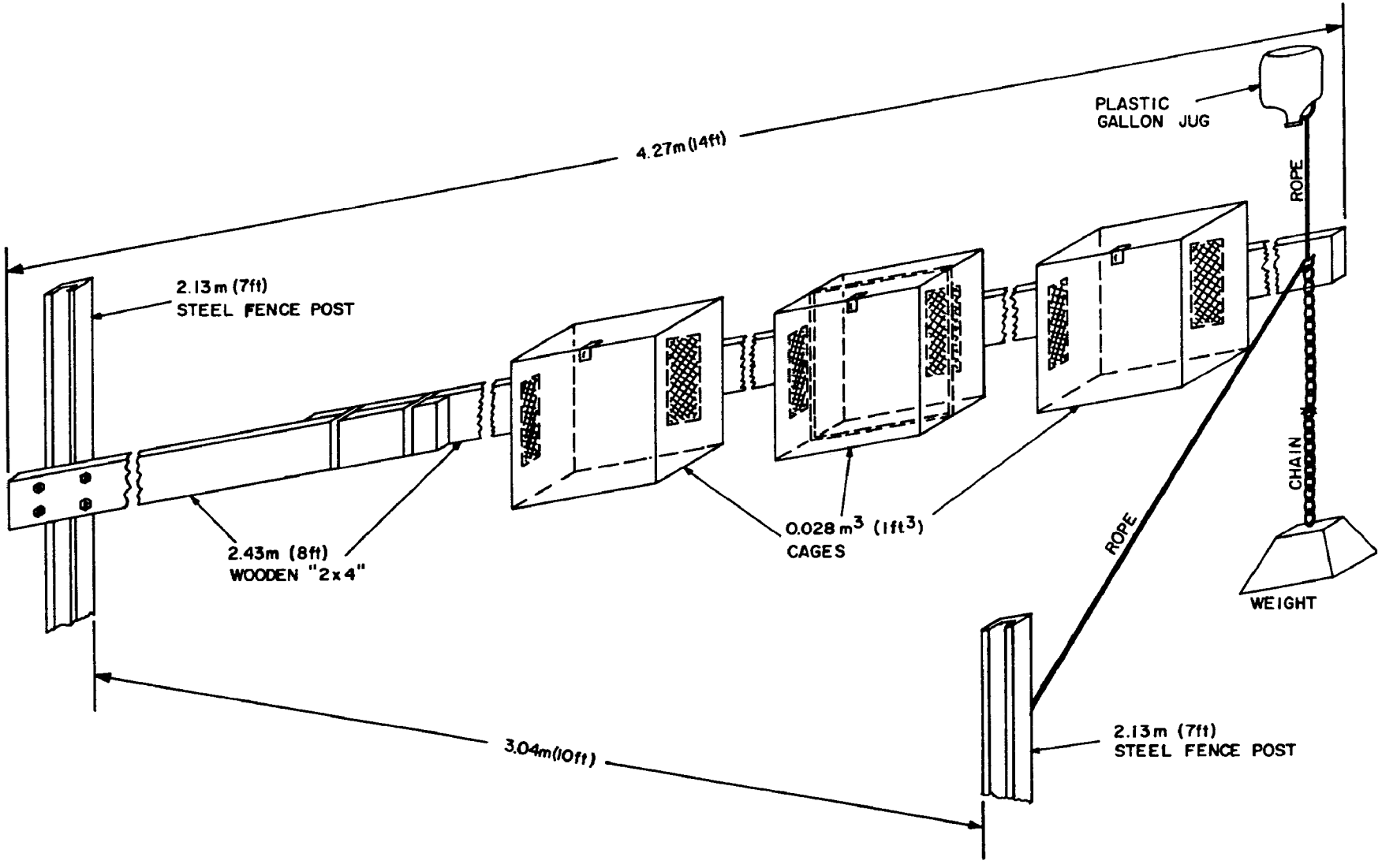
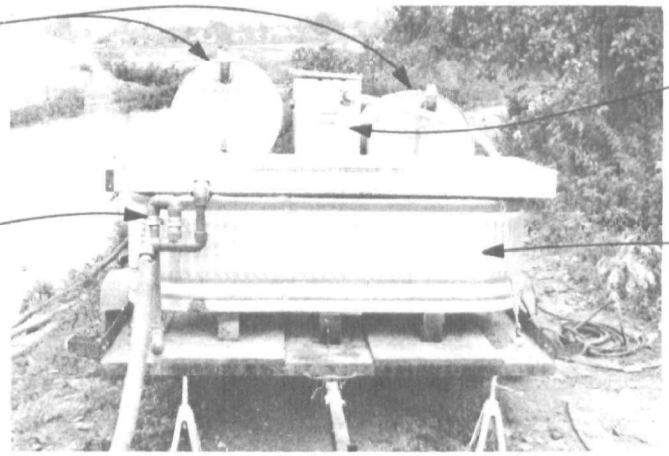
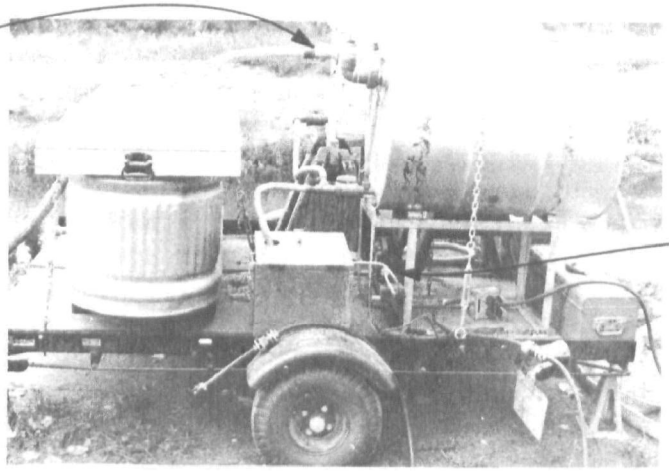


Figure 1. Boom arrangement employed during caged fish studies at Michigan power plants.

Figure 2. Dechlorination device employed during caged fish studies at Michigan power plants, 1972.



FRONT VIEW



SIDE VIEW

REAR VIEW

300 of each species were acclimated in dechlorinated water for 3-5 days prior to the test. The fish were held in the metal tank in separate cages constructed of 1.9-cm (0.75 inch) exterior plywood that enclosed a volume of nearly 0.2 m^3 (6 ft^3). Screened openings provided water circulation through the cage. At the start of each test the fish were transported from the stock cages to the test and control stations in an insulated cooler. Ten brown trout were placed in the inner and outer cages and 10 fathead minnows were placed in each half of the middle cage for a total of 20 individuals of each species per station.

In all tests large numbers of fathead minnows died at control stations, and therefore the data for this species are not presented.

Concentrations of free and total residual chlorine were determined at each station and at the condenser outlet during plant chlorination periods with three portable Fisher and Porter Model 17T1010 amperometric titrators at various times throughout the study. Test-station chlorine determinations were performed from a boat anchored at each station. Each titrator had a minimum detection level of approximately 0.02 mg/liter total residual chlorine. The minimum detection level was determined by serially diluting a known concentration of chlorinated tap water with distilled water and comparing measured total residual chlorine concentrations with computed concentrations based on dilution. A comparison of titration precision for total residual and free chlorine concentrations in tap water and field samples was made with the three titrators. Two operators using the different titrators independently made free and total residual chlorine determinations on duplicate samples. The percent relative deviation (Skoog and West 1963) for total residual and free chlorine determinations derived from this test was 5.4 and 13.8 percent, respectively. Thus reproducibility between operators and titrators was good for total residual chlorine determinations, but not good for free chlorine determinations. Because of the poor reproducibility the free chlorine data were not analyzed.

Water samples were collected from the intake and discharge every 4 hr for a 24-hr period. These samples were refrigerated and transferred to the MWRC Lansing Wastewater Laboratory for analysis of dissolved oxygen (DO), pH, temperature, and ammonia (NH_3 as N). Dissolved oxygen was determined by the azide modification of the Winkler method as given by the American Public Health Association (1971). Determinations of pH were made with an Orion Instrument Company pH meter (Model 701). Ammonia concentrations were determined by the phenate method

described in the U.S. Environmental Protection Agency (1971) Chemical Analysis Manual. Temperature was determined in the field with a glass-stem mercury thermometer.

Samples were collected once during each study from the intake, discharge, and dechlorinated control stations, transported to the MWRC Lansing Wastewater Laboratory, and analyzed by methods given by the American Public Health Association (1971) for DO, pH, NH_3, hardness, alkalinity, total solids (TS), suspended solids (SS), total dissolved solids (TDS), chlorides (Cl), sulphates (SO_4), cyanide (Cn), iron (Fe), sodium (Na), hexavalent chromium (Cr^{+6}), manganese (Mn), copper (Cu), and zinc (Zn).

Fish mortality was checked and dead fish were removed 24, 48, 72, and 96 hr after the start of the test. Fish were considered dead if no opercular movements were observed and tactile stimulation did not elicit movement.

The chlorinated plume normally extended over several stations and could not be monitored simultaneously at all stations. Therefore, chlorine was measured at each station during different chlorination periods at times of increasing, peak, and decreasing total residual chlorine concentration. The mean concentration during chlorination for each station for the 96-hr period was then determined by averaging all of the obtained values.

The exposure time at station 1, immediately below the discharge headwall, was approximately equal to the time that chlorine was applied to the condensers. At the farthest station downstream the chlorine was monitored to non-detection, when possible, and average exposure times were calculated for this station. Since all stations could not be monitored simultaneously, exposure times at intermediate stations were interpolated based on distances down the channel. Cumulative exposure times at each station were computed for each 24-hr period based on the number of chlorinations occurring.

It was assumed that fish mortality would be a function of chlorine concentration and exposure time. This has been shown for bacteria killed during sewage disinfection (Moore 1951; Sawyer and McCarty, 1967). For bacteria this relationship can be expressed as:

$$M = CT$$

where M = mortality, C = chlorine concentrations, and T = time of exposure.

Assuming this relationship would also apply to fish, the number of chlorine-minutes at each station in each 24-hr interval was computed by multiplying the average chlorine concentration by the corresponding cumulative exposure time. The numbers of chlorine-minutes lethal to 50 percent of the fish in the 48- and 96-hr periods, termed the CM-50, were computed by linear regression. In determining lethal concentrations the classical LC-50 or TL-50 concept utilized in laboratory bioassays could not be employed since the test fish were not continuously exposed to total residual chlorine. The total residual chlorine concentrations during the chlorination period that were lethal to 50 percent of the fish intermittently exposed during the 48- and 96-hr period were computed from the CM-50. These intermittent lethal concentrations (ILC-50) were calculated by dividing the CM-50 by the time of exposure. Since exposure times at each station were unknown, a range of times was employed. Exposure times ranged from the known time of chlorine application at the condensers to the average time determined at the farthest downstream station.

The intermittent lethal concentration was described as the ILC-50 ($\underline{x}$, $\underline{y}$), where $\underline{x}$ is the number of chlorination periods and $\underline{y}$ is the total number of minutes that chlorine was applied to the condensers during the test.

STUDY 1

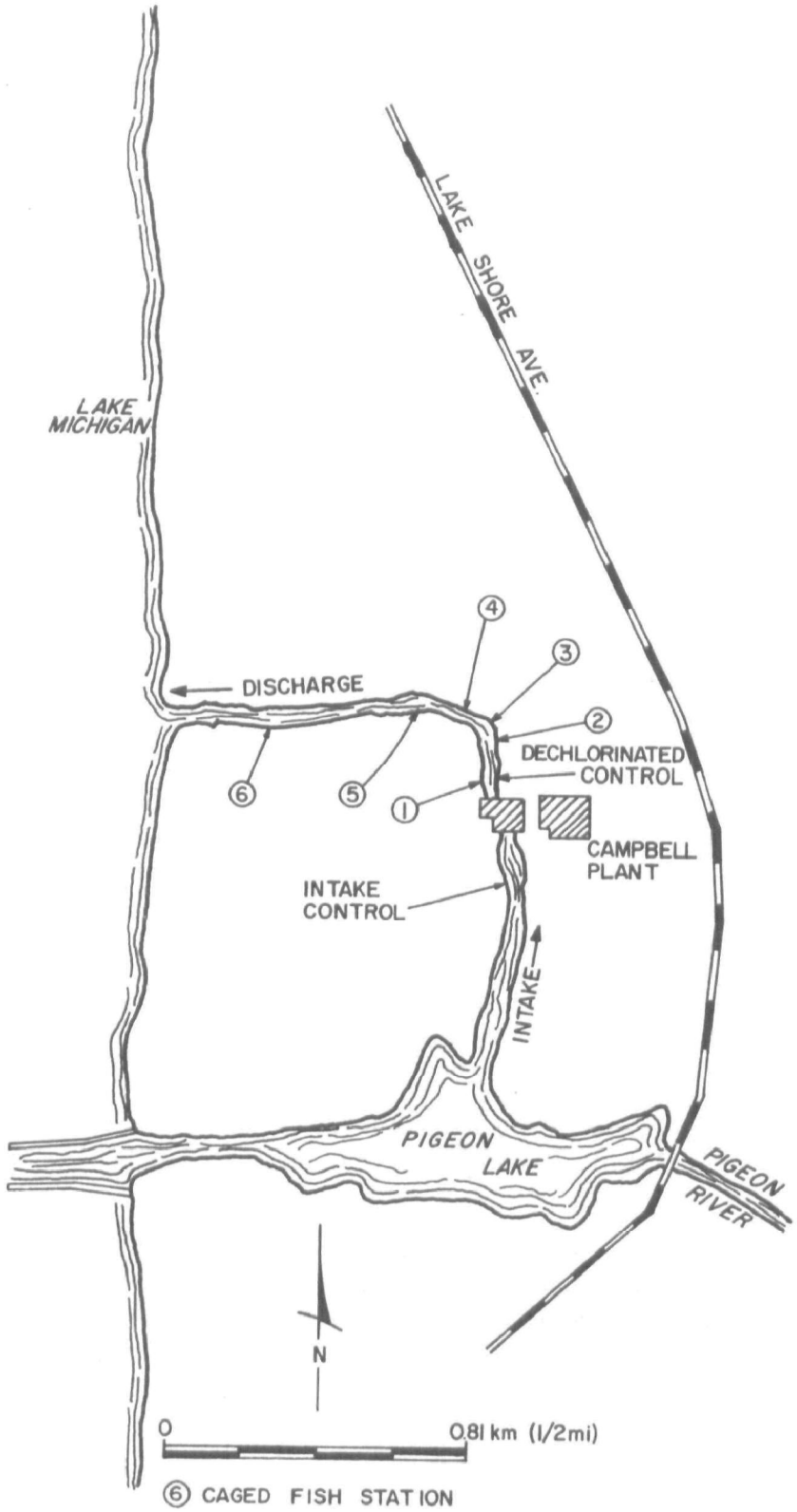
DESCRIPTION

The J. H. Campbell plant is a coal-fueled facility located north of the mouth of the Pigeon River in Port Sheldon Township, Ottawa County (Fig. 3). Two generating units produce a combined total of 647 megawatts electrical (MWe). Condenser cooling water for the plant is drawn through an intake channel from Lake Michigan via Pigeon Lake. The maximum rate of discharge from this plant is 18.9 m^3/sec (300,000 gpm), which flows into a 1.2-km (0.75-mile) discharge channel to Lake Michigan (Consumers Power Company 1972).

Each unit was chlorinated twice weekly for 30-min periods. Aqueous sodium hypochlorite (16 percent) was applied; approximately 18.1 kg (40 lb) and 26.5 kg (58.5 lb) were used during each chlorination of units 1 and 2, respectively.

The test fish were acclimated May 25-30, 1972, in dechlorinated water, transferred to all stations (Fig. 3) on May 30, 1972, and 15 fish placed in the inner and outer cages. The fish were exposed to chlorination periods on May 30, June 1, and June 2. The chlorine

Figure 3. Map of the J. H. Campbell plant showing caged fish stations, May 30 - June 3, 1972.



exposure concentrations are given in Appendix 1. Numbers of dead fish were checked every 24 hr, before and after the chlorination periods.

RESULTS AND DISCUSSION

Plant staff maintained the chlorine concentration during this test at less than 0.5 mg/liter at the confluence of the discharges from the two units. The maximum total residual chlorine concentration observed during this study was 0.43 mg/liter. Average total residual chlorine concentrations observed at the test stations ranged from 0.07 to 0.26 mg/liter. At stations 1-5 mortality was greater than 50 percent within 24 hr after the first chlorination; almost all fish were dead after 96 hr (Table 1). Brown trout mortality was lower at station 6, where the average total residual chlorine concentration was 0.07 mg/liter. No deaths were observed at either the intake or dechlorinated control station.

Linear regression was employed to determine the 48- and 96-hr ILC-50's. A regression was calculated for the cumulative number of dead brown trout based on the $\log_{10}$ of the cumulative chlorine-minutes. Separate regressions were computed for the 48- and 96-hr results. The r-values (0.43 and 0.53, respectively) for both the 48- and 96-hr regressions were not significantly different (at the 0.05 level), but accounted for 19 and 28 percent, respectively, of the variability in the regressions. The slope of the 96-hr regression differed significantly from zero, but the slope of the 48-hr regression did not.

The regression for the 96-hr results was:

$$y = 2.2450 + 8.1914 \text{ Log}_{10} (x)$$

where y is number of brown trout dead and x is cumulative chlorine-minutes. The 96-hr CM-50 value extrapolated from this regression was 4.38 chlorine-minutes.

The time chlorine was applied to the condensers was 30 min, while the exposure time at the last station averaged 60 min. Therefore, the average total residual chlorine concentration that could be expected to kill 50 percent of brown trout exposed to three 30-min chlorination periods at 0, 48, and 72 hr of elapsed time during 96 hr in this plant's channel [ILC-50 (3, 90)] was 0.02 to 0.05 mg/liter.

Water samples were taken from the intake and discharge channel on May 31, June 1, and June 2, 1972, and were transported to the MWRC Lansing Wastewater Laboratory for analysis (Appendices 2 and 3). The water temperature ranged from 17 C (63 F) to 20.5 C (69 F) in

Table 1. Brown trout mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the J. H. Campbell power plant intake and discharge channels, May 30 to June 3, 1972.

Item	Station							
	Intake control	Dechlorinated control	1	2	3	4	5	6
Elapsed time[a]								
2 hr - L[b]	0	0	27	0	7	27	0	7
- R	0	0	27	7	13	7	20	0
24 hr - L	0	0	67	60	33	67	47	33
- R	0	0	60	67	73	60	67	20
48 hr - L	0	0	93	67	73	80	73	40
- R	0	0	60	80	73	80	80	40
72 hr - L	0	0	100	80	80	93	73	53
- R	0	0	67	87	73	87	87	53
96 hr - L	0	0	100	93	80	93	93	60
- R	0	0	80	87	87	87	87	60
Total	0	0	90	90	83	90	90	60
TRC (mg/liter)[c]								
Maximum	-	-	0.37	0.43	0.27	0.26	0.20	0.14
Average[d]	-	-	0.26	0.22	0.18	0.10	0.13	0.07
Minimum	-	-	0.12	0.06	0.07	0.04	0.05	0.01
n[e]	-	-	11	8	6	6	9	19
Calculated exposure time (min)	-	-	96.6	104.4	118.3	127.2	142.5	180
Temperature [C (F)]								
Maximum	12 (54)	19 (66)	20.5 (69)	20.5 (69)	20.5 (69)	20.5 (69)	20.5 (69)	20 (68.5)
Average	10.5 (51)	18 (64)	19 (66)	19 (66)	19 (66)	19 (66)	19 (66)	19 (66)
Minimum	9	17 (62)	18 (64)	18 (64)	18 (64)	18 (64)	17.5 (63)	17.5 (63)
n[e]	7	7	7	7	7	7	7	7

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to left and right cages determined when facing downstream.
[c] TRC is total residual chlorine concentration.
[d] Average indicates average computed from values obtained in two 30-min chlorinations. Fish subjected to three 30-min exposures, but initial dosage was not monitored because of titrator malfunction.
[e] n is the total number of readings (non-zero) used to compute averages.

the discharge; no diurnal differences were observed in either the intake or discharge waters. No major differences were found between stations other than increased temperature and percentage saturation of dissolved oxygen and no concentrations were detected at lethal levels. The dechlorinated control station had a lowered DO concentration, which may be due partially to reduction by the thiosulfate in the mixing box. The DO, however, was sufficient (7.3 mg/liter) to support brown trout and fathead minnows. Oxygen saturation in the discharge channel ranged from 118 to 127 percent and averaged 123 percent. These levels are above the 8-day median lethal level of 119 percent for rainbow trout reported by Otto (1972). The shorter exposure period in this study (4 days) and different test species of fish may have lessened the number of deaths related to gas supersaturation.

Three SCUBA divers observed resident fish behavior in the discharge channel during the June 1, 1972, chlorination period. Total residual chlorine concentrations averaged 0.26 mg/liter, and 0.43 mg/liter was the highest concentration recorded in the channel. These divers initially positioned themselves across the channel at station 1 and followed the chlorinated water downstream to station 6. They noted that resident fish, predominately alewife, increased their activity and moved out of the main channel or to side eddies as the chlorinated slug passed. After the chlorinated water passed, fish returned to the main channel and resumed their normal activity.

SUMMARY

Chlorine concentrations measured in the J. H. Campbell plant discharge channel during this study were lethal to brown trout. Approximately 90 percent of all brown trout were killed within 96 hr at all stations in the discharge channel except at the furthest downstream station where 60 percent died. No fish died at either the intake or dechlorinated control stations. Brown trout exposed to three 30-min chlorination periods at 0, 48, and 72 hr of elapsed time during 96 hr in the plant's discharge channel could be expected to incur 50 percent mortality [ILC-50 (3, 90)] at average TRC concentrations ranging from 0.02 to 0.05 mg/liter.

STUDY 2

DESCRIPTION

The second study was conducted at the J. H. Campbell plant, October 9-13, 1972. The general plant description and plant operational information are given in study 1. Chlorination data and condenser cooling water flow rates applicable during this survey were similar to those of study 1, except that one unit was taken off line at 1440 hr on October 12, 1972.

The test fish were acclimated at the dechlorinated control station, October 6-9, 1972. They were transferred to all stations on October 9, 1972 (Fig. 4). The fish were held until October 13, 1972, and exposed to four chlorinations on October 9, October 10, October 12, and October 13. The total residual chlorine concentrations measured are given in Appendix 4. Cages were checked for dead fish every 24 hr.

RESULTS AND DISCUSSION

During this test the plant staff maintained the TRC concentration at less than 0.5 mg/liter at the confluence of the discharges from the two units. Average calculated TRC values at the test stations ranged from 0.06 to 0.18 mg/liter (Table 2). Mortalities at the test stations after 96 hr ranged from 50 to 100 percent; mortality at both control stations was 15 percent. The mortalities at each station were quite variable, especially at station 4, which had 10 and 90 percent survival in the two cages.

Separate linear regressions were computed for the 48- and 96-hr brown trout results. Neither r-value was statistically significant (at the 0.05 significance level), nor was either slope different from zero. Therefore ILC-50's were not calculated.

Water samples were taken from the intake and discharge channel on October 11 and 12, 1972, and transported to the MWRC Lansing Wastewater Laboratory for analysis (Appendices 5 and 6). Temperature was fairly constant averaging 9.5 C (49.5 F), 18 C (64 F), and 18 C (64 F) in the intake, dechlorinated control, and discharge, respectively. Dissolved oxygen ranged from approximately 9 to 11 mg/liter at all stations and was supersaturated in

Figure 4. Map of the J. H. Campbell plant showing caged fish locations, October 9-13, 1972.

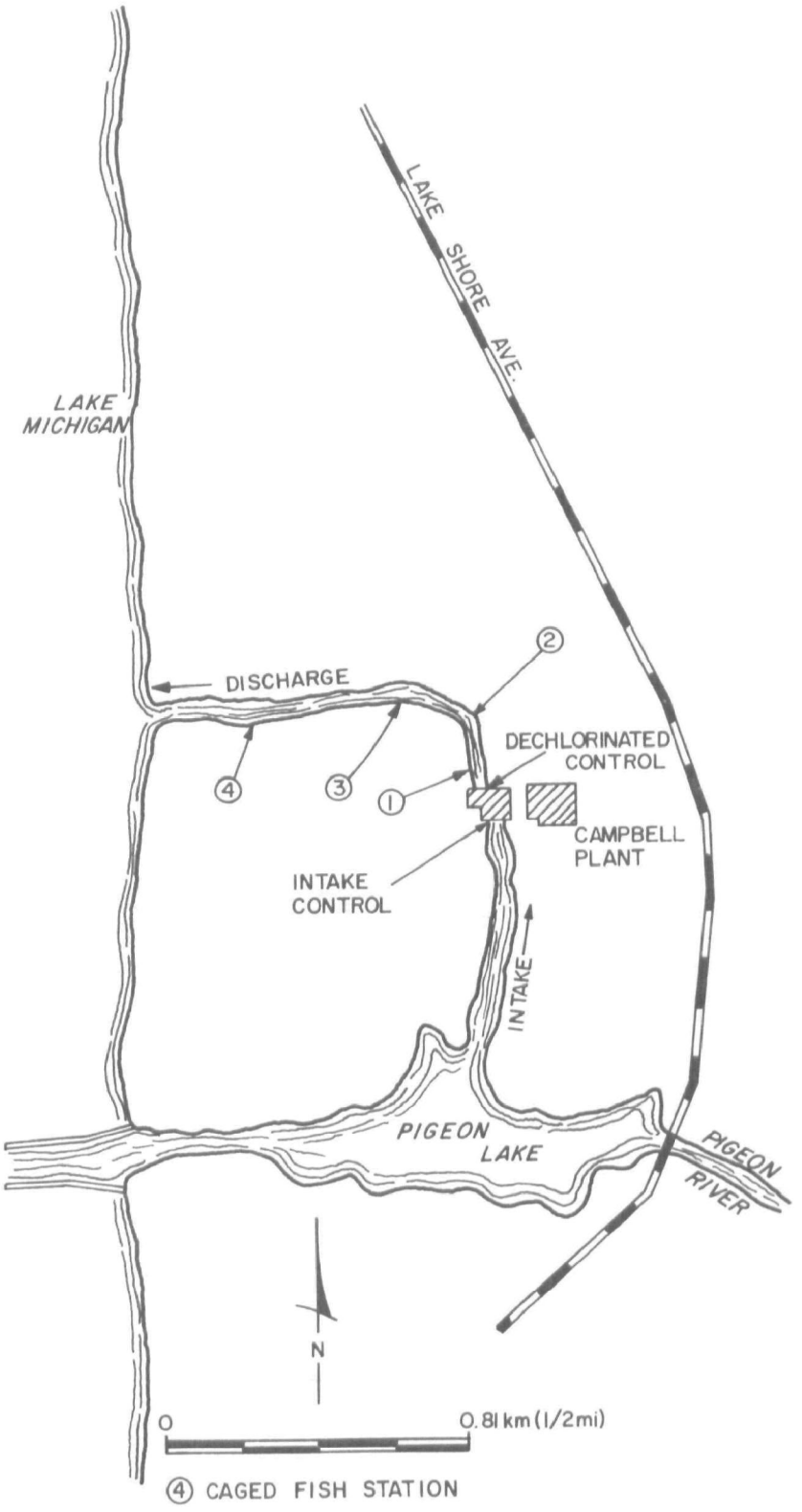


Table 2. Brown trout mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the J. H. Campbell power plant intake and discharge channels, October 9-13, 1972.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
Elapsed time[a]						
24 hr - L[b]	10	10	20	0	10	10
- R	0	0	70	40	0	0
48 hr - L	10	10	40	30	60	10
- R	10	0	70	40	30	50
72 hr - L	20	10	50	50	100	10
- R	10	0	100	50	80	80
96 hr - L	20	10	90	90	100	10
- R	10	20	100	50	100	90
Total	15	15	95	70	100	50
TRC (mg/l)[c]						
Maximum	-	-	0.41	0.50	0.34	0.17
Average[d]	-	-	0.13	0.18	0.15	0.06
Minimum	-	-	0.01	0.04	0.05	0.02
n[e]	-	-	16	14	11	18
Calculated exposure time (min)	-	-	123	132.2	141.9	160
Temperature [C (F)]						
Maximum	11.5 (53)	21 (70)	21 (70)	22 (72)	22 (72)	22 (72)
Average	10.5 (51)	18.5 (65)	19 (66)	18.5 (65)	18.5 (65)	18.5 (65)
Minimum	9 (48)	17 (63)	16.5 (62)	16.5 (62)	16.5 (62)	16 (61)
n[e]	4	5	7	7	6	6

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to the left and right cages determined when facing downstream
[c] TRC is total residual chlorine concentration.
[d] Average TRC is the average total residual chlorine concentration to which the fish were exposed. These averages were computed from values obtained during four 30-min chlorinations.
[e] n is the total number of readings (non-zero) used to compute averages.

the dechlorinated control and discharge with the corresponding percentage saturation ranges 95-114 and 104-114, respectively. These levels were less than the 8-day median lethal level of 119 percent for rainbow trout reported by Otto (1972). Except for the elevated temperature in the channel and an increase in ammonia at station 6 (0.20 mg/liter), no major differences were found that would be lethal to the test fish.

Abnormal behavior of rainbow trout, brook trout, and coho salmon was observed when total residual chlorine concentrations were monitored in the discharge channel on October 12, 1972 (Truchan 1972). Forty to eighty of these fish were observed floundering at the surface. Their behavior was described as listless swimming or jumping out of the water. The fish made no attempt to escape when approached. This abnormal behavior appeared to be related to the presence of chlorine in the channel since similar fish behavior was not noted before the chlorination period. The plant was operating normally with a maximum total residual chlorine concentration recorded in the channel of 0.2 mg/liter. Similar abnormal behavior of 10-15 salmonids was also noted at this plant on the following day, October 13, 1972, at a maximum measured total residual chlorine concentration of 0.5 mg/liter (Truchan 1972). Abnormal fish behavior was not observed in the discharge channel before or after these dates, even during chlorination periods.

SUMMARY

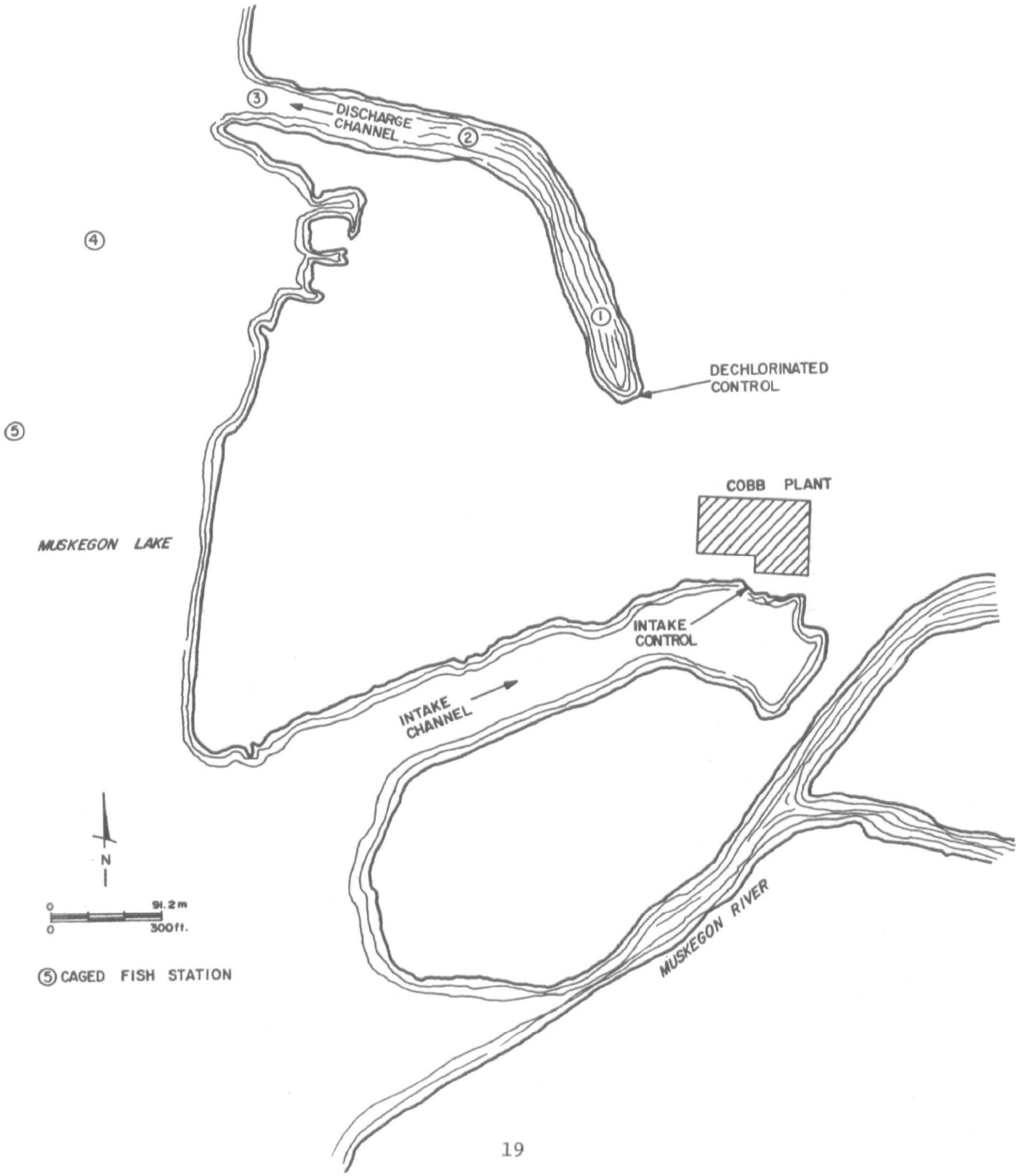
Chlorine concentrations in the J. H. Campbell plant discharge during this study were lethal to caged brown trout. Because of excessive variability in mortality, the ILC-50 concentrations could not be calculated. However, total residual chlorine was lethal at concentrations averaging less than 0.15 mg/liter. Resident rainbow trout, brook trout, and coho salmon were observed in distress on two occasions. This behavior was definitely related to the total residual chlorine concentrations, which measured 0.2 and 0.5 mg/liter.

STUDY 3

DESCRIPTION

The B. C. Cobb plant (Fig. 5) is a coal-fueled facility located at the east end of Muskegon Lake in Muskegon Township, Muskegon County. Five generating units have a combined capacity of 531 MWe. Condenser cooling water for the plant is drawn from Muskegon Lake via an intake channel north of the south branch of the Muskegon River. The combined discharge flows at a maximum rate of 25.6 m^3/sec (405,000 gpm) via a discharge channel into the north branch of the Muskegon River.

Figure 5. Map of the B. C. Cobb plant showing caged fish stations, June 26-30, 1972.



Each unit was chlorinated with aqueous sodium hypochlorite (16%) for 25-min periods on June 26, 28, and 30, 1972. Units 1, 2, and 3 were treated with 15 kg (33 lb) and units 4 and 5 with 22.7 kg (50 lb).

The test fishes were a mixture of centrarchid species which consisted of approximately equal numbers of rock bass (Ambloplites rupestris), black crappie (Pomoxis nigromaculatus), longear sunfish (Lepomis megalotis), and pumpkinseed (Lepomis gibbosus). These fish, ranging in size from 7.5 to 15.0 cm (3-6 inches), were seined from Muskegon Lake at the mouth of the B. C. Cobb discharge and acclimated at the dechlorinated control station from June 21 to 26, 1972. The test fish were transported to all stations on June 26, 1972, and 10 fish were placed in each of the inner and outer cages. Numbers of dead fish were noted daily before the 1100-hr and after the 1400-hr chlorinations. Chlorine concentrations and temperature were monitored during each chlorinatoin period (Appendix 7). The TRC levels were consistent at all test stations with average values ranging from 0.10 to 0.20 mg/liter.

RESULTS AND DISCUSSION

No fish died at the control stations. Mortality was low (0-15%) and variable at the test stations (Table 3). The low mortality and variability prohibited statistical analysis of the data. However, the lack of deaths at the control stations suggests that fish deaths at the test stations were related to chlorine.

Water samples were collected from the intake and dechlorinated control on June 21, 28, and 30 and transported to the MWRC Lansing Wastewater Laboratory for analysis (Appendices 8, 9, and 10). Temperatures were high, averaging approximately 21 C (70 F) in the intake and 26 C (79 F) in the discharge. The DO in the dechlorinated control at times was very low with the concentrations on June 28 (4.3 mg/liter) less than one-half the concentration in the intake (9.8 mg/liter) and two-thirds of the average value at the discharge channel stations (6.5 mg/liter). All DO levels were less than 100 percent saturated. In subsequent tests the dechlorinated control station was artificially aerated. Intake and discharge ammonia levels on June 21, 1972, had a maximum of 0.7 mg/liter which may have stressed the fish. All other ammonia concentrations were less than 0.32 mg/liter. Other characteristics did not differ widely between the intake, dechlorinated control, and the test stations, and none reached toxic levels.

Table 3. Sunfish mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the B. C. Cobb power plant intake and discharge channel, June 26-30, 1972.

Item	Station						
	Intake control	Dechlorinated control	1	2	3	4	5
Elapsed time[a]							
4 hr - L[b]	0	0	0	0	0	0	0
- R	0	0	0	0	0	0	0
24 hr - L	0	0	10	0	0	0	0
- R	0	0	0	0	0	0	0
48 hr - L	0	0	20	0	0	0	0
- R	0	0	10	0	0	0	0
72 hr - L	0	0	20	10	0	0	0
- R	0	0	10	0	0	0	10
96 hr - L	0	0	20	10	0	30	0
- R	0	0	10	0	0	0	10
Total	0	0	15	5	0	15	5
TRC (mg/l)[c]							
Maximum	-	-	0.38	0.34	0.30	0.41	0.26
Average[d]	-	-	0.19	0.20	0.17	0.16	0.10
Minimum	-	-	0.03	0.10	0.06	0.05	0.01
n[e]	-	-	19	14	13	13	16
Calculated exposure time (min)	-	-	132	150	185	210	176[f]
Temperature [C (F)]							
Maximum	22 (72)	26.5 (80)	27 (81)	27 (81)	27 (81)	27 (81)	26.5 (80)
Average	21.6 (71)	26 (79)	26 (79)	26 (79)	26 (79)	26 (79)	25.5 (78)
Minimum	17.5 (64)	24.5 (78)	24.5 (76)	24.5 (76)	24 (75)	24 (75)	24 (75)
n[e]	5	4	9	8	9	8	8

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to the left and right cages determined when facing downstream.
[c] TRC is total residual chlorine concentration.
[d] Average TRC is the average total residual chlorine to which the fish were exposed. These averages were computed from values obtained from 5- and 24-min chlorinations.
[e] n is the number of readings (non-zero) used to compute the average.
[f] Because of wind action on the chlorine plume, fish at this station were not exposed to the June 30, 1972, chlorination.

SUMMARY

Various sunfish species were held in the B. C. Cobb plant discharge channel and subjected to five 25-min chlorinations during the 96-hr period. Deaths among the test fish were few, but may have been due to chlorine since no deaths occurred at the control stations.

STUDY 4

DESCRIPTION

The fourth study was conducted at the B. C. Cobb plant, October 24-28, 1972. One plant operational difference from study 3 was that the normal Monday chlorination was conducted on Tuesday.

The test fish were acclimated in the dechlorinated control station from October 19 to 24, 1972, and transferred to all stations on October 24. The fish were exposed until October 28 and subjected to two chlorinations per day on October 24, 25, and 27. The chlorine concentrations are given in Appendix 11. Fish deaths were checked every 24 hr.

During this test plant staff maintained the total residual chlorine concentrations in the discharge channel at less than 0.5 mg/liter. A maximum of 0.32 mg/liter was observed in the channel, with average total residual chlorine concentrations ranging from 0.06 to 0.17 mg/liter.

RESULTS AND DISCUSSION

Brown trout mortality ranged from 10 to 70 percent at the test stations (Table 4). No deaths occurred at the control stations. No fish died until 48 hours had elapsed. This delay in death may be related to the lower average total residual chlorine levels.

Separate linear regressions were computed for the 48- and 96-hr periods. The r-values for both regressions (0.69 and 0.87) were statistically significant at the 0.05 significance level and accounted for 47 and 77 percent of the variability in the regressions, respectively. In addition, the slopes of both regressions were significantly different from zero. The regression for the 48-hr results was:

$$y = -4.9862 + 6.9737 \text{ Log}_{10}(x).$$

The corresponding regression for the 96-hr results was:

$$y = 12.9043 + 14.0329 \text{ Log}_{10}(x)$$

Table 4. Brown trout mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the B. C. Cobb power plant intake and discharge channel, October 24-28, 1972.

Item	Station						
	Intake control	Dechlorinated control	1	2	3	4	5
Elapsed time [a]							
4 hr - L[c]	0	0	0	b	0	0	0
- R	0	0	0	-	0	0	0
24 hr - L	0	0	0	-	0	0	0
- R	0	0	0	-	0	0	0
48 hr - L	0	0	50	-	40	20	0
- R	0	0	20	-	10	10	10
72 hr - L	0	0	60	-	60	20	0
- R	0	0	60	-	20	10	20
96 hr - L	0	0	70	-	60	30	0
- R	0	0	70	-	20	20	20
Total	0	0	70	-	40	25	10
TRC (mg/liter)[d]							
Maximum	-	-	0.32	0.32	0.24	0.17	0.12
Average[e]	-	-	0.17	0.17	0.10	0.09	0.06
Minimum	-	-	0.02	0.02	0.03	0.02	0.02
n[f]	-	-	30	20	20	14	22
Calculated exposure time (min)	-	-	150.4	152.4	153.8	155	156
Temperature [C (F)]							
Maximum	12 (54)	19.5 (67)	20.5 (69)	20 (68)	20 (68)	15.5 (60)	15 (59)
Average	10.5 (51)	16.5 (62)	16.5 (62)	17 (63)	16.5 (62)	14 (57)	13.5 (56)
Minimum	10 (50)	15.5 (60)	15.5 (60)	16 (61)	15.5 (60)	11.5 (53)	12 (54)
n[f]	4	4	8	5	6	8	8

[a] Elapsed time equals time fish were in cages.
[b] No brown trout were utlized at this station.
[c] L and R refer to the left and right cages determined when facing downstream.
[d] TRC is total residual chlorine concentration.
[e] Average TRC is the average total residual chlorine concentration to which the fish were exposed. These averages were computed from values obtained from six 25-min chlorinations.
[f] n is number of readings (non-zero) used to compute the averages.

where y is the number of brown trout dead and x is the cumulative chlorine-minutes. The 48- and 96-hr CM-50's calculated from the regressions were 18.9 and 27.0 chlorine-minutes, respectively.

The time chlorine was applied to the condensers averaged 24 min; the exposure time at the last station averaged 26 min. The average total residual chlorine concentration during the chlorination period that could be expected to kill 50 percent of brown trout exposed to four 25-min chlorination periods at 3, 6, 27, and 30 hr of elapsed time during 48 hr in this plant's discharge channel [ILC-50 (4,100)] was from 0.18 to 0.19 mg/liter. The average total residual chlorine concentration that could be expected to kill 50 percent of all brown trout exposed to six 25-min chlorination periods at 3, 6, 27, 30, 75, and 78 hr of elapsed time during 96 hr in this plant's discharge channel [ILC-50 (6,150)] was from 0.17 to 0.18 mg/liter.

Water samples were taken from the intake, dechlorinated control, and discharge channel October 25-27 and transported to the MWRC Lansing Wastewater Laboratory for analysis (Appendices 12 and 13). Temperature increased at the dechlorinated control station over the 24-hr period 15 C (59 F) to 16.5 C (62 F) and in the condenser cooling water from 15 C (59 F) to 17.5 C (63 F). Dissolved oxygen concentrations decreased slightly in the dechlorinated control (9.2 to 7.4 mg/liter), but the minimal DO value was adequate to support the test fish All DO saturation levels were less than 100 percent. No constituents were present at lethal concentrations (Appendix 12).

Adult chinook salmon and rainbow trout were observed floundering at the water surface at station 1 during the chlorination period on October 25, 1972. This behavior appeared related to the chlorine concentrations, which averaged 0.26 mg/liter and reached a maximum of 0.32 mg/liter during this period.

SUMMARY

Chlorine concentrations in the B. C. Cobb plant discharge channel were lethal to caged brown trout. Caged brown trout exposed to four 25-min chlorination periods at 3, 6, 27, and 30 hr of elapsed time during 48 hr in this plant's discharge channel could be expected to incur 50 percent mortality [ILC-50 (4,100)] at total residual chlorine concentrations during the chlorination periods averaging from 0.18 to 0.19 mg/liter. These fish exposed to six 25-min periods at 3, 6, 27, 30, 75, and 78 hr of elapsed time during 96 hr could be expected to have 50 percent mortality [ILC-50 (6,150)] at total residual chlorine concentrations during the chlorination periods averaging from 0.17 to 0.18 mg/liter. Resident adult chinook salmon and rainbow trout were observed in distress

on one date. This behavior appeared related to the total residual chlorine concentrations, which averaged 0.26 mg/liter and reached a maximum of 0.32 mg/liter during this period.

STUDY 5

DESCRIPTION

The Conners Creek plant (Fig. 6) is a coal-fueled facility located on the Detroit River at the north end of Belle Isle in the city of Detroit, Wayne County. Nine generating units have the capacity to produce 575 MWe. Condenser cooling water, 40.8 m^3/sec (646,000 gpm), is withdrawn from the Detroit River and discharged back to the river via a discharge channel. Each unit was chlorinated twice daily for 30-min periods; a maximum of 250 lb liquid chlorine gas was used during each chlorination.

The test fishes consisted of approximately equal numbers of largemouth bass (Micropterus salmoides), rock bass (Ambloplites rupestris), and black crappie (Pomoxis nigromaculatus). These fish, ranging in size from 0.6 to 1.2 cm (1.5 to 3 inches), were seined from the Detroit River near Belle Isle, acclimated from July 8 to 11, transported to all stations on July 11, 1972, and 10 specimens placed in the inner and outer cages. Cages were checked daily for dead fish before and after the morning chlorination period. Chlorine concentrations are presented in Appendix 14.

RESULTS AND DISCUSSION

Higher total residual chlorine concentrations were measured at this plant than at any other plant studied. A maximum total residual chlorine concentration of 1.05 mg/liter was observed in the channel; average concentrations ranged from 0.15 to 0.56 mg/liter.

Mortality of the test fish was high at the control stations, ranging from 15 to 30 percent, and variable at the test stations, ranging from 0 to 55 percent (Table 5). Because of the control mortality, mortality at the test stations could not be related to chlorine concentrations.

Water samples were taken from the intake and discharge channels on July 12-13, 1972, and transported to the MWRC Lansing Wastewater Laboratory for analysis (Appendix 15). Except for the temperature difference [20 C (68 F) in the intake versus 28.5 C (83.5 F) in the discharge] and one elevated ammonia reading in the intake (0.35 mg/liter), no consistent differences were found, and no concentrations were found that could be lethal. Dissolved

Figure 6. Map of the Conners Creek plant showing caged fish locations, July 11-15, 1972.

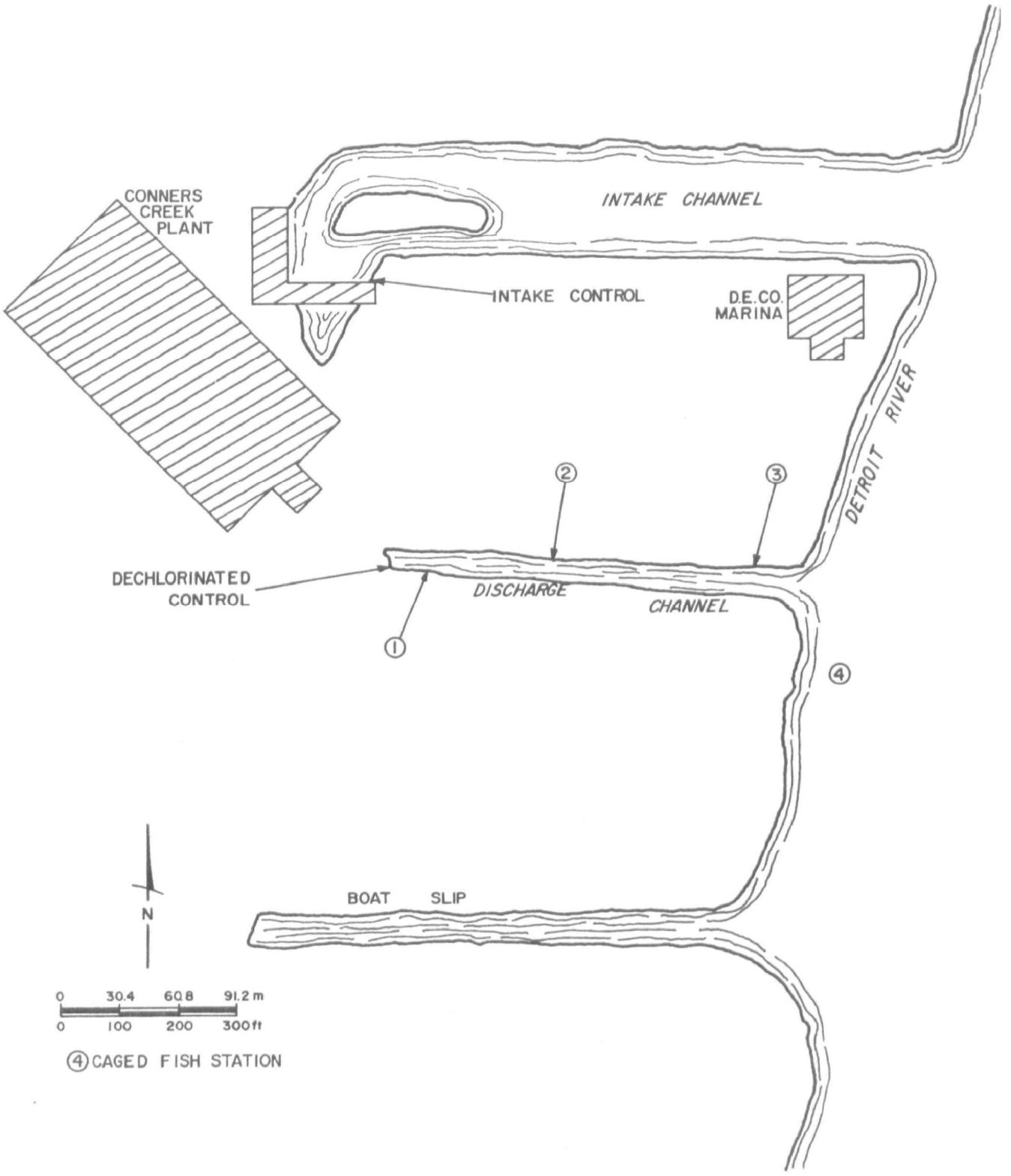


Table 5. Sunfish mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the Connors Creek power plant intake and discharge channel, July 11-15, 1972.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
Elapsed time[a]						
2 hr - L[b]	0	0	0	10	0	0
- R	0	0	0	[c]	0	0
24 hr - L	0	0	20	60	0	20
- R	0	0	40		0	0
48 hr - L	0	10	20	70	0	20
- R	20	10	40		0	10
72 hr - L	0	10	30	70	0	30
- R	30	20	70		0	30
96 hr - L	0	30	40	70	0	30
- R	30	30	70		0	30
Total	15	30	55	70	0	30
TRC (mg/liter)[d]						
Maximum	-	-	0.69	1.05	0.78	0.45
Average[e]	-	-	0.47	0.56	0.50	0.15
Minimum	-	-	0.04	0.03	0.07	0.01
n[f]	-	-	23	22	19	30
Calculated exposure time (min)	-	-	240	240	240	240
Temperature [C (F)]						
Maximum	20 (68)	29 (82)	29.5 (83)	31 (88)	30 (86)	24.5 (76)
Average	20 (68)	26.5 (80)	27 (81)	30.5 (87)	29 (82)	22 (72)
Minimum	20 (68)	25.5 (78)	25.5 (78)	29.5 (85)	25.5 (78)	19 (66)
n[f]	6	5	8	13	13	10

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to the left and right cages determined when facing downstream.
[c] No sunfish were placed in this cage.
[d] TRC is the total residual chlorine concentration.
[e] Averages computed from values obtained from eight 30-min chlorinations.
[f] n is the total number of readings (non-zero) used to compute averages.

oxygen levels were high, averaging approximately 9.6 at both stations. Dissolved oxygen saturation levels were correspondingly high, averaging 105 and 117 percent, respectively, in the intake and discharge channels.

SUMMARY

Various centrarchid species were held in the Conners Creek plant discharge channel and subjected to eight 30-min chlorinations during the 96-hr exposure period. Although test fish died, their death could not be attributed to chlorine because of the excessive number of deaths among the control fish.

STUDY 6

DESCRIPTION

The sixth study was conducted at the Conners Creek plant, November 6-10, 1972. The only difference in plant operation from study 5 was that chlorination occurred once daily at 1000 hr rather than twice daily.

Brown trout were acclimated in the dechlorinated control station November 2-6 and transported to all stations on November 6. The fish were held until November 10 and subjected to five 30-min chlorination periods. Chlorine concentrations and temperature data are given in Appendix 16.

RESULTS AND DISCUSSION

Total residual chlorine concentrations averaged approximately one-half of corresponding values determined during the first study at this plant (0.05 to 0.28 mg/liter compared to 0.15 to 0.56 mg/liter during the first study) (Table 6). Average temperatures were approximately 11 C (20 F) lower than corresponding values for the first study, except at station 4 where there was an 18 C (33 F) temperature difference between the two studies.

Brown trout mortality exceeded 20 percent in the dechlorinated control station after 48 hr. Therefore, all data beyond this time were not analyzed.

Linear regression was employed to determine the 48-hr CM-50. The r-value (0.94) was significant at the 0.01 significance level and accounted for 89 percent of the variability in the regression.

Table 6. Brown trout mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the Connors Creek power plant intake and discharge channel, November 6-10, 1972.

Item	Intake control	Dechlorinated control	Station 1	Station 2	Station 3	Station 4
Elapsed time[a]						
2 hr - L[b]	0	0	0	0	0	0
- R	0	0	0	0	0	0
24 hr - L	0	0	20	60	0	10
- R	0	10	40	80	10	0
48 hr - L	0	0	50	80	0	[c]
- R	0	30	50	90	20	0
72 hr - L	0	30	60	90	20	-
- R	0	30	80	100	30	10
96 hr - L	20	50	90	90	30	-
- R	0	60	90	100	30	20
Total	10	55	90	95	30	20
TRC (mg/liter)[d]						
Maximum	-	-	0.45	0.51	0.13	0.08
Average[e]	-	-	0.25	0.28	0.08	0.05
Minimum	-	-	0.03	0.05	0.03	0.03
n[f]	-	-	21	20	17	6
Calculated exposure time (min)	-	-	124	140	163	180
Temperature [C (F)]						
Maximum	8 (47)	18 (64)	18 (64)	18.5 (65)	15.5 (60)	10 (50)
Average	8 (47)	15.5 (60)	15.5 (60)	17 (63)	12 (54)	9.5 (49)
Minimum	7.5 (46)	14.5 (68)	13.5 (56)	15.5 (60)	10 (50)	9 (48)
n[f]	6	7	10	10	10	9

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to the left and right cages determined when facing downstream.
[c] The left cage was destroyed and the trout escaped.
[d] TRC is total residual chlorine concentration.
[e] Average TRC is the average total residual chlorine concentration to which the fish were exposed. These averages were computed from values obtained from four of the 30-min chlorinations.
[f] n is the number of readings (non-zero) used to compute averages.

The slope was significantly different from zero ($P < 0.01$). The regression for the 48-hr data was:

$$y = 3.1981 + 8.1421 \text{ Log}_{10}(x)$$

where y is the cumulative number of dead brown trout and x is the cumulative number of chlorine-minutes. The 48-hr CM-50 value computed from this regression was 10.0 chlorine-minutes. The time chlorine was applied to the condenser averaged 30 min, and the exposure time at the last station averaged 36 min. The average TRC concentration during the chlorination period that could be expected to kill 50 percent of brown trout exposed to two 30-min chlorination periods at 2 and 26 hr of elapsed time during 48 hr in this plant's discharge channel [ILC-50(2,60)] was 0.14 to 0.17 mg/liter.

Water samples were taken at the intake, dechlorinated control, and condenser cooling water discharge on November 8-9 and transported to the MWRC Lansing Wastewater Laboratory for analysis (Appendices 17 and 18). Temperatures in the intake were constant over the 24-hr sampling period [approximately 8.5 C (47 F)]. In the condenser discharge and the dechlorinated control the temperatures dropped approximately 5.6 C (10 F) between 2000 and 2400 hr and increased approximately 5.6 C (10 F) between 0400 and 0800 hr. This temperature fluctuation is due to the cyclic power generation pattern.

Dissolved oxygen levels were high at all stations averaging approximately 10 mg/liter. Saturation levels averaged approximately 93 percent in the intake and the dechlorinated control and 104 percent in the discharge channel. Except for an increased ammonia concentration in the samples collected at 2000 hr (0.47 mg/liter versus average values of 0.1 mg/liter), the other constituents did not fluctuate widely throughout the 24-hr sampling period, and no concentrations were found that could be lethal.

SUMMARY

Chlorine concentrations in the Conners Creek discharge channel were lethal to caged brown trout. Brown trout subjected to two 30-min chlorination periods at 2 and 26 hr elapsed time during 48 hr in this plant's discharge channel could be expected to incur 50 percent mortality [ILC-50 (2,60)] at average TRC concentrations, during chlorination periods, in the range of 0.14 to 0.17 mg/liter.

STUDY 7

DESCRIPTION

The D. E. Karn plant is a coal-fueled plant located at the south end of Saginaw Bay in Hampton Township, Bay County. Two units have a combined generating capacity of 547 MWe. Condenser cooling water for the plant is drawn from the mouth of the Saginaw River via an intake channel. The combined maximum discharge rate of 18.9 m^3/sec (300,000 gpm) flows via a discharge channel to the J. C. Weadock discharge channel (Fig. 7). Each unit in the Karn plant was chlorinated twice daily for 30-min periods. Approximately 21.5 kg (47.5 lb) of gaseous chlorine was applied in each period.

The J. C. Weadock plant is a coal-fueled plant located on the east bank near the mouth of the Saginaw River in Hampton Township, Bay County. Eight generating units have a combined generation capacity of 679 MWe. Condenser cooling water for the plant is drawn from the Saginaw River at the east bank. The combined maximum rate of discharge of 34.2 m^3/sec (540,000 gpm) flows to Saginaw Bay via a discharge channel shared with the D. E. Karn plant (Fig. 7). Units 1-6 in this plant were chlorinated once daily with 9.1 kg (20 lb) of gaseous chlorine. Units 7 and 8 were chlorinated twice daily with 15.9 kg (35 lb) per chlorination period.

Brown bullheads (Ictalurus nebulosus), ranging in size from 2.5 to 4.8 cm (1-2 inches), were collected from an unnamed pond southwest of Lansing, Michigan. The fish were transported to the Karn-Weadock plant complex, acclimated from July 28 to 31 at the dechlorinated station, and 10 specimens were transferred to the right cage at all stations on July 31. The fish were exposed until August 4, 1972. Chlorine concentration and temperature data are presented in Appendix 19. The number of chlorination periods at each station during the exposure could not be determined because of the extremely complex chlorination schedule employed and various plant operational difficulties. In addition, total residual chlorine was not detected at all channel stations during each chlorination period and was never observed at stations W-4 and W-5, both of which were located in Saginaw Bay.

RESULTS AND DISCUSSION

During this study the plant staff maintained the average total residual chlorine concentration at less than 0.5 mg/liter (Table 7).

Figure 7. Map of the Karn-Weadock power plant complex area showing caged fish locations, July 31-August 4, 1972.

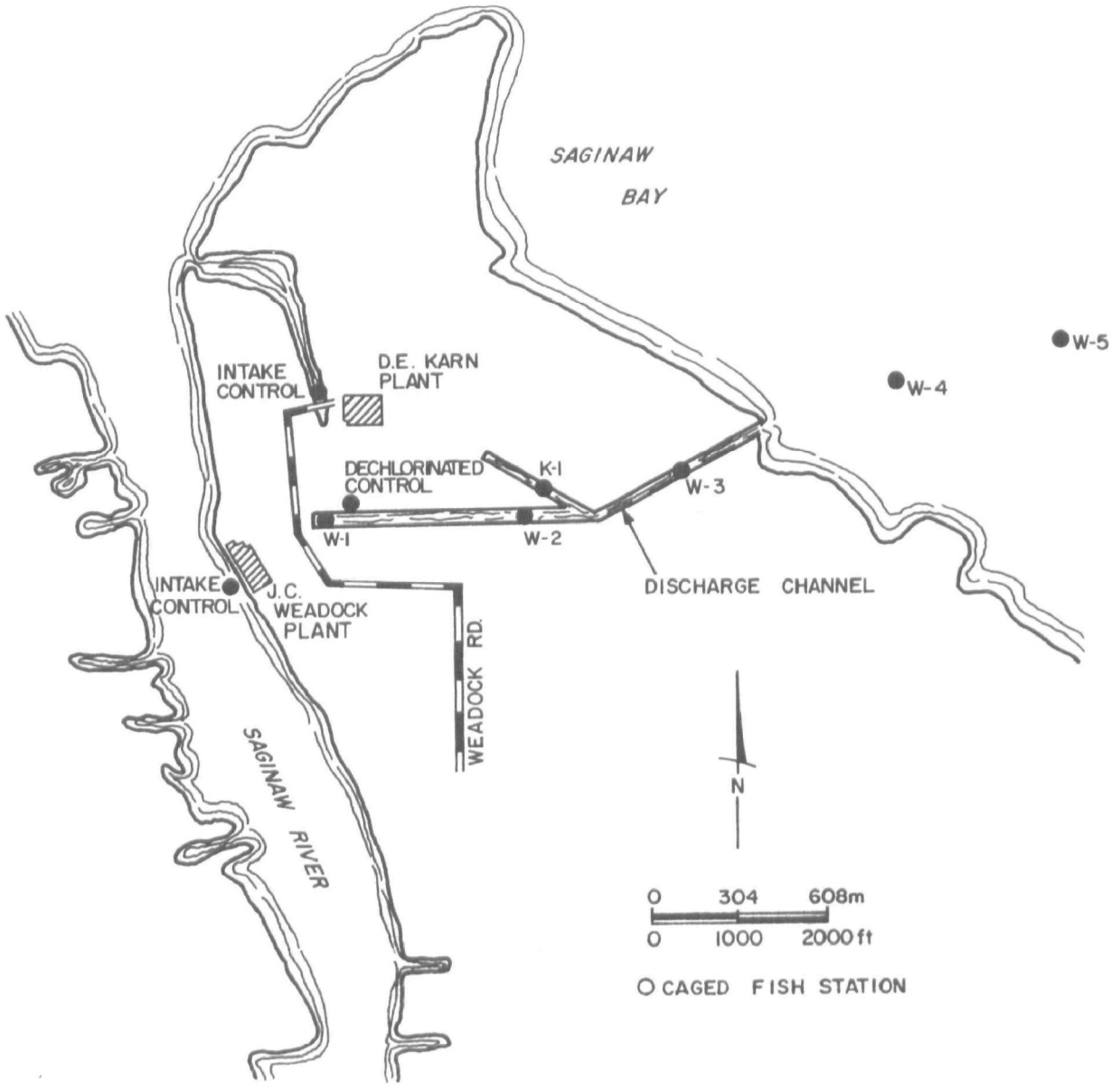


Table 7. Brown bullhead mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the Karn and Weadock power plants intakes and discharge channels, August 1-4, 1972.

Item	Station								
	Karn intake control	Weadock intake control	Dechlorinated control	K-1	W-1	W-2	W-3	W-4	W-5
Elapsed time [a]									
24 hr - R[b]	0	0	20	0	0	20	30	0	20
48 hr - R	30	20	40	10	20	30	30	0	30
72 hr - R	40	20	40	10	20	30	30	0	50
96 hr - R	40	30	40	10	20	30	30	[c]	70
Total	40	30	40	10	20	30	30	-	70
TRC (mg/liter)[d]									
Maximum	-	-	-	0.57	0.45	0.45	0.14	-	-
Average[e]	-	-	-	0.22	0.18	0.16	0.06	-	-
Minimum	-	-	-	0.03	0.03	0.02	0.02	-	-
n[f]	-	-	-	32	48	28	17	-	-
Calculated exposure time (min)[g]	-	-	-	-	-	-	-	-	-
Temperature [C (F)]									
Maximum	23.5 (74)	24.5 (76)	30.5 (87)	32 (90)	34.5 (94)	30 (86)	29 (84)	28 (82)	28 (82)
Average	23 (73)	23.5 (74)	29.5 (85)	30 (86)	29.5 (85)	28.5 (83)	28.5 (83)	28 (82)	29 (81)
Minimum	22.5 (72)	23 (73)	29 (84)	28 (82)	26.5 (80)	27 (81)	28 (82)	27 (81)	26 (79)
n[f]	4	4	4	12	16	12	7	4	4

[a] Elapsed time equals time fish were in cages.
[b] R refers to the right cages determined when facing downstream.
[c] The cage at this station was lost.
[d] TRC is total residual chlorine concentration.
[e] Average TRC is the average total residual chlorine concentration to which the fish were exposed. These averages were computed from values obtained from eight Karn chlorinations and nine Weadock chlorinations. The entire plume was not monitored at each station nor were all chlorination periods monitored.
[f] n is the number of readings (non-zero) used to compute the averages.
[g] The chlorination schedule was too complicated and variable to allow the computation of an exposure time.

The highest maximum and average TRC values were 0.57 and 0.22 mg/liter, respectively, at station K-1 in the Karn channel.

Extremely high temperatures were detected at the test and dechlorinated control stations. Average discharge temperatures ranged from 28 C (82 F) to 30 C (86 F) at these stations (Table 7). Except for two samples from the Karn intake, all DO values were less than the 100 percent saturation level. Fish mortality was variable at the test stations (10 to 70 percent), but because of the high mortality at the control stations (30 to 40 percent) deaths could not be attributed to residual chlorine (Table 7). Therefore, the mortality data were not analyzed further.

Water samples were taken August 4-5 from the intake and discharge channel of each of these plants (Appendices 20, 21 and 22). In both plants similar diurnal patterns were observed in the intake and condenser discharge for each characteristic measured. The maximum concentrations or fluctuations in these measurements were not sufficient to cause fish deaths.

SUMMARY

Brown bullheads were held in the Karn and Weadock power plant discharge channels and subjected to an undetermined number of chlorination periods during a 96-hr period. Deaths of test fish could not be attributed to total residual chlorine concentrations because of deaths at the control stations.

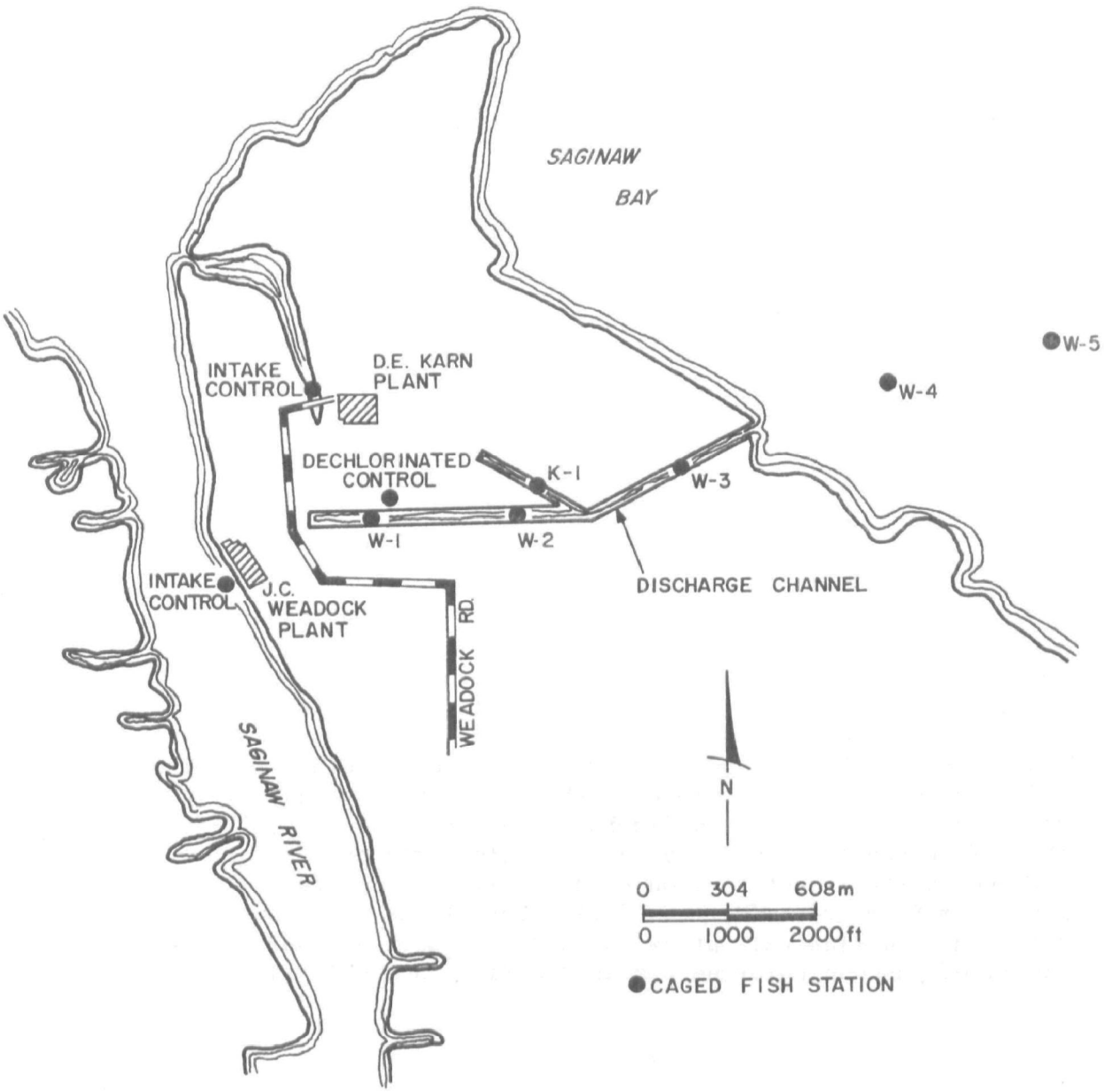
STUDY 8

DESCRIPTION

The eighth study was conducted at the Karn and Weadock plants, November 27-December 1, 1972. The general plant description and operational data were similar to those given in study 7. Station locations were changed, and the revised locations are shown in Fig. 8.

Brown trout were acclimated at the dechlorination control station from November 22 to 27, transferred to all stations on November 27, and exposed until December 1, 1972. During each day and selected night chlorinations the total residual chlorine concentrations were monitored (Appendix 23).

Figure 8. Map of Karn-Weadock plants showing caged fish locations, November 27 - December 1, 1972.



RESULTS AND DISCUSSION

The mean total residual chlorine levels ranged from 0.06 mg/liter at station W-4 in Saginaw Bay to 0.27 mg/liter at station W-1 (Table 8). Mortality of the brown trout controls was low; 15 percent died in both the Weadock intake and dechlorinated controls. From 85 to 100 percent of the fish at all test stations, except W-5, died (Table 8).

Exposure times could not be determined or estimated because of the complex and variable chlorination schedule. Therefore, the brown trout data were not analyzed further. Since deaths among control fish were minimal, it was apparent that test fish deaths were related to the total residual chlorine concentrations present.

Water samples were taken on November 29-30 in the intakes, discharge, and dechlorinated control stations (Appendices 24 and 25). Except for temperature differences, there were no consistent differences between plants. No water characteristics were found at levels that would cause the observed mortalities.

SUMMARY

Brown trout were held in the Karn and Weadock plant discharge channels and subjected to an undetermined number of chlorination periods during the 96-hr period. Fish deaths were related to total residual chlorine concentrations in the condenser cooling water, but ILC-50 values could not be computed.

STUDY 9

DESCRIPTION

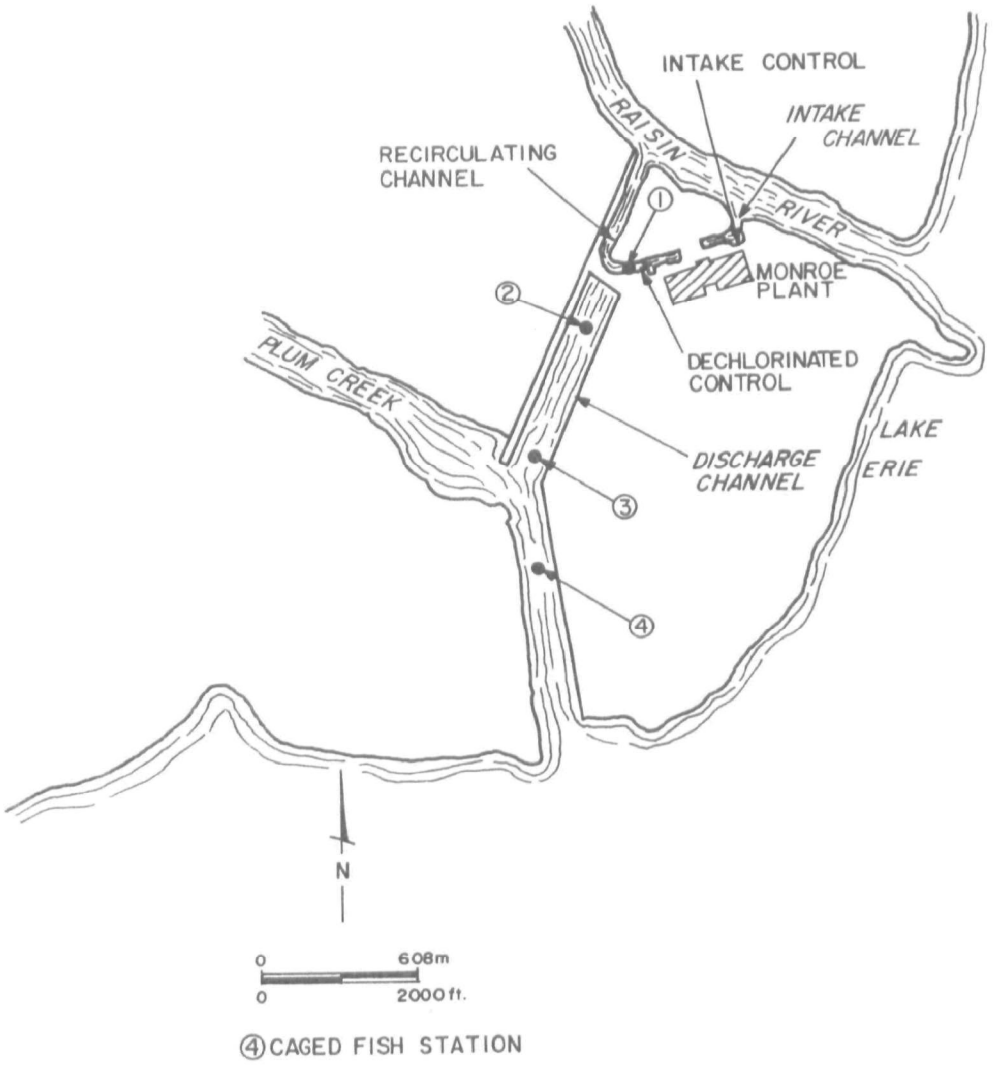
The Monroe plant is a coal-fueled facility located on Lake Erie at the mouth of the Raisin River in the city of Monroe, Monroe County. Construction of two of four generating units was completed during the study, but only one unit was operational. This unit had a generating capacity of 800 MWe. Condenser cooling water, approximately 21.2 m^3/sec (335,700 gpm), was withdrawn from the Raisin River at the interface of the river and Lake Erie (Fig. 9). The cooling water was discharged via a 3,018-m (9,900-ft) channel to the lake (Cole 1972). The discharge channel also receives a small contribution of approximately 1 m^3/sec (16,000 gpm) from Plum Creek (Marcus 1972). Unit 1 was chlorinated twice daily during this study for a 30-min period; approximately 250 lb of gaseous chlorine was used during each chlorination.

Table 8. Brown trout mortality (expressed as percentage) after various time intervals, total residual chlorine concentration and temperature at caged fish and control stations in the Karn and Weadock power plants intakes and discharge channels, November 27-December 1, 1972.

Item	Station								
	Karn intake control	Weadock intake control	Dechlorinated control	K-1	W-1	W-2	W-3	W-4	W-5
Elapsed time[a]									
24 hr - L[b]	0	0	0	90	50	20	70	0	0
- R	0	0	0	60	70	0	50	0	0
48 hr - L	0	0	10	100	50	60	100	10	0
- R	0	0	0	90	70	10	70	0	20
72 hr - L	0	10	10	100	60	70	100	40	10
- R	0	10	10	100	80	60	70	20	50
96 hr - L	0	10	10	100	90	90	100	100	60
- R	0	20	20	100	100	80	100	90	70
Total	0	15	15	100	95	85	100	95	65
TRC (mg/liter)[c]									
Maximum	-	-	-	0.25	0.83	0.33	0.17	0.11	0.20
Average[d]	-	-	-	0.12	0.27	0.09	0.08	0.06	0.10
Minimum	-	-	-	0.02	0.01	0.01	0.01	0.02	0.01
n[e]	-	-	-	44	44	54	36	21	10
Calculated exposure time (min)[f]	-	-	-	-	-	-	-	-	
Temperature [C (F)]									
Maximum	2 (37)	2 (37)	13 (57)	13.5 (58)	13 (57)	14.5 (60)	14 (59)	14 (59)	13.5 (58)
Average	1.5 (36)	2 (37)	13 (57)	12 (56)	12 (56)	13.5 (58)	11.5 (55)	11.5 (55)	10.5 (53)
Minimum	1 (35)	2 (37)	12.5 (56)	9 (48)	11 (52)	12 (56)	10.5 (51)	10.5 (51)	3.5 (38)
n[e]	4	2	4	14	11	13	8	8	8

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to the left and right cages determined when facing downstream.
[c] TRC is total residual chlorine concentration.
[d] Average TRC indicates the average total residual chlorine concentration to which fish were exposed. These averages were obtained from results obtained during eight 35-min chlorinations at the Karn plant and nine 30-min chlorinations at the Weadock plant. The entire plume was not monitored at each station nor were all chlorinations monitored.
[e] n is the number of readings (non-zero) used to compute the averages.
[f] The chlorination schedule was too complex and variable to allow computation of exposure times.

Figure 9. Map of the Monroe plant showing caged fish locations, December 11-15, 1972.



Brown trout were acclimated at the dechlorinated control station December 8-11, 1972, transported to all stations on December 11, and exposed until December 15 (Fig. 9). Deaths were noted daily and total residual chlorine concentrations were monitored (Appendix 26).

RESULTS AND DISCUSSION

Mean total residual chlorine levels were high, ranging from 0.26 to 0.40 mg/liter (Table 9). These values were exceeded only by those determined in the first study at the Connors Creek plant, July 11-15. Exposure times at all stations could not be determined becasue of various plant operational and experimental problems.

Water samples were collected December 13 from the intake, dechlorinated control, and condenser cooling water discharge (Appendix 27). Water samles were also collected at 4-hr intervals December 13-14 from these stations (Appendix 28). Temperatures were low in the intake, averaging approximately 1 C (34 F) and approximately 9 C (48 F) in the dechlorinated control and test stations. The DO levels were high, averaging approximately 11.5 mg/liter in the intake and 10.5 and 11.5 mg/liter in the dechlorinated control and discharge, respectively. Dissolved oxygen saturation levels at all three stations averaged near 100 percent. Ammonia and pH were consistent at all times at all stations, averaging approximately 0.3 mg/liter and 7.9, respectively. No constituents were found at toxic levels.

SUMMARY

Brown trout were held in the Monroe plant discharge channel and subjected to nine 30-min chlorination periods during the 96-hr exposure period. Some brown trout deaths appeared to be due to chlorine, but lethal concentrations could not be determined.

Table 9. Brown trout mortality (expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the Monroe power plant intake and discharge channel, December 11-15, 1972.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
Elapsed time [a]						
24 hr - L[b]	0	0	60	40	0	0
- R	0	0	80	70	0	0
48 hr - L	30	20	100	100	100[c]	100[c]
- R	30	0	100	100	100[c]	10
72 hr - L	40	20	100	100	100	100
- R	50	0	100	100	100	30
96 hr - L	40	20	100	100	100	100
- R	50	0	100	100	100	30
Total	45[d]	10	100	100	100	65
TRC (mg/liter)[e]						
Maximum	-	-	1.03	0.87	0.59	-
Average[f]	-	-	0.36	0.40	0.26	-
Minimum	-	-	0.02	0.02	0.01	-
n[h]	-	-	43	39	22	-
Calculated exposure time (min)[g]	-	-	-	-	-	-
Temperature [C (F)]						
Maximum	3.5 (38)	13.5 (56)	13.5 (56)	13 (55)	10 (50)	9 (48)
Average	1.5 (35)	11 (52)	10 (50)	10 (50)	8.5 (47)	7.5 (45)
Minimum	1 (34)	9.5 (49)	7.5 (45)	7 (44)	7 (44)	6.5 (43)
n[h]	4	4	8	9	6	5

[a] Elapsed time equals time fish were in cages.
[b] L and R refer to the left and right cages determined when facing downstream.
[c] Due to a three feet overnight drop in water level all cages at Station 3 and the left cage at Station 4 were found completely out of the water (other cages at Station 4 were partially out of water).
[d] These mortalities could be due to chlorine present in the intake channel since a maximum TRC concentration of 0.31 mg/l was recorded at the junction of the plants recirculation channel and the River Raisin approximately 200 yards upstream from the intake. The presence of chlorine in the intake was not documented.
[e] TRC is total residual chlorine concentration.
[f] Average TRC refers to the average total residual chlorine concentration to which the fish were exposed. These averages were computed from values obtained from five 30-min chlorinations.
[g] No exposure times could be calculated.
[h] n is the total number of readings (non-zero) used to compute averages.

CONCLUSIONS

Nine caged fish bioassays were conducted at five Michigan power plants from May to December 1972. The results of these studies are summarized in Table 10. The 48-hr ILC-50 concentration ranges calculated for brown trout at two plants were 0.14 to 0.17 mg/liter and 0.18 to 0.19 mg/liter. The 96-hr results were more variable: ILC-50 ranges calculated at two plants were 0.02 to 0.05 mg/liter and 0.17 to 0.18 mg/liter. Mortality in two of the other brown trout studies was related to total residual chlorine concentrations, but corresponding ILC-50 values could not be calculated.

Three studies were conducted with centrarchid species or brown bullheads. Mortalities in these three tests could not be related to total residual chlorine concentrations. The sunfish, based on two studies, were able to tolerate intermittent mean total residual chlorine levels up to 0.5 mg/liter without excessive numbers of deaths. Brown bullheads were able to tolerate intermittent mean total residual chlorine concentrations of 0.2 mg/liter with no chlorine-attributable deaths. Similar results were reported by Arthur (1971) (cited in Brungs 1973) for largemouth bass. He found a 1-hr TL-50 of >0.74 mg/liter for this species.

The discharge channel temperature appears to be a major factor affecting the lethality of the TRC concentrations. The maximum mean discharge channel temperature at which brown trout were tested was 18.9 C (66 F) (Campbell, May 30-June 3, 1972). This study also had the lowest 96-hr ILC-50 range. Stober and Hanson (1974) also found that the lethality of chlorine increased with increasing temperature for pink and chinook salmon held in sea water and subjected to brief exposures ($\leq$1 hour).

Table 10. Summary of caged fish bioassay results obtained in nine studies at five Michigan power plants, 1972.

Plant	Date	Test species	Mean temperature [C (F)]		48 hr		96 hr	
			Intake	Discharge	Number of chlorinations	ILC-50 (mg/liter)	Number of chlorinations	ILC-50 (mg/liter)
Campbell	5/30 - 6/3	Brown trout	10.5 (51)	19 (66)	1	a	3	0.02 - 0.05
Campbell	10/9 - 10/13	Brown trout	10.5 (51)	18 (65)	2	a	4	a
Cobb	6/26 - 6/30	Sunfish[b]	21.5 (71)	26 (79)	---	---	---	---
Cobb	7/24 - 7/28	Brown trout	10.5 (51)	15.5 (60)	4	0.18 - 0.19	6	0.17 - 0.18
Conners Creek	7/11 - 7/15	Sunfish[c]	20 (68)	27 (81)	---	---	---	---
Conners Creek	11/6 - 11/10	Brown trout	8.5 (47)	14 (57)	2	0.14 - 0.17	---	a
Karn-Weadock	7/31 - 8/4	Brown bullhead[c]	23.5 (74)	29 (84)	Not determined			
Karn-Weadock	11/27 - 12/1	Brown trout[a]	3 (37)	13.5 (56)	Not determined			
Monroe	12/11 - 12/15	Brown trout[a]	1.5 (35)	9 (48)	Not determined			

[a] Mortality related to TRC concentrations, but confounding factors prohibited further analysis.
[b] Limited number of deaths possibly due to TRC concentration.
[c] Excessive control deaths; deaths not attributable to TRC.

SECTION V

1973 FIELD STUDIES

Four caged fish tests were conducted at the J. H. Campbell plant during the spring of 1973 to determine differences in ILC-50 concentrations for brown, rainbow, and lake trout and coho salmon. Death attributable to stresses from fish acclimation or handling, or both, was also studied.

TEST 1

METHODS

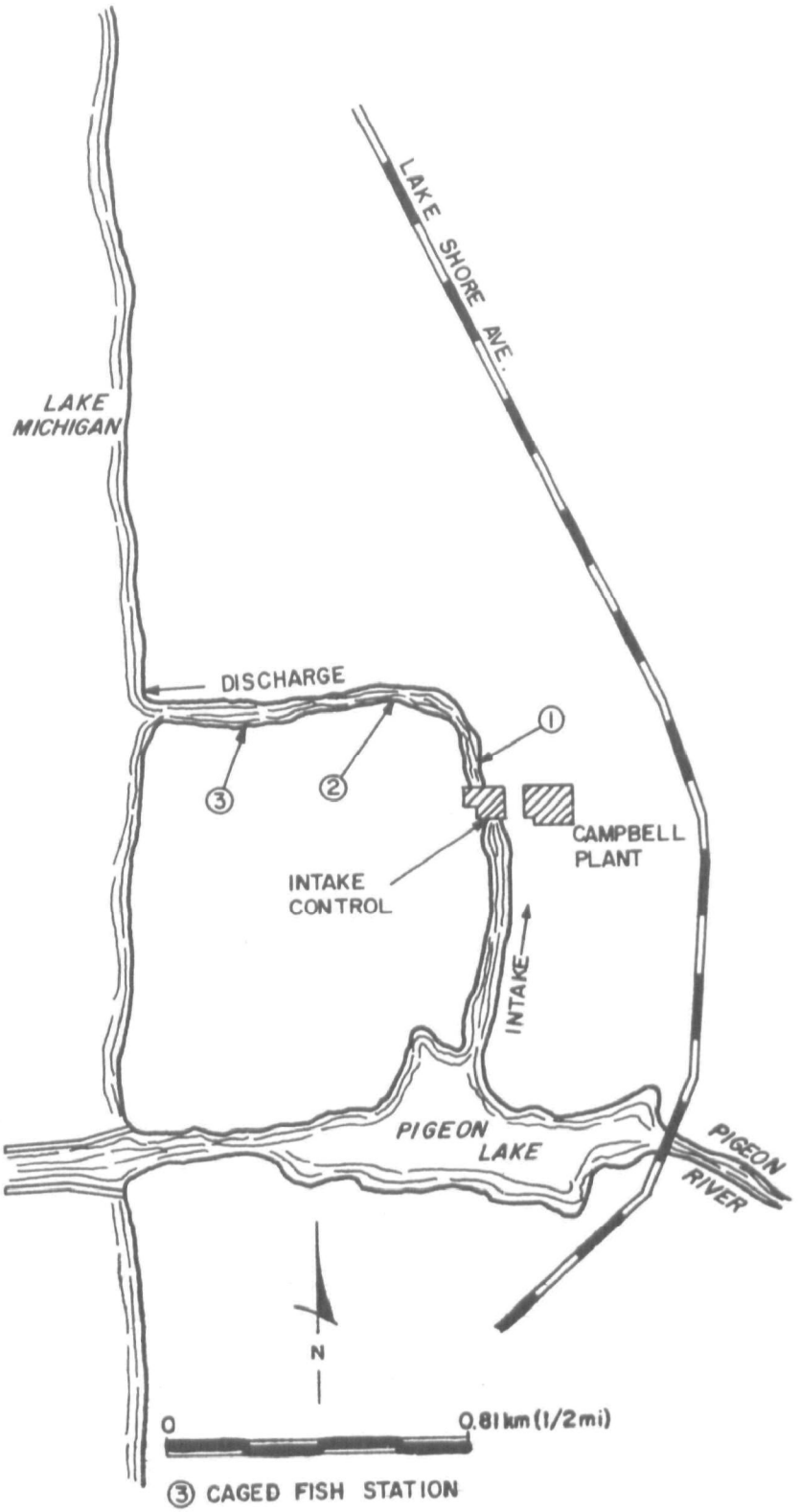
Unit 2 of the Campbell plant was in operation during this test while Unit 1 was being repaired. The description of this plant and general operating information is given in study 1 of the 1972 field studies. Station locations used in the study are given in Fig. 10.

During the 1973 field tests the fish were acclimated in test cages at each station in the discharge channel from Friday to Monday instead of in the dechlorination apparatus. Since chlorine was not applied to the condensers on weekends this procedure was employed to evaluate stresses due to handling or dechlorination or both. Each exposure station consisted of three booms, each of which contained three cages.

Rainbow trout, 13-20 cm (5-8 inches) long, and coho salmon, 10-15 cm (4-6 inches) long, were obtained from the Sturgeon River Rearing Station on April 27, 1973. Brown trout, ranging from 10 to 15 cm (4 to 6 inches), were obtained from the Oden State Fish Hatchery. Fifteen individuals of each species were placed in separate cages on two booms at each test station and intake control. Fish were also placed in stock cages in the intake and held until April 30, 1973. On April 30, 1973, before chlorination, the survival of all fish acclimated in the test cages was determined and the number in each cage reduced to 10.

Fish held in intake stock cages water temp [10 C (50 F)] were acclimated to the discharge water temperature [17 C (63 F)] by slowly adding water from the discharge channel to the stock cages over a 30-min period. After chlorination, 10 fish of each species

Figure 10. Map of J. H. Campbell Plant showing caged fish locations April 30-May 4, 1973.



were transported to each test station and placed in cages on the third boom. At each station, after chlorination, 20 individuals of each species were present that had been subjected to chlorination and 10 individuals of each species were present that had not been subjected to chlorination. The latter served as controls. Fish mortality was checked 24, 48, 72, and 96 hr after chlorination.

Water samples were taken May 2, 1973, from the intake and each test station and were transported to the MWRC Lansing Wastewater Laboratory for selected physical and chemical analyses.

RESULTS AND DISCUSSION

The cumulative fish mortalities observed througout this study are presented in Table 11, and total residual chlorine concentrations and temperature data are summarized in Appendix 29.

No heat was added to the discharge water on April 27, 1973, when fish were placed in the test cages to acclimate since both units were not operating. Unit 2 was brought on-line at approximately 1145 hr on this date. The temperature in the discharge channel increased by approximately 6.7 to 9.6 C (12-16 F) over a 24-hr period. This temperature increase may have stressed the brown and rainbow trout as seen by the losses of these fish in the discharge channel during the acclimation period. However, none of the coho salmon died during this period.

In addition to heat from unit 2, the temperatures in the intake water rose steadily from 9.5 C (49 F) on April 27 to a peak of 14.5 C (58 F) on May 2, and then decreased to 10.5 C (51 F) on May 4 (Appendix 29). As a result of this rise in the temperature of the intake water, a similar pattern was seen in the discharge channel with a maximum observed temperature of 22.5 C (72.5 F).

Deaths of brown trout during the first 24 hr after chlorination may be related to total residual chlorine concentrations since approximately half the fish of this species died during this period and no control fish died. The average total residual chlorine values during the chlorination period were low, ranging from 0.03 to 0.11 mg/liter. Mortality of control brown trout was high after 48 hr, and therefore no 48- or 96-hr mortalities were calculated. Rainbow trout deaths in the discharge channel could not be attributed to chlorine because of the high mortality of control fish. Mortality was low in both the test and control coho salmon. High mortality in the control brown and rainbow trout may

Table 11. Fish mortality expressed as percentage) after various time intervals, total residual chlorine concentration, and temperature at the caged fish and control stations in the J. H. Campbell plant intake and discharge channel, April 30-May 4, 1973.

Species and time	Stations											
	Intake			1			2			3		
Boom:	A[a]	B	C	A	B	C	A	B	C	A	B	C
Brown trout												
Acclimation loss	0	0	-	7	0	-	7	13	-	0	0	-
24 hr	0	0	0	50	40	0	50	40	0	60	70	0
48 hr	0	0	0	80	90	20	100	90	50	80	100	10
72 hr	0	0	0	80	90	70	100	90	70	90	100	30
96 hr	0	0	0	100	100	80	100	90	80	90	100	30
Rainbow trout												
Acclimation loss	7	0	0	7	0	-	7	7	-	27	7	-
24 hr	0	0	0	0	30	20	10	0	0	20	0	0
48 hr	10	0	0	0	30	70	10	20	10	50	0	10
72 hr	30	0	0	10	40	70	20	20	10	50	0	10
96 hr	30	0	0	10	40	70	20	20	10	50	0	20
Coho salmon												
Acclimation loss	0	0	-	0	0	-	0	0	-	0	0	-
24 hr	0	0	0	0	0	0	0	0	0	0	0	0
48 hr	0	0	0	0	0	0	20	10	0	10	20	0
72 hr	0	0	0	0	0	0	20	10	10	10	30	0
96 hr	0	0	0	10	0	20	20	10	10	20	30	10
TRC mg/liter)[b]												
Maximum		-			0.22			0.14			0.04	
Average		-			0.11			0.08			0.03	
Minimum		-			0.02			0.02			Trace	
n[c]		-			10			10			6	
Calculated exposure time (min)		-			30			30			30	
Temperature [C (F)]												
Maximum		14.5 (58)			22.5 (72.5)			22 (72)			22 (72)	
Average		11 (52)			18.5 (65)			18.5 (65)			18 (64)	
Minimum		9.5 (49)			10.5 (51)			10.5 (51)			10.5 (51)	
n[c]		6			6			6			6	

[a] In boom A and B fish were subjected to chlorine. Fish in boom C were put in after chlorination and served as controls.
[b] TRC is total residual chlorine concentration.
[c] n is the number of readings (non-zero) used to compute averages.

have been due to wide temperature fluctuations. During the study temperatures in the channel ranged from 10.5 to 22.5 C (51-72.5 F), with an average of approximately 19 C (66 F).

Dissolved oxygen, total alkalinity, and hardness were slightly lower during this study than in the 1972 studies conducted at the plant (Appendix 30). Concentrations of nitrate, total phosphorus and iron were higher. These differences, however, were minor and would not account for the difference in mortalities between species.

SUMMARY

A caged fish bioassay was conducted in the J. H. Campbell plant April 30 to May 4, 1973, with brown trout, rainbow trout, and coho salmon. Mortality results obtained were inconclusive, but indicated a possible lethal effect of chlorine on brown trout in the 48 hr immediately after chlorination. The death of brown trout after 48 hr and all deaths of rainbow trout and coho salmon could not be attributed to chlorine. A possible cause of these deaths was the widely fluctuating temperature in the discharge channels.

TEST 2

A second caged fish bioassay was conducted during the 1973 spring field studies at the J. H. Campbell plant. Because of the wide temperature fluctuations in the channel during the previous test, the circulating water pumps of unit 1, which was off-line, were operated to reduce the temperature variation. Unit 2 was chlorinated three times during this test to prevent condenser fouling. Other conditions were similar to those of test 1 of this series. Station locations are given in Fig. 10.

METHODS

The test fish were obtained on May 10, 1973, from the following hatcheries: rainbow trout from the Sturgeon River Rearing Station; brown trout from the Oden State Fish Hatchery; and coho salmon from the Platte River State Fish Hatchery. These fish were similar in size to those used in test 1 of this series. Fifteen fish of each species were placed in separate cages on each of four booms in the intake on May 11. Additional fish were acclimated to the discharge channel temperature in wooden stock cages in a 545.5-liter (144-gal) metal tank filled with intake water [13 C (56 F)] while slowly replacing the water with discharge channel water [17.5 C (64 F)] over a 60-min period. Fifteen fish of each species were then transferred to separate cages on two booms at each discharge channel station. The remaining fish were held in stock cages in the channel at station 1. All fish

were held in the test and stock cages until May 14, when the losses were noted and the number of fish in each cage reduced to 10.

Before each chlorination period (May 14, 16, and 18) the stock cages containing fish at station 1 were removed from the discharge channel and held in a 545.5-liter (144-gal) tank filled with unchlorinated discharge channel water. After passage of the chlorinated water, the stock cages were transferred back to the discharge channel. To provide controls for each chlorination period, 10 fish of each species were transferred from the stock cages to the test cages after each chlorination.

Deaths were checked every 24 hr, and total residual and free chlorine concentrations were monitored at each station commencing May 14. Water samples were taken from the intake and discharge channel on May 17 and transported to the MWRC Lansing Wastewater Laboratory for analysis.

RESULTS AND DISCUSSION

There were minor losses of rainbow trout during the acclimation period; however, during the test no TRC-related deaths occurred in any of the three test species (Table 12). The fish were exposed three times to chlorine for a maximum of 30 min during the 96-hr period at average TRC concentrations ranging from 0.05 to 0.25 mg/liter and a recorded maximum of 0.39 mg/liter (Appendix 31).

The lack of deaths during test 2 may be due to decreased temperature fluctuations and lower average discharge channel temperatures, 16 C (61 F) vs. 19 C (66 F). Temperature fluctuations during test 1 averaged 12 C (21 F) in the channel and 5 C (9 F) in the intake. In test 2, however, the temperature fluctuations averaged 1 C (2 F) at the test stations and 0.5 C (1 F) in the intake. The decreased fluctuations are due to decreased variability in the intake water temperature and the additional flow from the operation of the circulating water pumps of unit 1.

Dissolved oxygen, total alkalinity, and hardness increased slightly, and iron concentrations were less than those obtained in test 1 of this series (Appendix 32). These minor differences would not cause the difference in mortality observed in these two tests.

Table 12. Fish mortality (expressed as percentage) after various time intervals, total residual chlorine concentration and temperature at the caged fish and control stations in the J. H. Campbell power plant intake and discharge channel, May 14-18, 1973.

Species and time	Stations															
	Intake				1				2				3			
Boom:	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Brown trout																
Acclimation loss	0	0	0	0	0	0			0	0			0	0		
24 hr	0	0	0	0	0	0	0		0	0	0		0	0	0	
48 hr	0	0	0	0	0	0	0		0	0	0		0	0	0	
72 hr	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
96 hr	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Rainbow trout																
Acclimation loss	0	0	7	13	7	7			7	0			7	0		
24 hr	0	0	0	0	0	0	0		0	0	0		0	0	0	
48 hr	0	0	0	0	0	0	0		0	0	0		10	0	0	
72 hr	0	0	0	0	0	0	0	0	0	0	10	0	10	0	0	0
96 hr	0	0	0	0	0	0	10	0	0	0	10	0	10	0	0	0
Coho salmon																
Acclimation loss	0	0	0	0	0	0			0	7			0	0		
24 hr	0	0	0	0	0	0	0		0	0	0		0	0	0	
48 hr	0	10	0	0	0	0	0		0	0	0		10	0	0	
72 hr	0	10	0	0	10	10	0	10	0	0	0	0	20	0	0	0
96 hr	0	20	0	0	10	10	0	20	0	0	0	0	40	0	0	0
TRC (mg/liter)[b]																
Maximum		-				0.39				0.23				0.10		
Average		-				0.25				0.12				0.05		
Minimum		-				0.03				0.02				0.03		
n[c]		-				22				33				22		
Calculated exposure time (min)		-				90				90				90		
Temperature [C (F)]																
Maximum		11 (52)				16.5 (62)				16 (61)				16.5 (62)		
Average		11 (52)				16 (61)				15.5 (60)				16 (61)		
Minimum		10.5 (51)				15 (59)				15 (59)				15.5 (60)		
n[c]		5				5				5				5		

[a] Booms A and B contained fish subjected to chlorinations on May 14, 16 and 18, 1973. Boom C fish were put in following the May 14 chlorination and subjected to May 16 and 18 chlorinations. Boom D fish were put in following the May 16 chlorination and subjected to the May 18 chlorination.

[b] TRC is total residual chlorine concentration.

[c] n is number of readings (non-zero) used to compute the averages.

SUMMARY

A caged bioassay was conducted at the J. H. Campbell plant May 14-18, 1973, with brown trout, rainbow trout, and coho salmon. Fish deaths were minimal for fish subjected to one to three chlorination periods during 96 hr and could not be related to total residual chlorine concentrations in the channel. Lower average water temperatures could have reduced chlorine toxicity to these fish and may partially account for the lack of fish deaths.

TESTS 3 AND 4

Additional caged fish bioassays were conducted at the J.H. Campbell plant May 21-30, 1973, with brown trout, rainbow trout, lake trout, and coho salmon. These fish were subjected to multiple chlorinations (up to six 30-min exposures) at mean TRC levels during chlorination ranging from 0.07 to 0.19 mg/liter. Water temperatures ranged from 16.5 to 18 C (62 to 64 F). Few deaths occurred throughout these tests, and none was attributable to the total residual chlorine concentrations in the channel.

At the request of the MWRC staff, the chlorination level was increased on May 25 to a maximum of 0.38 mg/liter and a mean of 0.17 mg/liter at station 1. Small rainbow and brown trout [20.3-27.9 cm (8-11 inches)]were observed at station 1 in stress as they swam into the shallow waters and gulped at the water's surface. Numerous shiners were also observed dead and rolling along the channel bottom. It could not be determined if these fish were initially near the headwall and were subjected to extremely high total residual chlorine levels and then floated downstream to station 1. Even though these fish were stressed or killed, no deaths were observed in the caged fish that could be related to the total residual chlorine concentrations in the channel.

SUMMARY

Caged bioassays were conducted at the J. H. Campbell plant, May 21 to 30, 1973, with brown trout, rainbow trout, lake trout, and coho salmon. Deaths among fish subjected to up to six 30-min chlorinations were few and could not be related to total residual chlorine concentrations in the channel.

CONCLUSIONS

Four bioassays were conducted at the J. H. Campbell plant during May, 1973, with brown trout, rainbow trout, lake trout, and coho salmon. Fish were subjected to up to six 30-min chlorination periods at concentrations similar to concentrations occurring in the 1972 studies conducted at this plant. Unlike the 1972 studies, no deaths occurred during the 1973 studies that could be attributed to total residual chlorine concentrations in the channel, except possibly the deaths of

brown trout during the first 48 hr after chlorination in test 2. Overall lower water temperatures could have reduced chlorine toxicity to fish, and thus the apparent discrepancies between the 1972 and 1973 field studies may be explained. The results indicate that chlorine toxicity to salmonids will be most severe during warmwater periods.

SECTION VI

LABORATORY BIOASSAYS

INTRODUCTION

Continuous flow bioassays were conducted during July and August 1973 at the MWRC bioassay laboratory in Lansing, Michigan, to determine the effect of water temperature on the lethality of one 30-min intermittent dose of chlorine and the lethal effect of sodium thiosulfate on fish.

METHODS

The test fish, brown trout, ranged in length from 4.8 to 8.1 cm (1.9 to 3.2 inches) and averaged 6.5 cm (2.4 inches). Fish weight ranged from 0.6 to 5.6 g and adveraged 2.2 g. The fish were obtained from Oden State Fish Hatchery and held at the MWRC Bioassay Laboratory. Twelve 15-liter glass aquaria were used as test chambers, of which six were equipped with 15-w electric heaters. A modified serial dilution system (Mount and Brungs 1967) supplied the aquaria with filtered, dechlorinated municipal water. The diluter supplied each aquarium with 250 ml of water in approximately 112 sec, giving 99 percent replacement in about 1.8 hr. The fish (10) were acclimated in the aquaria for 72 hr at test temperatures of 17 C and 21 C (63 F and 70 F). Six aquaria were used at each temperature with one control and five test solutions containing total residual chlorine concentrations ranging from approximately 0.6 to 1.0 mg/liter.

A stock solution of chlorine was made by adding 30 ml of commercial bleach (5 percent NaOCl) to 3.6 liters of dechlorinated city water. The chlorine solution was added by pipet to the test aquaria and mixed thoroughly by stirring with a glass rod.

During the 30-min chlorination period, total residual chlorine readings were taken at 5-min intervals with a Fisher-Porter amperometric titrator. Both control aquaria were checked before and after chlorination for the presence of chlorine. After the exposure period, 66 ml of dilute solution of sodium thiosulfate ($\sim$6.5 mg/liter $Na_2S_2O_3$) was added to all aquaria, controls included, stirred thoroughly, and a chlorine sample taken to verify that all chlorine had been neutralized.

A water sample was taken from each aquarium before, midway through, and 48 hr after the chlorination and was analyzed for dissolved oxygen with the Winkler-Azide method; for pH with an Analytical Instruments glass electrode pH meter; for total alkalinity with a Hach kit; and for hardness by means of the EDTA method. Temperature was recorded during each test with a maximum-minimum thermometer and periodically checked with a thermistor.

Deaths, fish behavior, and gill-irrigation rates were observed and recorded throughout the 96-hr test period. Gill-irrigation rates were determined from both controls and test aquaria before chlorination, at 5-min intervals for 1/2 hr after dechlorination, and at 24-hr intervals thereafter. The irrigation rates were calculated by averaging the rates determined for three randomly chosen fish in each aquarium.

In the dechlorination test, 15 fathead minnows were added to each of four aquaria and acclimated to 21 C (70 F) for 72 hr. At the end of the acclimation period the chlorine stock solution was added to each aquarium, and chlorine determinations were made. After one-half hour two of the aquaria were dechlorinated, and the fish in the remaining two aquaria were transferred to aquaria containing fresh water. Fish behavior was observed, and deaths recorded during the following 96 hr.

RESULTS AND DISCUSSION

Brown trout mortalities in the 17 C (63 F) aquaria ranged from 10 percent to 50 percent; no fish died at concentrations below 0.71 mg/liter (Table 13). Mortalities in the 21 C (70 F) aquaria ranged from 50 to 90 percent; some fish died at all chlorine concentrations tested. At both temperatures an average of 90 percent of the total number of deaths occurred within 24 hr.

At the lower concentrations and temperature abnormal behavioral symptoms did not appear as soon and the reaction was milder. The behavioral symptoms included violent gill movement, jaw snapping, and an increase in gill-irrigation rate. After the initial behavior changes the fish became lethargic, resting on the bottom and swimming very little or swimming at the water surface with jaws snapping. Eventually the fish lost their equilibrium and began whirling and jerking violently. Dandy (1972) reported similar behavior and increased irrigation rates for his test fish (brook trout). Once the fish lost equilibrium, death always followed even when the fish were transferred to clean water. Similar results were reported for green sunfish,

Table 13. Brown trout mortality (expressed as percentage) after one 30 min exposure to total residual chlorine during laboratory bioassay, July 16-20, 1973.

Elapsed time (hr)	Temperature: 17 C (63 F)						21 C (70 F)					
	Chlorine concentration					0.0	Chlorine concentration					0.0
	0.99[a]	0.93	0.78	0.71	0.58	(Control)	1.02	0.86	0.78	0.67	0.56	(Control)
0.5	0	0	0	0	0	0	30	0	0	0	0	0
1	20	0	0	0	0	0	70	30	60	30	20	0
2	30	0	10	0	0	0	70	40	70	40	20	0
24	50	20	10	20	0	0	80	80	90	40	30	0
48	50	20	10	20	0	0	80	80	90	50	40	0
72	50	20	10	20	0	0	80	80	90	50	50	0
96	50	20	10	20	0	0	90	80	90	50	50	0

[a] Mean total residual chlorine concentrations (mg/liter).

goldfish, black bullhead, and golden shiner (Panikkar 1960); for brown trout (Pike 1971); for brook trout (Dandy 1972); and for pink and chinook salmon (Stober and Hanson 1974).

Linear regression was employed to determine the 48- and 96-hr CM-50's. Three regressions were calculated for cumulative number of brown trout dead on the $\log_{10}$ of the chlorine-minutes. Separate regressions were calculated for the 48- and 96-hr exposure at 21 C (70 F), and one regression was calculated for the 17 C (63 F) results. The r-values for the 21 C (70 F) 48-hr (0.82) and 17 C (63 F) (0.81) exposures were significant ($P < 0.05$). The 96-hr exposure r-value at the 21 C (70 F) (0.77) temperature was not significant, but accounted for 60 percent of the variability in this regression. All three slopes were significantly different from zero ($P<0.05$). The 48-hr and 96-hr regressions for the 21 C (70 F) exposure were:

$$y = -17.5252 + 17.8994 \text{ Log}_{10}(x)$$

$$y = -12.7601 + 14.5402 \text{ Log}_{10}(x)$$

and the regression for the 17 C (63 F) exposure was:

$$y = -20.5193 + 16.4219 \text{ Log}_{10}(x)$$

where, in all regressions, y is the number of brown trout dead and x is the number of chlorine-minutes.

The CM-50's calculated for 48- and 96-hr exposures at 21 C (70 F) were 18.1 and 16.8 chlorine-minutes, respectively, whereas the 17 C (63 F) CM-50 was 35.8 chlorine-minutes. The average total residual chlorine concentration during one 30-min chlorine dosage that could be expected to kill 50 percent of all brown trout in 96 hr under the conditions of this bioassay would be 1.19 mg/liter at 17 C (63 F) and 0.56 mg/liter at 21 C (70 F). This is greater than a 50 percent increase in lethality with an increase of 4 C (7 F) from 17 C (63 F) to 21 C (70 F).

Dissolved oxygen concentrations ranged from 7.6 to 9.2 mg/liter before chlorination, 6.8 to 7.6 mg/liter during chlorination, and 6.2 to 7.0 mg/liter after dechlorination (Appendix 33). The pH increased in all aquaria to approximately 9.2 at 48 hr after chlorination. Alkalinity and hardness remained fairly constant in all aquaria, 68 and 86 mg/liter, respectively, throughout the 48 hr.

In the dechlorination test as many fathead minnows died after transfer to fresh waters as died after dechlorination with sodium thiosulfate, indicating that the dechlorination process was not lethal to the test fish (Table 14). Pyle (1960) found that exposure to a 5 percent (50,000 mg/liter) solution of sodium thiosulfate caused no distress in brook, rainbow, and brown trout fingerlings after 3 hours exposure. All of his fish survived 24 hr in a 1 percent (10,000 mg/liter) solution.

Table 14. Mortality of fathead minnows (expressed as percentage) exposed for 30 min to total residual chlorine at 21 C (70 F) and subjected to two methods of dechlorination, July 27-31, 1973.

	Dechlorination with sodium thiosulfate		Dechlorination by transfer to fresh water	
Time (hr)	A[a]	B	A	B
0.5	13	7	13	7
0.75	47	20	47	13
1	93	47	80	40
1.25	93	47	80	40
24	93	47	80	40
48	93	47	80	40
72	93	47	80	40
96	93	47	80	40
Mean total residual chlorine (mg/liter)	1.14	1.00	1.05	0.99

[a] A and B refer to replicate tanks

SECTION VII

GENERAL DISCUSSION

The primary objective of this project was to determine if intermittently chlorinated cooling waters from power plant condensers are lethal to fish inhabiting the discharge channels of these plants. The results show that under certain circumstances chlorinated condenser cooling waters are extremely toxic to caged brown trout. Brown trout were used in six caged bioassays in 1972, and in all six tests deaths occurred that were related to chlorine concentrations in the channels. The 48-hr ILC-50 total residual chlorine values ranged from 0.14-0.17 mg/liter for fish exposed to two chlorinations at the Conners Creek plant to 0.18-0.19 mg/liter for brown trout exposed to four chlorinations at the Cobb plant. The 96-hr ILC-50 values were more variable, ranging from 0.02-0.05 mg/liter for brown trout exposed to three chlorinations at the Campbell plant to 0.17-0.18 mg/liter for fish exposed to six chlorinations at the Cobb plant.

Fathead minnows were used as a test species in all nine of the 1972 studies, and no deaths occurred that could be attributed to chlorine. Fathead minnows were not killed by intermittent exposures to total residual chlorine levels up to 0.5 mg/liter.

Other warmwater fishes used during the 1972 studies were the brown bullhead and various centrarchid species. These warmwater fish were able to tolerate short exposures to mean total residual chlorine levels up to 0.5 mg/liter.

The brown trout results obtained in 1973 indicate that the sensitivity of brown trout to intermittent exposures of chlorine can be extremely variable depending on other ambient variables. In the 1973 caged brown trout bioassays at the Campbell plant, unlike the 1972 tests, almost no fish died after exposure to similar numbers of chlorination periods and chlorine concentrations.

Chlorine-related lethality was documented in the 1972 field studies conducted at the Campbell plant, but definite chlorine-related fish deaths did not occur during the 1973 studies. To determine if dechlorination with sodium thiosulfate may have caused this descrepancy, the brown trout data from the 1972 spring and fall studies were compared with data from test 2 of the 1973 series (Table 15). The 1973 studies did not utilize the dechlorination

Table 15. Summary of important variables in the 1972 and 1973 caged brown trout bioassays conducted at the J. H. Campbell power plant.

	Spring 1972	Fall 1972	Test 2 Spring 1973
TRC - related mortality	Yes	Yes	No
Acclimation procedure	Dechlorination	Dechlorination	In-channel
Temperature change [C (F)]	3.5 (6)	6 (11)	1 (2)
Temperature maximum [C (F)]	20.5 (69)	22 (72)	16.5 (62)
Maximum TRC[a] (mg/liter)	0.43	0.50	0.39
Mean TRC range (mg/liter)	0.07 - 0.26	0.06 -0.18	0.05 - 0.25
Number of chlorinations	3	4	3
DO - mean (mg/liter)	11.2	10.4	7.5
DO - percent saturation	117	108	86
Mean fish size [cm (inches)]	6.4-10.2 (2.5-4.0)	6.4-10.2 (2.5-4.0)	10.2-15.2 (4.0-6.0)
pH (standard units)	8.3	7.5	7.2
Total alkalinity (mg/liter)	110	120	115
Hardness (mg/liter)	140	150	160

[a] Total residual chlorine.

device used in 1972 studies. However, the dilute mixture (~6.5 mg/liter) of sodium thiosulfate used in the dechlorination device in 1972 should not stress the fish according to various MWRC studies and toxicity levels reported in the literature (Pyle 1960). The dechlorination procedure may have stressed the fish more than acclimating them in the discharge channel, as was done in 1973. If this were true, the number of deaths among the control fish would have been significantly greater during the dechlorination studies. Since this was not the case, the dechlorination procedure did not cause the discrepancy in these tests.

Temperature ranges during the 1973 tests averaged 2-5 C (4-9 F) less than in 1972. The maximum temperature averaged 4-5.5 C (7-10 F) less in 1973. Deaths among the test fish during 1972 cannot be attributed solely to temperature since the dechlorinated control fish were subjected to similar maximum temperatures and temperature fluctuations as the test fish and deaths among the controls were not excessive.

The laboratory bioassays showed a very pronounced effect of temperature on the lethality of chlorine to brown trout. Brown trout exposed to one 30-min exposure and held at 17 C (63 F) and 21 C (70 F) had corresponding 96 hr ILC-50's of 1.19 and 0.56 mg/liter. The increase in lethality is greater than 50 percent with a 4 C (7 F) temperature increase.

Since the maximum and average temperatures were higher in the 1972 field studies, and chlorine lethality was also greater, it appears that increased temperatures can increase chlorine toxicity to caged brown trout. This effect has also been shown for saltwater salmonids by Stober and Hanson (1974).

Brown trout used in the 1972 studies ranged in size from approximately 6.4 to 10.2 cm (2.5 to 4 inches). The brown trout used in the 1973 studies were somewhat larger, ranging from 10.2 to 15.2 cm (4 to 6 inches) long. With respect to the size-specific effect of chlorine on fish, Fobes (1971) found that smaller white suckers were more affected than larger individuals at a given chlorine concentration. Rosenberger (1971) observed, however, that size and lethality were directly related for coho salmon. In the third test of the spring 1973 series, the smaller brown trout were tested and no TRC-attributable deaths resulted. It therefore appears that differences in mortality cannot be directly attributed to size differences of the fish tested.

Variations in pH, total alkalinity, and hardness, although not enough to directly account for differences in mortality, may interact to modify the toxicity of chlorine (Table 15). No reports on the effect of these variables on chlorine lethality were found in the

literature. Warren (1971) and McKee and Wolf (1963) present studies where these parameters interact to affect the lethality of other toxicants.

Chlorine concentrations were similar during all three studies, as were the number of chlorinations to which fish were subjected. Average total residual chlorine levels in 1972 ranged from 0.06 to 0.26 mg/liter, whereas in 1973 the levels ranged from 0.05 to 0.25 mg/liter. Fish during both years were subjected to three or four chlorinations. Free chlorine, when levels were high enough to detect, comprised 30-65 percent of the total residual chlorine in 1972 and 50-70 percent in 1973. Levels of total residual chlorine and free chlorine as well as number of chlorinations were similar in both years and could not account for the difference in mortality.

Heated effluents from power plant cooling systems can be saturated or supersaturated with dissolved oxygen and can cause the formation of emboli in fishes that damage gills, eyes, epidermis, and other tissues and may be lethal. Newly hatched whitefish and lake herring have been reported to be susceptible to damage from dissolved gas supersaturation (U.S. Department of Interior 1970). This potential problem was recognized at power plants by Krenkel and Parker (1969). DeMont and Miller (1971) reported the first incidence of gas bubble disease symptoms in various species of warmwater fishes in the discharge channel of the Marshall Steam Station, Lake Norman, North Carolina. Otto (1972), in laboratory studies at the Waukegan Generating Station on Lake Michigan, found that rainbow trout were unaffected when exposed to gas saturation levels less than 110 percent and had an estimated 8-day TL-50 saturation level of 119 percent. Yellow perch were more tolerant and were unaffected at less than 115 percent and had an 8-day TL-50 saturation level of 126 percent. Dissolved oxygen saturation was lower in the 1973 Campbell plant studies, averaging 86 percent as compared with 108 and 117 percent saturation during 1972 (Table 15). Gas supersaturation does not solely account for the difference in number of fish deaths observed in the 1972 and 1973 studies at the Campbell plant since in 1972 deaths at the Cobb, Monroe, and Karn-Weadock plants were attributable to TRC at average gas saturation levels less than 100 percent.

It appears that brown trout intermittently subjected to total residual chlorine concentrations in power plant discharge channels can exhibit variable mortality. By eliminating factors that were similar in three Campbell plant studies, temperature and dissolved oxygen saturation interactions with chlorine appeared to account for the observed mortality differences.

Even though the field bioassay data are inconsistent between 1972 and 1973, the observations of resident fish in distress during 1972 support the conclusion that chlorinated condenser cooling waters are lethal or toxic to fish inhabiting power plant discharge channels. On three occasions during the 1972 field studies large [45.7 - 71.1 cm (18 - 28 inches), total length] salmonid fish were observed in distress. The presence of distressed fish at the water's surface at the Campbell plant on two occasions was definitely related to the presence of chlorine. The maximum chlorine concentrations were 0.25 and 0.5 mg/liter, and the discharge channel temperature was 17 - 19 C (62 - 66 F). Other authors have also noted fish in stress in power plant discharged which they attributed to chlorine (Truchan and Basch, 1971); Massey, 1972; Fairbanks et al., 1971).

Brungs (1973), after summarizing the available literature, arrived at guidelines for intermittent chlorine discharges in which he recommended that to protect salmonids in areas with high concentrations of free chlorine, residual chlorine levels would need to be kept below 0.01 mg/liter for a 30-min exposure in any 24 hr period. It appears, based on the 1972 and 1973 results, that at times the 0.01 level suggested by Brungs may be overly protective.

The mortality of fish exposed to intermittent power plant chlorination practices was found to be variable in this project. Brungs (1973), in discussing continuous exposure chlorination results, felt that chlorine lethality to fish was not significantly affected by typical environmental variables. The results of this project demonstrated that fish mortality from exposure to intermittent dosages of chlorine is difficult to predict and will remain so until additional controlled laboratory studies have delineated the interaction of chlorine with other ambient variables. particularly temperature.

SECTION VIII

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SECTION IX

APPENDICES

Appendix 1. Total residual chlorine readings, temperatures, and descriptive statistics for caged fish and control stations, J. H. Campbell power plant, May 30 - June 3, 1972.

Item	Station							
	Intake control	Dechlorinated control	1	2	3	4	5	6
TRC[a]								
5-30-72	0.00	0.00 0.00						
6-1-72	-	-	0.23 0.20 (0.10)[b] 0.26 (0.10) 0.37 0.37 0.32 (0.20)	0.28 0.43 0.06	0.13 0.10 0.07	0.05 0.05	0.20 0.15 (0.07) 0.14	0.08 0.11 (0.04) 0.14 (0.05 0.09 0.06 0.06 0.04
6-2-72	-	-	0.12 0.23 0.22 0.24 (0.13) 0.25	0.21 0.21 (0.14) 0.21 (0.14) 0.21 (0.15) 0.17	0.25 0.27 0.25 (0.12)	0.19 (0.16) 0.26 0.035 0.035	0.17 0.16 (0.08) 0.15 0.13 0.05	0.01 0.065 0.095 0.095 0.10 0.12 0.07 0.005 0.03 0.02 0.005
Maximum TRC	-	-	0.37	0.43	0.27	0.26	0.20	0.14
Average TRC	0.0	0.0	0.26	0.22	0.18	0.10	0.13	0.07
Minimum TRC	-	-	0.12	0.06	0.07	0.035	0.05	0.005
n[c]	1	2	11	8	6	6	9	19
Maximum free chlorine			0.20	0.15	-	-	0.08	0.06
Average free chlorine			0.13	0.14	0.12	0.16	0.08	0.05
Minimum free chlorine			0.10	0.14	-	-	0.07	0.04
n			4	3	1	1	2	2
Temperature [C (F)]								
5-30	11 (52)	18.5 (65)	20.5 (69)	20.5 (69)	20.5 (69)	20.5 (69)	20.5 (69)	20 (68.5)
5-31	10.5 (51)	19 (66)	20.5 (69)	20 (68)	20 (68)	20 (68)	20 (68)	20 (68)
6-1	9 (48)	16.5 (62)	18 (64)	18 (64)	18 (64)	18 (64)	18 (64)	18 (64)
6-1	9.5 (49)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)
6-2	11 (52)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)	18.5 (65)
6-2	11 (52)	18.5 (65)	19.5 (67)	19.5 (67)	19.5 (67)	19.5 (67)	19.5 (67)	19.5 (67)
6-3	12 (54)	16.5 (62)	18.5 (65)	18.5 (65)	18 (64)	18 (64)	17 (63)	17 (63)
Maximum temp. [C (F)]	12 (54)	19 (66)	20.5 (69)	20.5 (69)	20.5 (69)	20.5 (69)	20.5 (69)	20 (68.5)
Average temp.	10.5 (51)	18 (64)	19 (66)	19 (66)	19 (66)	19 (66)	19 (66)	19 (66)
Minimum temp.	9 (48)	16.5 (62)	18 (64)	18 (64)	18 (64)	18 (64)	17 (63)	17 (63)
n	7	7	7	7		7	7	7

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentrations (mg/liter).
[c] n is the number of readings (non-zero) used to compute the averages.

Appendix 2. Chemical and bacteriological characteristics of water samples collected at the J. H. Campbell power plant, May 31 and June 2, 1972.

Characteristic[a]	Station: Intake control		Dechlorinated control	1		2	3	4	5	6
Date:	5-31-72	6-2-72	6-2-72	5-31-72	6-2-72	6-2-72	6-2-72	6-2-72	6-2-72	6-2-72
Time	1200	1400	1400	1200	1120	1130	1135	1145	1150	1230
Temp.	10.5 (51)	11.0 (52)	18 (65)	20.5 (69)	19 (66)	19 (66)	19 (66)	19 (66)	19 (66)	19 (66)
DO		11.2	7.3		11.5	11.9	11.3	11.1	11.9	11.0
DO (percent saturation)		101	77		123	127	121	119	127	118
BOD		3.4				5.7		4.5		3.3
pH	8.3	8.2	8.1	8.3	8.3	8.3	8.3	8.3	8.3	8.3
TS	191			190						
TDS	188			188						
SS	3			2						
Cl	10			10						
NH_3-N	0.02	<0.01	0.01	0.02	<0.01	0.03	<0.01	0.01	0.01	0.02
Fe	0.21			0.25						
SO_4	31			26						
Total alkalinity	110			110						
Carbonate alkalinity	0			0						
Hardness	135			140						
Cn	<0.01			<0.01						
Cr^{+6}	<0.01			<0.01						
As	<0.01			<0.01						
Mn	<0.1			<0.1						
Cu	<0.01			<0.01						
Zn	<0.01			<0.01						
Total coliform		25,000	10,000		4,000	32,000	14,000	1,000	350,000	80,000
Fecal coliform		<10	<10		<10	<10	<10	<10	<10	<10

[a] All characteristics except temperature [C (F)], pH (standard units), and total and fecal coliform (counts/100 ml) are expressed as mg/liter.

Appendix 3. Chemical characteristics of water samples collected at the J. H. Campbell power plant, May 31 - June 1, 1972. I and C denote samples collected from the intake and condenser cooling water discharge, respectively.

Date	Time	Temperature [C (F)]		DO (mg/liter)		pH (standard units)		NH_3-N (mg/liter)	
		I	C	I	C	I	C	I	C
6-31-72	1200	10.5 (51)	20.5 (69)	10.8	10.1	8.3	8.3	0.02	0.02
5-31-72	1650	11.5 (53)	20.0 (68)	11.0	11.0	8.3	8.3	0.02	0.02
5-31-72	2015	11.0 (52)	20.0 (68)	----	----	8.3	8.3	0.02	0.02
6-1-72	0015	10.5 (51)	20.0 (68)	----	----	8.3	8.3	0.02	0.02
6-1-72	0400	10.0 (50)	17.0 (63)	----	----	8.3	8.3	0.02	0.02
6-1-72	0800	9.0 (48)	18.0 (65)	----	----	8.3	8.3	0.02	0.02

Appendix 4. Total residual chlorine readings, temperatures, and descriptive statistics for caged fish and control stations, J. H. Campbell power plant, October 9-13, 1972.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
TRC[a]						
10-9-72	–	–	0.03 0.03 0.09 0.01 0.06	0.08 0.09 0.06	0.05 0.08 0.06	0.04 0.04
10-10-72	–	–	0.07 0.09 0.08 0.07	0.14 0.13	0.11 0.13 0.13 0.10 0.06	0.07 0.08 0.07 0.06
10-12-72	–	–	0.12 0.11 0.22 0.20 0.13	0.10 0.20 0.16 0.13 0.15	-	0.03 0.04 0.06 0.08 0.14 0.07 0.06 0.05 0.04
10-13-72	–	–	0.40 0.41	0.37 0.50 0.33 (0.22)[b] 0.04	0.31 0.34 0.26 (0.18)	0.17
Maximum TRC	-	-	0.41	0.50	0.34	0.17
Average TRC	-	-	0.13	0.18	0.15	0.06
Minimum TRC	-	-	0.01	0.04	0.05	0.02
n[c]	-	-	16	14	11	18
Temperature [C (F)]						
10-9	-	21 (70)	22 (72)	22 (72)	22 (72)	22 (72)
10-10	10.5 (51)	18.5 (65)	20 (68)	20 (68)	20 (68)	19.5 (67)
10-10	-	-	19 (66)	18 (64)	18.5 (65)	18.5 (65)
10-11	9 (48)	18 (64)	16.5 (62)	16.5 (62)	16.5 (62)	16.5 (62)
10-12	-	-	19 (66)	19 (66)	-	18.5 (65)
10-13	10.5 (51)	18 (64)	16.5 (62)	16.5 (62)	16.5 (62)	16.5 (62)
10-13	14.5 (58)	17 (63)	17 (63)	16.5 (62)	16.5 (62)	16 (61)
Maximum Temp.	11.5 (53)	21 (70)	22 (72)	22 (72)	22 (72)	22 (72)
Average Temp.	10.5 (51)	18.5 (65)	19 (66)	18.5 (65)	18.5 (65)	18.5 (65)
Minimum Temp.	9 (48)	17 (63)	16.5 (62)	16.5 (62)	16.5 (62)	16 (61)
n[c]	4	5	7	7	6	6

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parenthese denote free chlorine concentrations (mg/liter).
[c] n is the total number of readings (non-zero) used to compute the averages.

Appendix 5. Chemical characteristics of water samples collected from the J. H. Campbell power plant intake and stations 2 and 6 in the condenser cooling water discharge, October 11 and 12, 1972.

Characteristic[a]	Station		
	Intake	2	6
	10-12-72	10-11-72	10-12-72
Time	1700	1430	1615
Temperature	10.5 (51)	18.0 (64)	19.0 (66)
TS	196	187	---
TDS	192	182	---
SS	4	5	7
pH	7.4	7.5	7.4
NO_3-N	0.21	0.28	0.20
NH_3-N	0.05	0.02	0.20
$SOPO_4$	0.01	0.01	0.01
TPO_4	0.03	0.02	0.02
Cl	10	10	10
Fe	0.1	0.1	0.1
Ca	38	38	38
Mg	12	12	12
Na	7	7	8
K	1.3	1.2	1.2
SO_4	27	27	27
Total alkalinity	120	120	90
Carbonate alkalinity	0	0	0
Hardness	150	150	140
CN	0.01	0.01	0.01
Cr^{+6}	0.01	0.01	0.01
Mn	0.01	0.01	0.01
Cu	0.02	0.02	0.02
F	0.16	0.13	0.13
Zn	0.02	0.01	0.01

[a] All characteristics except temperature [C (F)] and pH (standard units) are expressed as mg/liter.

Appendix 6. Chemical characteristics of samples collected at the J. H. Campbell power plant, October 11-12, 1972. I, D, and C denote samples collected from the intake, dechlorinated control, and condenser cooling water discharge, respectively.

Date	Time	Temperature [C (F)]			DO (mg/liter)			pH (standard units)			NH_3-N (mg/liter)		
		I	D	C	I	D	C	I	D	C	I	D	C
10-11-72	1600	9.0 (49)	18 (64)	18 (64)	11.0	9.0	10.8	7.3	7.1	7.3	0.01	0.01	0.02
10-11-72	2000	9.0 (49)	18 (64)	18 (64)	10.8	9.4	10.6	7.1	7.3	7.3	0.03	0.01	0.05
10-11-72	2400	10.0 (50)	18 (64)	18 (64)	10.6	10.4	10.6	7.5	7.5	7.5	0.01	0.02	0.03
10-12-72	0400	9.0 (49)	18 (64)	18 (64)	9.2	10.8	10.4	7.3	7.3	7.2	0.03	0.02	0.04
10-12-72	0800	10.0 (50)	19 (66)	19 (66)	9.8	9.6	9.8	7.3	7.3	7.3	0.02	0.02	0.05
10-12-72	1200	10.5 (51)	19 (66)	19 (66)	10.2	9.4	10.4	7.3	7.1	7.2	0.03	0.01	0.04

Appendix 7. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, J. H. Campbell power plant, June 26-30, 1972.

Item	Station						
	Intake control	Dechlorinated control	1	2	3	4	5
TRC[a]							
6/26 (1200)	-	-	0.16 0.31 0.36	0.16 0.17 0.33	0.11 0.21 0.17	0.10 0.17 0.12	0.11 0.06 0.01
6/26 (1400)	-	-	0.12 0.20 0.38 0.30 (0.07)[b]	0.15 0.34	0.03 0.24	0.17 0.30 0.41 0.14	0.26 0.14 0.08 0.03
6/26 (1100)	-	-	0.13 0.16 0.20	0.15 0.23 0.28 0.10	0.20 0.13 0.17	0.15 0.18 0.05	0.17 0.11 0.02
6/28 (1430)	0.0	-	0.03 0.04 0.21 0.21 (0.07) 0.29	0.29 0.15 (0.08) 0.10	0.23 0.13 (0.05)	c	0.02 0.04 0.16 0.16 0.03 0.01
6/30 (1045)	-	-	0.06 0.15 0.20 0.18 (0.10)	0.14 0.18	0.09 0.15 0.15 0.06	0.08 0.13 0.05	0.00
Maximum TRC	-	-	0.38	0.34	0.30	0.41	0.26
Average TRC	0.0	-	0.19	0.20	0.17	0.16	0.10
Minimum TRC	-	-	0.03	0.10	0.06	0.05	0.01
n[d]	1	-	19	14	13	13	16
Maximum free chlorine	-	-	0.10	-	-	-	-
Average free chlorine	-	-	0.08	0.08	0.05	-	-
Minimum free chlorine	-	-	0.07	-	-	-	-
n	-	-	3	1	1	-	-
Temperature [C (F)]							
6/26	-	-	25.5 (78)	24.5 (76)	24.5 (76)	25 (77)	24 (75.5)
6/26	21.5 (71)	-	24.5 (76)	24.5 (76)	24 (75)	24 (75)	24 (75)
6/26	-	-	-	-	-	-	-
6/27	21.5 (71)	26.5 (80)	27 (81)	27 (81)	27 (81)	27 (81)	26.5 (80)
6/28		-	25 (77)	25.5 (78)	25.5 (78)	25.5 (78)	24.5 (76)
6/28	22 (72)	-	26.5 (80)	26.5 (80)	26.5 (80)	26 (79)	26 (79)
6/28	20.5 (69)	26 (79)	25.5 (78)	27 (81)	26.5 (80)	26.5 (80)	25.5 (78)
6/28	-		-	-	-	-	-
6/29	21 (70		26.5 (80)	25.5 (78)	26.5 (80)	26 (79)	26 (79)
6/30	-		27 (81)	27 (81)	27 (81)	26.5 (80)	26.5 (80)
6/30	-	[illegible]	27 (81)	-	27 (81)	-	-
6/30	-	-	-	-	-	-	-
Maximum Temp. [C (F)]	22 (72)	26.5 (80)	27 (81)	27 (81)	27 (81)	27 (81)	26.5 (80)
Average Temp.	21.5 (71)	26 (79)	26 (79)	26 (79)	26 (79)	26 (79)	25.5 (78)
Minimum Temp.	18 (64)	25.5 (78)	24.5 (76)	24.5 (76)	24 (75)	24 (75)	24 (75)
n	5	4	9	8	9	8	8

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentrations (mg/liter).
[c] The chlorine plume was missed at this station.
[d] n is the total number of readings (non-zero) used to compute the averages.

Appendix 8. Chemical characteristics of water samples collected at the B.C. Cobb power plant intake and dechlorinated control stations, June 21, 1972.

Characteristic[a]	Station: Intake	Station: Dechlorinated control
Time	0900	0900
Temperature	20.5 (69)	25.5 (78)
DO	5.6	4.8
DO (Percent saturation)	62	58
TS	222	225
TDS	208	214
SS	14	11
pH	7.8	7.8
Cl	17	18
NH_3-N	0.65	0.70
Fe	b	b
Na	b	b
SO_4	23	26
Total alkalinity	110	120
Carbonate alkalinity	0	0
Hardness	160	160
CN	<0.01	<0.01
Cr^{+6}	<0.01	0.03
Mn	b	b
Cn	b	b
Zn	<0.01	0.05

[a] All characteristics except pH (standard units) and temperature [C (F)] are expressed as mg/liter.
[b] Quantity not sufficient to be detected.

Appendix 9. Chemical characteristics of water samples collected at the B.C. Cobb power plant, June 21-22, 1972. I and C denote samples collected from the intake and condenser cooling water discharge, respectively.

Date	Time	Temperature [C (F)]		DO (mg/liter)		pH (stanard units)		NH_3 (mg/liter)	
		I	C	I	C	I	C	I	C
6/21/72	1200	20.5 (69)	25.5 (78)	7.0	5.8	7.9	7.7	0.65	0.70
6/21/72	1600	22 (71)	27 (82)	8.0	7.0	7.9	7.9	0.65	0.18
6/21/72	2000	21 (70)	26.5 (80)	8.0	7.0	7.7	7.8	0.15	0.18
6/21/72	2400	21 (70)	25 (77)	6.6	6.2	7.8	7.8	0.18	0.21
6/22/72	0400	20 (69)	23 (73)	5.8	6.4	7.7	7.8	0.24	0.20
6/22/72	0800	20 (68)	25.5 (78)	6.6	5.6	7.9	7.8	0.15	0.24

Appendix 10. Chemical characteristics of water samples collected at the control and test stations at the B. C. Cobb power plant, June 28-30, 1972.

Item	Station						
	Intake	Dechlorinated control	1	2	3	4	5
Date	6/28/72	6/28/72	6/28/72	6/28/72	6/28/72	6/28/72	6/28/72
Time	1255	1100	1115	1140	1200	1225	1235
Temp. [C (F)]	--	25 (77)	25 (77)	25.5 (78)	--	25.5 (78)	24 (76)
DO (mg/liter)	9.8	4.3	6.7	6.9	6.1	6.4	6.6
pH (mg/liter)	8.2	7.5	7.8	7.8	7.9	7.9	7.9
NH_3-N (mg/liter)	0.28	0.29	0.20	0.28	0.27	0.27	0.27
Date	6/28/72	6/28/72	6/28/72	6/28/72	6/28/72	6/28/72	6/28/72
Time	1640	1650	1440	1518	1525	1630	1602
Temp. [C (F)]	22 (72)	26.5 (80)	26.5 (80)	26.5 (80)	25.6 (90)	26 (79)	26 (79)
pH (mg/liter)	8.0	7.7	8.0	7.9	7.9	8.0	8.0
NH_3-N (mg/liter)	0.33	0.32	0.25	0.28	0.29	0.30	0.27
Date	-	-	6/30/72	6/30/72	6/30/72	6/30/72	6/30/72
Time	-	-	1105	1120	1135	1150	1215
Temp. [C (F)]	-	-	27 (81)	27 (81)	27 (81)	26.5 (80)	26.5 (80)
pH (mg/liter)	-	-	7.9	8.0	7.9	7.9	7.9
NH_3-N (mg/liter)	-	-	0.21	0.21	0.20	0.21	0.21

Appendix 11. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, B. C. Cobb power plant, October 24-28, 1972.

Item	Station						
	Intake control	Dechlorinated control	1	2	3	4	5
TRC[a]	-	-					
10/24 (1115)			0.02 0.04 0.10 0.20 0.10	0.13 0.11 0.13 0.10 0.09	0.11 0.10 0.05 0.03	0.11 0.10	0.03 0.08 0.10 0.10 0.03 0.03
10/24 (1400)	-	-	0.11 0.16 0.21 0.24	0.02 0.15 0.21 0.17 0.10	0.13 0.10 0.06	0.09 0.09 0.10 0.05 0.02	0.09 0.12 0.02 0.03 0.03
10/25 (1045)	-	-	0.09 0.17 0.22 0.28 0.28	0.32 0.32 0.21 0.24 0.18	0.16 0.16 0.09 0.04	0.09 0.10 0.10 0.06	0.07 0.06 0.03 0.03
10/25 (1300)	-	-	0.16 0.23 0.32 0.31 0.23	0.31 0.32 0.18 0.10 0.03	0.03 0.13 0.04	0.06 0.17 0.12	0.05 0.06 0.08 0.05
10/27 (1045)	-	-	0.03 0.18 0.27 0.10 0.10 0.07	b	0.09 0.06 0.09	b	b
10/27 (1415)	-	-	0.15 0.24 0.28 0.26 0.09	b	0.24 0.13 0.13	0.00	0.11 0.06 0.09
Maximum TRC	-	-	0.32	0.32	0.24	0.17	0.12
Average TRC	-	-	0.17	0.17	0.10	0.09	0.05
Minimum TRC	-	-	0.02	0.02	0.03	0.02	0.02
n[c]	-	-	30	20	20	14	22
Temperature [C (F)]							
10/24	-	-	16 (61)	16 (61)	15.5 (60)	15.5 (60)	15 (59)
10/24	-	-	15.5 (60)	16 (61)	15.5 (60)	15 (59)	15 (59)
10/24	-	-	-	-	-	-	-
10/25	-	-	16.5 (62)	-	-	14.5 (58)	14 (57)
10/25	-	-	-	-	-	14.5 (58)	13.5 (56)
10/25	10 (50)	15.5 (60)	16.5 (62)	16.5 (62)	16.5 (62)	14.0 (57)	12 (54)
10/26	10 (50)	15.5 (60)	-	-	-	-	-
10/27	-	-	16 (61)	-	-	11.5 (53)	-
10/27	-	-	15.5 (60)	-	15.5 (60)	12 (54)	13.5 (56)
10/27	10 (50)	16.5 (62)	18 (64)	18 (64)	18 (64)	13.5 (56)	12 (54)
10/28	12 (54)	19.5 (67)	20.5 (69)	20 (68)	20 (68)		12 (54)

Appendix 11. Continued.

Item	Station						
	Intake control	Dechlor-inated control	1	2	3	4	5
Maximum Temp. [C (F)]	12 (54)	19.5 (67)	20.5 (69)	20 (68)	20 (68)	15.5 (60)	15 (59)
Average Temp.	10.5 (51)	16.5 (62)	16.5 (62)	17 (63)	16.5 (62)	14 (57)	13.5 (56)
Minimum Temp.	10 (50)	15.5 (60)	15.5 (60)	16 (61)	15.5 (60)	11.5 (53)	12 (54)
n	4	4	8	5	6	8	8

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] The chlorine plume was missed at these stations.
[c] n is the total number of readings (non-zero) used to compute the averages.

Appendix 12. Chemical characteristics of water samples collected at the B. C. Cobb power plant intake, condenser cooling water discharge, and dechlorinated control station, October 26, 1972.

Characteristic[a]	Station					
	Intake		Condenser cooling water discharge		Dechlorinated control	
Time	1200	2400	1200	2400	1200	2400
Temperature	10 (50)	9.5 (49)	15.5 (60)	16.5 (62)	15.5 (60)	16.0 (61)
DO	9.2	9.0	9.0	9.0	7.4	7.8
DO (percent saturation)	81	78	89	92	73	78
TS	252	235	244	236	255	239
TDS	238	231	238	231	244	238
SS	14	4	6	5	11	1
pH	7.6	8.1	8.0	8.1	7.8	8.0
Cl	23	23	23	23	23	26
NO_3-N	0.2	0.17	0.2	0.17	0.19	0.17
NH_3-N	0.14	0.12	0.13	0.12	0.13	0.13
$SOPO_4$	0.05	0.05	0.04	0.05	0.03	0.05
TPO_4	0.1	0.11	0.09	0.11	0.09	0.1
Fe	0.4	0.32	0.4	0.27	0.25	0.3
Ca	48		48		48	
Mg	16		16		16	
Na	15		15		17	
K	1.4		1.3		1.4	
SO_4	24	24	23	24	30	30
Total alkalinity	150	145	150	150	145	145
Carbonate alkalinity	0	0	0	0	0	0
Hardness	185	190	185	190	185	185
Cr^{+6}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	<0.01		<0.01		<0.01	
Mn	0.05	0.04	0.04	0.04	0.04	0.05
Cu	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
F	0.23	0.26	0.23	0.23	0.23	0.23
Zn	0.02	0.02	0.02	0.02	0.02	0.04

[a] All characteristics except temperature [C (F)] and pH (standard units) are expressed as mg/liter.

Appendix 13. Chemical characteristics of water samples collected at the B. C. Cobb power plant, October 26-27, 1972. I, D, and C denote samples collected from the intake, dechlorinated control station, and condenser cooling water discharge, respectively.

Date	Time	Temperature [C (F)]			DO (mg/liter)			pH (standard units)			NH_3-N (mg/liter)		
		I	D	C	I	D	C	I	D	C	I	D	C
10/26/72	1200	10 (50)	15.5 (60)	15.5 (60)	9.2	7.4	9.0	7.6	7.8	8.0	0.14	0.13	0.13
10/26/72	1600	10 (30)	15.5 (60)	15.5 (60)	9.8	7.6	9.2	7.8	7.8	7.9	0.13	0.11	0.13
10/26/72	2000	10 (50)	15.5 (60)	15.5 (60)	9.0	9.2	9.0	7.9	7.8	8.0	0.16	0.15	0.17
10/26/72	2400	9.5 (49)	16 (61)	16.5 (62)	9.0	7.8	9.0	8.1	8.0	8.1	0.12	0.11	0.12
10/27/72	0400	10 (50)	15 (59)	15.5 (60)	9.0	8.0	8.2	7.9	7.9	7.9	0.23	0.17	0.18
10/27/72	0800	10 (50)	16.5 (62)	17.5 (64)	9.0	8.6	8.8	7.9	7.9	7.8	0.20	0.23	0.33

Appendix 14. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, Conners Creek power plant, July 11-15, 1972.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
TRC[a]						
7/11 (1030)	-	-	0.18 0.38 (0.28)[b] 0.50 (0.38) 0.62 0.21 (0.11)	0.33 0.50 (0.38) 0.55 0.66 (0.48) 0.10	0.25 0.10	0.03 0.03
7/11 (2230)	-	-	0.32 0.62	0.22 (0.15) 0.85	0.65 0.78	0.38 0.45 0.25
7/12 (1000)	-	-	0.50 0.51 (0.38)	0.59 (0.47) 0.56	0.46 0.57 0.66	0.17 0.16 0.14 0.04 0.02
7/12 (2200)	-	-	0.04 0.43 0.68 (0.54)	0.03 0.48 (0.33) 0.74	0.58 0.73	0.34 0.40 0.29 0.30 0.07 0.04 0.02
7/13 (1000)	-	-	0.50 0.63 (0.48)	0.59 (0.43) 0.72 (0.52)	0.56 (0.37) 0.58 (0.43)	0.14 0.18 0.20 0.08 0.01
7/13 (2200)	-	-	0.33 0.55 (0.42) 0.67 (0.52)	0.08 0.59 (0.40) 0.71 (0.54)	0.70 0.71 (0.50)	0.03 0.03
7/14 (1000)	-	-	0.25 0.55 0.57 (0.44) 0.62	0.64 (0.48) 0.73 0.69 (0.56)	0.55 (0.32) 0.30 (0.17) 0.15 0.07	0.21 0.11 0.17 0.11 0.03
7/14 (2200)	-	-	0.36 (0.13) 0.69 (0.51)	0.93 (0.73) 1.05 (0.83)	0.41 (0.24) 0.70	0.02
Maximum TRC	-	-	0.69	1.05	0.78	0.45
Average TRC	-	-	0.47	0.56	0.50	0.15
Minimum TRC	-	-	0.04	0.03	0.07	0.01
n[c]	-	-	23	22	19	30
Maximum free chlorine	-	-	0.54	0.83	0.50	-
Average free chlorine	-	-	0.42	0.49	0.34	-
Minimum free chlorine	-	-	0.13	0.15	0.17	-
n[c]	-	-	10	13	6	-

Appendix 14. Continued.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
Temperature [C (F)]						
7/11	-	-	28 (82)	31 (88)	28 (82)	23.5 (74)
7/11	20 (68)	28 (82)	28 (82)	31 (88)	28.5 (83)	23.5 (74)
7/11	-	-	26.5 (80)	31 (88)	26.5 (80)	23.5 (74)
7/12	20 (68)	26.5 (80)	28 (82)	29.5 (85)	29 (84)	-
7/12	-	-	28.5 (83)	31 (88)	29 (84)	-
7/12	-	-	-	-	-	-
7/12	-	-	25.5 (78)	31 (88)	27 (81)	24.5 (76)
7/13	20 (68)	26.5 (80)	27 (81)	30 (86)	28 (82)	22 (72)
7/13	-	-	27 (81)	30.5 (87)	29 (84)	24.5 (76)
7/13	-	-	-	-	-	-
7/13	-	-	26.5 (80)	30 (86)	25.5 (78)	19 (66)
7/14	20 (68)	25.5 (78)	25.5 (78)	30 (86)	27 (81)	23.5 (74)
7/14	20 (68)	-	26.5 (80)	30.5 (87)	28 (82)	-
7/14	-	-	-	-	-	-
7/14	-	-	26.5 (80)	31 (88)	30 (86)	21 (70)
7/15	20 (68)	26.5 (80)	26.5 (80)	30.5 (87)	28 (82)	20 (68)
Maximum temp. [C (F)]	20 (68)	28 (82)	28.5 (83)	31 (88)	30 (86)	24.5 (76)
Average temp.	20 (68)	26.5 (80)	27 (81)	30.5 (87)	28 (82)	22 (72)
Minimum temp.	20 (68)	25.5 (78)	25.5 (78)	29.5 (85)	25.5 (78)	19 (66)
n[c]	6	5	8	13	13	10

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentrations (mg/liter).
[c] n is the total number of readings (non-zero) used to compute the averages.

Appendix 15. Chemical and bacteriological characteristics of water samples collected at the Connors Creek power plant, July 12-13, 1972. I and C denote samples collected from the intake and condenser cooling water discharge, respectively.

Date	Time	Temp. [C (F)]		DO (mg/liter)		pH (standard units)		NH_3 (mg/liter)		Total coliforms (counts/100 ml)		Fecal coliforms (counts/100 ml)	
		I	C	I	C	I	C	I	C	I	C	I	C
7-12-72	1200	20 (68)	29 (84)	9.4	8.6	8.3	8.1	0.01	0.01	5,200	280,000	70	10
7-12-72	1600	20 (68)	31 (88)	9.4	8.9	8.3	8.2	<0.01	0.01	4,800	55,000	<10	<10
7-12-72	2000	20 (68)	30 (86)	9.8	9.3	8.4	8.4	0.35	0.01	44,000	280,000	20	10
7-12-72	2400	20 (68)	26.5 (80)	9.7	10.0	8.5	8.5	0.02	0.01	3,200	5,500	<10	10
7-13-72	0400	20 (68)	26 (79)	9.5	9.4	8.5	8.5	0.03	0.01	6,300	1,400	30	10
7-13-72	0800	20 (68)	28.5 (84)	9.7	9.7	8.6	8.6	0.03	0.01	2,600	4,300	10	<10
7-13-72	0915[a]	26.5 (80)		8.1		8.3		0.02		4,900		10	

[a] Sample collected from dechlorinated control station.

Appendix 16. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, Conners Creek power plant, November 6 - 10, 1972.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
TRC[a]						
11/6	-	-	0.03	0.45 (0.33)[b]	0.13	0.05
			0.19	0.45 (0.33)	0.11	0.03
			0.33		0.11	0.03
			0.31 (0.23)		0.08	
			0.38 (0.26)		0.05	
11/7	-	-	0.03	0.06	0.08	c
			0.12	0.17	0.09	
			0.14	0.20 (0.08)	0.09	
			0.16	0.19 (0.07)	0.10	
			0.18	0.19 (0.13)	0.05	
				0.17 (0.11)		
				0.17 (0.14)		
				0.13 (0.05)		
11/8	-	-	0.22	0.35 (0.18)	0.09	6.00
			0.30 (0.14)	0.38 (0.15)	0.03	
			0.30 (0.11)	0.25 (0.09)		
			0.32 (0.22)			
			0.31 (0.12)			
11/10	-	-	0.08	0.22 (0.10)	0.05	0.08
			0.26	0.44	0.07	0.05
			0.33 (0.08)	0.45 (0.21)	0.06	0.05
			0.41 (0.12)	0.46 (0.27)	0.10	
			0.45 (0.18)	0.51	0.06	
			0.43	0.22 (0.10)		
				0.05		
Maximum TRC	-	-	0.45	0.51	0.13	0.08
Average TRC	-	-	0.25	0.28	0.08	0.05
Minimum TRC	-	-	0.03	0.05	0.03	0.03
n[d]	-	-	21	20	17	6
Maximum free chlorine	-	-	0.26	0.33	-	-
Average free chlorine	-	-	0.16	0.16	-	-
Minimum free chlorine	-	-	0.08	0.05	-	-
n	-	-	9	15	-	-

Appendix 16. Continued.

Item	Station					
	Intake control	Dechlorinated control	1	2	3	4
Temperature [C (F)]						
11/6	-	-	16.5 (62)	18.5 (65)	13.5 (56)	9.5 (49)
11/6	8 (46)	18 (64)	18 (64)	18.5 (65)	13.5 (56)	9.5 (49)
11/7	8 (46)	14.5 (58)	14.5 (58)	15.5 (60)	11 (52)	10 (50)
11/7	-	-	13.5 (56)	15.5 (60)	11 (52)	-
11/8	8.5 (47)	14.5 (58)	15.5 (60)	16.5 (62)	15.5 (60)	10 (50)
11/8	-	-	15.5 (60)	18 (64)	15.5 (60)	10 (50)
11/9	8.5 (47)	15.5 (60)	15.5 (60)	17 (63)	11 (52)	9.5 (49)
11/10	8 (46)	15.5 (60)	15.5 (60)	18 (64)	10.5 (51)	9.5 (49)
11/10	-	15.5 (60)	15.5 (60)	18 (64)	10 (50)	9 (48)
11/10	8.5 (47)	15.5 (60)	16.5 (62)	18 (64)	10 (50)	9 (48)
Maximum temp. [C (F)]	8.5 (47)	18 (64)	18 (64)	18.5 (65)	15.5 (60)	10 (50)
Average temp.	8.5 (47)	15.5 (60)	15.5 (60)	17 (63)	12 (54)	9.5 (49)
Minimum temp.	8 (46)	14.5 (58)	13.5 (56)	15.5 (60)	10 (50)	9 (48)
n[d]	6	7	10	10	10	9

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentrations (mg/liter).
[c] The chlorine plume was missed at this station.
[d] n is the total number of readings (non-zero) used to compute the averages.

Appendix 17. Chemical characteristics of water samples collected at the Conners Creek power plant intake, condenser cooling water discharge and dechlorinated control station, November 8, 1972.

Characteristic [a]	Station					
	Intake		Condenser discharge		Dechlorinated control	
Time	1200	2400	1200	2400	1200	2400
Temperature	9.0 (48)	8.0 (46)	16.5 (62)	9.5 (49)	15.5 (60)	10 (50)
DO	10.8	11.1	10.7	10.8	9.3	10.1
DO (percent saturation)	93	97	109	94	93	89
pH	7.5	7.7	7.6	7.8	7.6	7.8
TS	188	226	252	216	239	219
TDS	156	208	215	202	208	202
SS	32	18	37	14	31	17
NO_3-N	0.28	0.36	0.28	0.36	0.28	0.36
NH_3-N	0.10	0.12	0.12	0.12	0.12	0.12
Cl	10	13		13	10	15
SO_4	21	26	22	25	22	27
Total alkalinity	80	80	80	80	80	80
Carbonate alkalinity	0	0	0	0	0	0
Hardness	110	125	110	120	110	120
CN	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cr^{+6}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe	0.85	0.43	1.1	0.55	0.85	0.44
Mn	0.03	0.02	0.04	0.04	0.03	0.03
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	0.04	0.02	0.05	0.03	0.07	0.04
F	0.1	0.15	0.1	0.15	0.1	0.15
As	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] All characteristics except pH (standard units) and temperature [C (F)] are expressed as mg/liter.

Appendix 18. Chemical characteristics of water samples collected at the Conners Creek power plant, November 8-9, 1972. I, D, and C, denote samples collected from the intake, dechlorinated control and condenser cooling water discharge, respectively.

Date	Time	Temperature [C (F)]			DO (mg/liter)			pH (standard units)			NH_3-N (mg/liter)		
		I	D	C	I	D	C	I	D	C	I	D	C
11-8-72	1200	9.0 (48)	15.5 (60)	16.5 (62)	10.8	9.3	10.7	7.5	7.6	7.6	0.10	0.12	0.12
11-8-72	1600	9.0 (48)	16.5 (62)	17.5 (64)	10.9	9.4	10.6	7.8	7.8	7.9	0.12	0.16	0.10
11-8-72	2000	8.5 (47)	15.5 (60)	16.5 (62)	11.0	9.2	10.4	7.7	7.6	7.6	0.47	0.34	0.57
11-8-72	2400	8.0 (46)	10.0 (50)	9.5 (49)	11.1	10.2	10.8	7.7	7.8	7.8	0.12	0.12	0.12
11-9-72	0400	8.5 (47)	9.5 (49)	10.0 (50)	10.8	10.2	10.8	7.4	7.6	7.5	0.10	0.14	0.16
11-9-72	0800	8.5 (47)	15.5 (60)	15.0 (59)	10.9	9.8	10.8	7.7	7.7	7.7	0.12	0.16	0.14

Appendix 19. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, Karn and Weadock power plants, August 1 - 4, 1972.

Item	Station K-1	W-1	W-2	W-3
TRC[a]				
8/1 (0200)	0.18 0.20 0.19 0.23 0.11	-	-	-
8/1 (0900)	-	0.14 0.12 0.18	0.03 0.03	-
8/1 (1300)	-	0.06 0.09 0.05	0.00	-
8/1 (1400)	0.04	-	-	-
8/1 (1900)	-	0.03 0.04 0.06 0.03 0.14 0.26 0.20 0.26 0.23	0.0	-
8/2 (0900)	-	0.03	-	-
8/2 (1300)	-	0.03 0.31 0.21	0.04 0.02	-
8/2 (1700)	0.08 0.03 0.03	-	-	-
8/2 (1900)	-	0.11 0.08 0.45 0.33 0.40 0.29	0.19 0.24 0.35 0.28 0.15	0.08 0.14 0.08
8/3 (0900)	-	0.18 0.25 0.13 0.11 0.17 0.21 0.23 0.23 0.20 0.33 0.20 0.22 0.38 0.40 0.25 0.22	0.06 0.11 0.11 0.11 0.12 0.12 0.11 0.10 0.11 0.06 0.06 0.03	0.06 0.04 0.06 0.06 0.06 0.09 0.06 0.02

Appendix 19. Continued.

Item	Station K-1	W-1	W-2	W-3
TRC[a]				
8/3 (1400)	0.38 0.48 0.56 0.57 0.47 0.55	-	-	-
8/3 (1700)	0.03 0.17 0.17 0.18 0.17 0.26 0.27 0.20 (0.06)[b] 0.07	-	-	0.0
8/4 (0900)	-	0.03 0.17 0.12	0.10 0.32 0.52 0.45 0.42 0.23 0.05	0.09 0.06 0.06 0.06 0.03 0.03
8/4 (1300)		0.03 0.03 0.03	0.00	-
8/4 (1400)	0.20 0.07 0.13 0.18 0.21 0.22 0.11	-	-	-
Maximum TRC	0.57	0.45	0.45	0.14
Average TRC	0.22	0.18	0.16	0.06
Minimum TRC	0.03	0.03	0.02	0.02
n[c]	32	48	28	17
Maximum free chlorine	-	-	-	-
Average free chlorine	0.06	-	-	-
Minimum free chlorine	-	-	-	-
n[c]	1	-	-	-

Temperature [C (F)]

Date	Karn intake	Weadock intake control	Dechlorinated control	K-1	W-1	W-2	W-3
8/1	23 (73)	23.5 (74)	30.5 (87)	31 (88)	30.5 (87)	29 (84)	29 (84)
8/1	-	-	-	30 (86)	27 (81)	28.5 (83)	28.5 (83)
8/1	-	-	-	30.5 (87)	26.5 (80)	-	-
8/1	-	-	-	31 (88)	29 (84)	28 (82)	-
8/1	-	-	-	-	31.5 (89)	29 (84)	-
8/1	-	-	-	-	30.5 (87)	-	-
8/2	22 (72)	24.5 (76)	29 (84)	30 (86)	29 (84)	29 (84)	28 (82)
8/2	-	-	-	28 (82)	29 (84)	-	-
8/2	-	-	-	30 (86)	29 (84)	27 (81)	-
8/2	-	-	-	32 (90)	34.5 (94)	-	-
8/2	-	-	-	-	30 (86)	28 (82)	28 (82)
8/3	23.5 (74)	23.5 (74)	29.5 (85)	30 (86)	29.5 (85)	28.5 (83)	28.5 (83)
8/3	-	-	-	29 (84)	28 (82)	29 (84)	28 (82)
8/4	-	-	-	28.5 (83)	29 (84)	28 (82)	-
8/4	-	-	-	-	29.5 (85)	30 (86)	-
8/4	23 (73)	23 (73)	29 (84)	28.5 (83)	30 (86)	29.5 (85)	28.5 (83)

Appendix 19. Continued.

Item	Karn intake	Weadock intake control	Dechlor-inated control	K-1	W-1	W-2	W-3
Maximum temp. [C (F)]	23.5 (74)	24.5 (76)	30.5 (87)	32 (90)	34.5 (94)	30 (86)	29 (84)
Average temp.	23 (73)	23.5 (74)	29.5 (85)	30 (86)	29.5 (85)	28.5 (83)	28.5 (83)
Minimum temp.	22 (72)	23 (73)	29 (84)	28 (82)	26.5 (80)	27 (81)	28 (82)
n	4	4	4	12	16	12	7

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentrations (mg/liter).
[c] n is the number of readings (non-zero) used to compute averages.

Appendix 20. Chemical characteristics of water samples collected at the Karn and Weadock power plants, August 14, 1972.

Characteristic[a]	Station			
	Weadock Plant		Karn Plant	
	Intake	Discharge	Intake	Discharge
DO	4.4	4.5	5.8	5.8
TS	441	475	367	392
SS	25	33	29	34
TDS	416	442	338	358
pH	7.9	7.8	8.2	7.9
Cl	100	110	76	82
NO_3-N	0.6	0.7	0.5	0.6
NH_3-N	0.24	0.33	0.15	0.21
$SOPO_4$	0.09	0.10	0.01	0.04
TPO_4	0.26	0.26	0.21	0.21
Fe	0.94	1.0	0.81	1.1
Ca	72	72	58	62
Mg	15	16	13	15
Na	39	41	27	32
K	4.0	4.5	4.0	3.5
SO_4	51	53	43	46
Total alkalinity	150	150	130	145
Carbonate alkalinity	0	0	0	0
Hardness	240	245	200	215
CN	<0.01	<0.01	<0.01	<0.01
Cr^{+6}	<0.01	<0.01	<0.01	<0.01
As	<0.01	<0.01	<0.01	<0.01
Mn	0.1	0.1	0.1	0.1
Cu	0.05	<0.05	<0.05	<0.05
F	0.62	0.72	0.49	0.52
Zn	<0.01	<0.01	<0.01	<0.01

[a] All parameters except pH (standard units) are expressed as mg/liter.

Appendix 21. Chemical characteristics of water samples collected at the Weadock plant, August 4, 1972. I and C denote intake and condenser discharge, respectively.

Time	DO (mg/liter)		pH (standard units)		NH_3-N (mg/liter)	
	I	C	I	C	I	C
0100	4.4	4.5	----	----	----	----
0500	4.0	3.9	8.1	7.8	0.08	0.14
0900	5.3	5.4	7.6	7.6	0.15	0.11
1300	7.3	5.0	8.6	8.6	0.03	<0.01
1700	7.5	6.8	8.5	8.6	0.01	<0.01
2100	7.0	5.2	8.7	7.6	<0.01	0.37

Appendix 22. Chemical characteristics of water samples collected at the Karn plant, August 4, 1972. I and C denote intake and condenser discharge, respectively.

Time	DO (mg/liter)		pH (standard units)		NH_3-N (mg/liter)	
	I	C	I	C	I	C
0100	5.8	5.8	---	---	---	---
0500	5.2	4.9	8.2	8.1	0.07	0.07
0900	6.0	5.8	8.1	7.8	0.08	0.15
1300	9.7	8.0	8.6	8.6	<0.01	0.03
1700	9.2	7.7	8.6	8.6	<0.01	<0.01
2100	7.7	7.8	8.5	8.6	0.02	<0.01

Appendix 23. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, Karn and Weadock power plants, November 27 and December 1, 1972.

Item	Station K-1	W-1	W-2	W-3[a]	W-4[a]	W-5[a]
TRC[b]						
11/27 (1400)	0.12 0.16 0.21 0.21 0.12	-	-	-	-	-
11/27 (1700)	0.03 0.06 0.13 0.13 0.09	-	-	0.06 0.09 0.07 0.07	-	-
11/27 (1700)	-	0.07 0.37 0.41 0.59 0.18	0.15 0.25 0.33 0.25 0.22	0.08 0.13 0.15 0.15 0.07 0.02	0.03 0.10 0.06 0.03	0.0
11/28 (1300)	-	0.12 0.21 0.17 0.02	0.06 0.06 0.05 0.03 0.02	0.03 0.05 0.05 0.03	-	-
11/28 (1400)	0.05 0.08 0.11 0.11 0.02	-	-	-	-	-
11/28 (1700)	0.02 0.04 0.06 0.12 0.13 0.18 0.19 0.08	-	-	0.04 0.08 0.06 0.05	-	-
11/29 (0900)	-	0.21	0.06 0.05 0.06 0.07 0.07 0.02	-	-	-
11/29 (0100)		0.03 0.53 0.83 0.50 (0.21)[c] 0.24 0.04	0.06 0.15 0.15 0.13 0.10	0.17 0.14 0.14 0.12 0.10	0.07 0.08 0.10 0.11 0.11 0.10	0.13 0.17 0.15 0.20 0.15 0.09 0.06 0.04 0.03 0.01
11/29 (1400)	0.03 0.19 0.19 0.21 0.13 0.06	-	-	-	-	-
11/29 (1700)	0.03 0.03 0.03	-	-	-	-	-

Appendix 23. Continued.

Item	Station K-1	W-1	W-2	W-3[a]	W-4[a]	W-5[a]
TRC[b]						
11/29 (1900)	-	0.28 0.50 0.34 0.36 0.09	0.03 0.03 0.03 0.06 0.08 0.08 0.07 0.07 0.08	d	0.03 0.03 0.03 0.02	-
11/30 (0100)	-	0.23 0.28 (0.06) 0.28 0.07 0.01	0.01 0.03 0.03 0.03 0.03	0.0	-	-
11/30 (0900)	-	0.08 0.09 0.30 0.15 0.15 0.05	0.07 0.07 0.07 0.07 0.05	0.02	-	-
11/30 (1300)	-	0.21 0.36 (0.04) 0.46 (0.11) 0.33 (0.14) 0.10 (0.04)	0.03 0.07 0.11 0.11 0.06	0.09 0.09 0.06 0.03 0.03	0.06 0.04 0.04 0.06 0.06 0.06 0.04	-
11/30 (1400)	0.07 0.13 0.18 0.18 0.17	-	-	-	-	-
11/30 (1700)	0.06 0.06 0.18 0.23 0.25 0.18 0.08	-	-	-	-	-
12/1 (0900)	-	0.46 0.62 (0.37) 0.71 0.50 0.32 0.16 0.02	0.03 0.07 0.07 0.12 0.17 0.18 0.16 0.12 0.04	0.09 0.07 0.05 0.05 0.07 0.05 0.01	-	-
Maximum TRC	0.25	0.83	0.33	0.17	0.11	0.20
Average TRC	0.12	0.27	0.09	0.08	0.06	0.10
Minimum TRC	0.02	0.01	0.01	0.01	0.02	0.01
n[e]	44	44	54	36	21	10
Maximum free chlorine	-	0.37	-	-	-	-
Average free chlorine	-	0.14	-	-		
Minimum free chlorine	-	0.04	-	-		
n[e]	-	7	-	-		

Appendix 23. Continued.

Temperature [C (F)] Date	Karn intake control	Weadock intake control	Dechlorinated control	K-1	W-1	W-2	W-3	W-4	W-5
11/27	-	-	-	16.5 (62)	14.5 (58)	14 (57)	15 (59)	13.5 (56)	3.5 (38)
11/27	-	-	-	15 (59)	14.5 (58)	-	14.5 (58)	-	-
11/28	3 (37)	-	-	16.5 (62)	14 (57)	14 (57)	14 (57)	-	-
11/28	-	-	14 (57)	14 (57)	14 (57)	13.5 (56)	14.5 (58)	12 (54)	10.5 (50)
11/29	1.5 (35)	3 (37)	13.5 (56)	13.5 (56)	13.5 (56)	-	13.5 (56)	-	-
11/29	-	-	-	18 (64)	14 (57)	13.5 (56)	15.5 (60)	10.5 (51)	14 (57)
11/29	-	-	-	16.5 (62)	14 (57)	13.5 (56)	13.5 (56)	12 (54)	13 (55)
11/29	-	-	-	13.5 (56)	13 (55)	14 (57)	13.5 (56)	13 (55)	13.5 (56)
11/30	2 (36)	-	13.5 (56)	- -	13.5 (56)	12 (54)	14 (57)	-	
11/30	-	-	-	- -	9 (48)	-	13.5 (56)	14 (57)	14 (57)
11/30	-	-	-	14 (57)	13 (55)	11 (52)	15 (59)	15 (59)	14.5 (58)
11/30	-	-	-	16.5 (62)	13.5 (56)	14 (57)	13.5 (56)	-	-
12/1	2 (36)	3 (37)	14 (57)	16.5 (62)	14 (57)	13.5 (56)	15.5 (60)	12 (54)	13 (53)
12/1	-	-	-	-	13.5 (56)	13.5 (56)	-	-	-
Maximum temp.[C (F)]	3 (37)	3 (37)	14 (57)	14.5 (58)	14 (57)	15.5 (60)	15 (59)	15 (59)	14.5 (58)
Average temp.	2 (36)	3 (37)	14 (57)	13.5 (56)	13.5 (56)	14.5 (58)	13 (55)	13 (55)	12 (53)
Minimum temp.	1.5 (35)	3 (37)	13.5 (56)	9 (48)	9 (48)	13.5 (56)	10.5 (51)	10.5 (51)	3.5 (38)
n[e]	4	2	4	14	11	13	8	8	8

[a] Stations W-3 through W-5 were exposed to both Karn and Weadock chlorinations. Stations W-1 and W-2 were exposed only to Weadock chlorinations while station K-1 was exposed only to Karn chlorinations.
[b] TRC is the total residual chlorine concentration (mg/liter).
[c] Parentheses denote free chlorine concentrations (mg/liter).
[d] The chlorine plume was missed at this station.
[e] n is the total number of readings (non-zero) used to compute the averages.

Appendix 24. Chemical characteristics of water samples collected at the intakes, condenser cooling water discharges and dechlorinated control station at the Karn and Weadock power plants, November 29-30, 1972.

Characteristic[a]	Station: Intake, Plant: Karn		Intake, Weadock		Condenser cooling water discharge, Karn		Condenser cooling water discharge, Weadock		Dechlorinated control	
Time	1300	0100	1300	0100	1300	0100	1300	0100	1300	0100
Temperature	1.5 (35)	2.0 (36)	2.5 (37)	2.0 (36)	17.0 (63)	16.0 (61)	14.0 (57)	9.0 (48)	13.5 (56)	9.5 (49)
DO	11.5	10.6	11.4	10.7	10.1	9.6	10.6	10.4	10.1	9.8
TS	459	558	532	552	529	585	582	500	591	525
TDS	455	527	527	540	520	569	572	491	585	525
SS	4	31	5	12	9	16	10	9	6	5
pH	8.1	8.1	8.0	8.1	8.0	8.1	8.0	8.1	7.9	8.1
Cl	77	77	97	77	85	88	97	77	100	77
NO_3-N	1.6	2.1	2.2	2.1	1.8	2.1	2.2	2.1	2.2	2.1
NH_3-N	0.34	0.39	0.47	0.41	0.41	0.41	0.44	0.39	0.4	0.39
Fe	0.21	0.32	0.29	0.19	0.16	0.29	0.19	0.25	0.2	0.25
SO_4	60	85	75	84	83	89	81	88	80	86
Total alk.	170	200	200	200	180	200	195	200	195	200
Carbonate alk.	0	0	0	0	0	0	0	0	0	0
Hardness	300	345	355	345	320	350	360	345	355	345
CN	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
As	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr^{+6}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	0.03	0.05	0.06	0.03	0.04	0.04	0.04	0.06	0.06	0.05
Cu	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02
F	0.41	0.36	0.36	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Zn	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.03

[a] All characteristics except pH (standard units and temperature [C (F)] are expressed as mg/liter.

Appendix 25. Chemical characteristics of water samples collected at the Karn and Weadock power plants, November 29-30, 1972. I, D, and C denote sample taken from the intake, dechlorinated control and condenser cooling water discharge, respectively. K and W denote samples taken from the Karn and Weadock plants, respectively.

		Temperature [C (F)]					DO (mg/liter)				
		I		D	C		I		D	C	
Date	Time	K	W	W	K	W	K	W	W	K	W
11-29-72	1300	1.5 (35)	13.5 (37)	13.5 (56)	12.0 (63)	14.0 (57)	11.5	11.4	10.1	10.1	10.6
11-29-72	1700	1.5 (35)	2.0 (36)	13.5 (56)	13.5 (56)	14.0 (57)	10.6	10.8	9.8	10.4	10.0
11-29-72	2100	4.0 (39)	3.0 (37)	11.5 (53)	16.0 (61)	13.0 (55)	10.4	9.9	9.3	9.9	-
11-30-72	0100	2.0 (36)	2.0 (36)	9.5 (49)	16.0 (61)	9.0 (48)	10.6	10.7	9.8	9.6	10.4
11-30-72	0500	3.0 (37)	3.0 (37)	9.5 (49)	14.0 (57)	9.5 (49)	10.6	10.4	9.8	9.4	10.4
11-30-72	0900	2.0 (36)	2.0 (36)	12.0 (54)	16.5 (62)	13.0 (55)	10.6	10.9	9.9	9.7	10.4

		pH (standard units)					NH_3-N (mg/liter)				
		I		D	C		I		D	C	
Date	Time	K	W	W	K	W	K	W	W	K	W
11-29-72	1300	8.1	8.0	7.9	8.0	8.0	0.34	0.47	0.40	0.41	0.49
11-29-72	1700	8.0	8.0	7.9	7.9	8.0	0.39	0.39	0.37	0.41	0.39
11-29-72	2100	7.9	7.9	7.9	8.0	8.2	0.43	0.40	0.39	0.47	0.38
11-30-72	0100	8.1	8.1	8.1	8.1	8.1	0.39	0.41	0.39	0.41	0.39
11-30-72	0500	8.1	8.0	7.0	8.0	8.0	0.47	0.48	0.41	0.42	0.44
11-30-72	0900	8.1	8.0	7.9	8.0	7.8	0.41	0.41	0.43	0.39	0.41

Appendix 26. Total residual chlorine readings, temperatures and descriptive statistics for caged fish stations, Monroe power plant, December 12-15, 1972.

Item	Station 1	2	3	4
TRC[a]				
12/12 (0800)	0.06	0.87 (0.30)	0.43	0.00
	0.07	0.87	0.43 (0.30)	
	0.06	0.41 (0.09)	0.49	
	0.45	0.14	0.56	
	0.86	0.09	0.59	
	1.03 (0.08)[b]	0.05	0.59 (0.15)	
	0.51	0.03	0.59 (0.15)	
	0.44	0.02	0.47 (0.28)	
	0.12	0.02	0.35 (0.05)	
	0.06		0.26	
	0.06		0.19	
	0.06		0.12	
	0.06		0.07	
	0.06		0.03	
	0.05		0.02	
	0.04		0.01	
	0.05			
	0.03			
	0.03			
	0.05			
	0.05			
	0.03			
	0.03			
12/13 (0800)	0.91	0.20	-	-
	0.16	0.64 (0.06)		
	0.07	0.81		
		0.81 (0.40)		
		0.81 (0.30)		
		0 65 (0.18)		
		0.13		
		0.16 (0.07)		
12/13 (2000)	0.56	0.03	-	-
	0.79	0.18		
	0.90	0.48		
	0.83 (0.43)	0.47 (0.06)		
	0.69 (0.25)	0.62 (0.06)		
	0.20	0.73 (0.16)		
	0.02	0.75 (0.11)		
	0.58	0.67 (0.10)		
		0.44 (0.03)		
		0.12		
		0.03		
12/14 (0800)	0.63	0.78	0.10	0.00
	0.85 (0.29)	0.57	0.10	
	0.97 (0.27)	0.36	0.06	
	0.47	0.16 (0.07)	0.05	
		0.14	0.07	
		0.06	0.09	
12/15 (0800)	0.34 (0.18)	0.25 (0.03)	-	-
	0.85 (0.13)	0.47 (0.06)		
	0.90 (0.20)	0.61 (0.03)		
	0.08	0.49		
	0.03	0.35		
Maximum TRC	1.03	0.87	0.59	-
Average TRC	0.36	0.40	0.26	-
Minimum TRC	0.02	0.02	0.01	-
n[c]	43	39	22	-
Maximum free chlorine	0.43	0.40	0.30	-
Average free chlorine	0.23	0.12	0.19	-
Minimum free chlorine	0.08	0.03	0.05	-
n[c]	8	17	5	-

Appendix 26. Continued.

Temperature [C (F)]

Date	Intake control	Dechlorinated control	Station 1	Station 2	Station 3	Station 4
12/12	0.5 (33)	11 (52)	11 (52)	11 (52)	9 (48)	6.5 (44)
12/12	-	-	10.5 (51)	10 (50)	9 (48)	6.5 (44)
12/13	1 (34)	10 (50)	10 (50)	6.5 (44)	6.5 (44)	9 (48)
12/13	-	-	9.5 (49)	9.5 (49)	-	-
12/13	-	-	8 (46)	8.5 (47)	-	-
12/14	1.5 (35)	9.5 (49)	9.5 (49)	9 (48)	8.5 (47)	-
12/14	-	-	10 (50)	9.5 (49)	8.5 (47)	6 (43)
12/15	3.5 (38)	13.5 (56)	-	13 (55)	10 (50)	6.5 (44)
12/15	-	-	13.5 (56)	13 (55)	-	
Maximum temp.	3.5 (38)	13.5 (56)	13.5 (56)	13 (55)	10 (50)	9 (48)
Average temp.	1.5 (35)	11 (52)	10 (50)	10 (50)	8.5 (47)	7.5 (45)
Minimum temp.	0.5 (34)	9.5 (49)	8 (46)	6.5 (44)	6.5 (44)	6 (43)
n[c]	4	4	8	9	6	5

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine readings (mg/liter).
[c] n is the total number of readings (non-zero) used to calculate the averages.

Appendix 27. Chemical characteristics of water samples collected at the Monroe power plant intake, condenser cooling water discharge channel and dechlorinated control, December 13, 1972.

Characteristic[a]	Station					
	Intake		Condenser cooling water discharge		Dechlorinated control	
Time	1200	2400	1200	2400	1200	2400
Temperature	1.0 (34)	1.0 (34)	10.0 (50)	7.5 (45)	10.0 (50)	7.5 (45)
DO	11.6	12.7	11.5	12.4	10.5	11.2
DO (percent saturation)	82	89	102	103	93	93
pH	7.6	8.0	7.9	8.0	8.0	8.0
TS	484	461	470	456	495	452
TDS	465	450	460	450	485	450
SS	19	11	10	6	9	2
Cl	60	43	58	46	72	46
Fe	0.55	0.55	0.55	0.45	0.75	0.55
NO_3-N	5.7	5.2	5.7	5.5	5.2	5.4
NH_3-N	0.34	0.39	0.32	0.39	0.33	0.36
SO_4	170	170	160	170	160	170
Total alkalinity	190	195	190	195	190	200
Carbonate alkalinity	0	0	0	0	0	0
Hardness	360	370	355	370	355	375
CN	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr^{+6}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	0.05	0.05	0.05	0.05	0.05	0.05
Cu	0.02	0.02	0.02	0.02	0.02	0.02
F	0.28	0.32	0.28	0.28	0.28	0.28
Zn	0.06	0.03	0.04	0.02	0.17	0.05

[a] All characteristics except temperature [C (F)] and pH (standard units) are expressed as mg/liter.

Appendix 28. Chemical characteristics of water samples taken at the Monroe power plant, December 13-14, 1972. I, D, and C denote samples collected from the intake, dechlorinated control and condenser cooling water discharge, respectively.

Date	Time	Temperature [C (F)]			DO (mg/liter)			pH (standard units)		
		I	D	C	I	D	C	I	D	C
12-13-72	0800	2 (36)	8.5 (47)	10 (50)	12.3	10.5	12.1	7.9	7.7	7.7
12-13-72	1200	1 (34)	10 (50)	10 (50)	11.6	10.5	11.5	7.9	8.0	7.9
12-13-72	1600	0.5 (33)	6 (43)	7.5 (45)	11.2	10.6	10.0	7.8	7.8	7.8
12-13-72	2000	1 (34)	8 (47)	8.5 (47)	11.7	10.3	11.2	7.8	7.8	7.8
12-13-72	2400	1 (34)	7.5 (45)	7.5 (45)	12.7	11.2	12.4	8.0	8.0	8.0
12-14-72	0400	3 (37)	8.5 (47)	8.5 (47)	10.7	10.1	12.3	7.9	7.9	7.9

Date	Time	NH_3-N (mg/liter)		
		I	D	C
12-13-72	0800	0.29	0.27	0.30
12-13-72	1200	0.34	0.33	0.32
12-13-72	1600	0.26	0.25	0.26
12-13-72	2000	0.32	0.30	0.31
12-13-72	2400	0.39	0.36	0.39
12-14-72	0400	0.41	0.41	0.41

Appendix 29. Total residual chlorine readings, temperatures and descriptive statistics for caged fish and control stations, J. H. Campbell power plant, April 27 - May 4, 1973.

Item	Station			
	Intake	1	2	3
TRC[a]				
4-30-73	0.00	0.05	0.02	0.04
		0.04	0.05	TR
		0.13	0.06	0.04
		0.16	0.12	0.02
		0.18 (0.02)[b]	0.14	0.02
		0.17 (0.03)	0.14	TR
		0.22	0.10	
		0.10 (TR)[c]	0.05	
		0.03 (TR)	0.04	
		0.02	0.03	
Maximum TRC		0.22	0.14	0.04
Average TRC		0.11	0.08	0.03
Minimum TRC		0.02	0.02	TR
n[d]		10	10	6
Temperature [C (F)]				
4-27-73	9.5 (49)	10.5 (51)	10.5 (51)	10.5 (51)
4-30-73	10 (50)	17 (63)	16.5 (62)	17 (63)
5-1-73	10 (50)	19 (66)	19 (66)	18.5 (65)
5-2-73	14.5 (58)	22.5 (72.5)	22 (72)	22 (72)
5-3-73	13.5 (56)	21 (70)	21 (70)	20.5 (69)
5-4-73	10.5 (51)	19 (66)	19 (66)	19 (66)
Maximum Temp. [C (F)]	14.5 (58)	22.5 (72.5)	22 (72)	22 (72)
Average Temp.	11 (52)	18.5 (65)	18.5 (65)	18 (64)
Minimum Temp.	9.5 (49)	10.5 (51)	10.5 (51)	10.5 (51)
n[d]	6	6	6	6

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentration (mg/liter).
[c] TR denotes a trace.
[d] n is the number of readings (non-zero) used to compute averages.

Appendix 30. Chemical characteristics of water samples collected at the J. H. Campbell power plant intake and condenser cooling water discharge May 2, 1973.

Characteristic[a]	Station			
	Intake	1	2	3
Temperature	14.5 (58)	22.5 (72.5)	22 (72.0)	23 (73)
DO	7.8	7.6	7.2	7.8
DO (percent saturation)	76	87	84	90
SS	7	18	7	9
SVS	-	10	-	-
pH	7.5	7.3	7.4	7.4
Cl	12	12	12	12
NO_3-N	0.65	0.60	0.59	0.57
NH_3-N	0.03	0.05	0.05	0.04
Org. N	1.0	1.1	0.80	0.63
$SOPO_4$	0.04	0.05	0.04	0.03
TPO_4	0.12	0.16	0.12	0.09
Total alkalinity	70	75	70	85
Carbonate alkalinity	0	0	0	0
Hardness	120	110	85	115
Fe	0.8	0.8		
SO_4	27	29		
Cn	<0.02	<0.02		
Cr^{+6}	<0.01	<0.01		
As	<0.01	<0.01		
Mn	0.02	0.03		
Cu	<0.01	<0.01		
F	0.20	0.24		
Zn	<0.01	<0.01		

[a] All characteristics except temperature [C (F)] and pH (standard units) are expressed as mg/liter.

Appendix 31. Total residual chlorine readings, temperature and descriptive statistics for caged fish and control stations, J. H. Campbell power plant, May 14-18, 1973.

Item	Intake	1	2	3
TRC[a]				
5-14-73	-	0.1	0.17	0.03
		0.2	0.12	0.03
		0.3	0.10	0.05
		0.03	0.11	0.05
			0.09	0.04
			0.14	0.04
			0.09	0.03
			0.08	0.03
			0.06	TR[c]
			0.06	
5-16-73	-	0.06	0.05	0.05
		0.26	0.15	0.06
		0.29	0.20	0.10
		0.33	0.13 (0.03)	0.10
		0.32 (0.29)[b]	0.19	0.06
		0.39 (0.3)	0.19 (0.03)	0.05
		0.39	0.20 (0.03)	0.03
		0.37	0.23	TR[c]
		0.05	0.20	
		TR	0.13	
			0.10	
			0.03	
			0.03	
			0.02	
5-18-73	-	0.21	0.1	0.04
		0.27	0.15 (0.04)	0.06
		0.25 (0.16)	0.15	0.07
		0.24 (0.17)	0.16	0.08
		0.29 (0.22)	0.15	0.08
		0.26 (0.20)	0.16	0.07
		0.27 (0.21)	0.18 (TR)	0.03
		0.33	0.15	
		0.37 (0.27)	0.05	
			TR	
Maximum TRC		0.39	0.23	0.10
Average TRC		0.25	0.12	0.05
Minimum TRC		0.03	0.02	0.03
n[d]		22	33	22
Maximum free chlorine		0.30	0.04	-
Average free chlorine		0.23	0.03	-
Minimum free chlorine		0.16	0.03	-
n[d]		8	4	-
Temp. [C (F)]				
Date				
5-14-73	11 (52)	16.5 (62)	16 (61)	16.5 (62)
5-15-73	11 (52)	16 (61)	15.5 (60)	15.5 (60)
5-16-73	10.5 (51)	15 (59)	15 (59)	15.5 (60)
5-17-73	11 (52)	16.5 (62)	16.5 (62)	16.5 (62)
5-18-73	10.5 (51)	16 (61)	15.5 (60)	16 (61)
Maximum Temp. [C (F)]	11 (52)	16.5 (62)	16 (61)	16.5 (62)
Average Temp.	11 (52)	16 (61)	15.5 (60)	16 (61)
Minimum Temp.	10.5 (51)	15 (59)	15 (59)	15.5 (60)
n[d]	5	5	5	5

[a] TRC is the total residual chlorine concentration (mg/liter).
[b] Parentheses denote free chlorine concentration (mg/liter).
[c] TR denotes a trace.
[d] n is the number of non-zero readings, not including traces, used to compute averages.

Appendix 32. Chemical characteristics of water samples collected at the J. H. Campbell power plant, May 17, 1973.

Characteristic[a]	Station			
	Intake	1	2	3
Temperature	11 (52)	16.5 (62)	16.5 (62)	16.5 (62)
DO	9.8	9.8	10.0	10.0
DO (percent saturation)	88	100	102	102
pH	7.0	7.2		
NO_3-N	0.15	0.15		
NH_3-N	<0.01	<0.01		
Cl	10	10		
Total alkalinity	115	115		
Carbonate alkalinity	0	0		
Hardness	160	160		
Fe	0.05	0.05		
SO_4	28	27		
Cn	<0.02	<0.02		
Cr^{+6}	<0.01	<0.01		
As	<0.01	<0.01		
Mn	0.01	0.01		
Cu	<0.01	<0.01		
F	0.16	0.20		
Zn	0.01	<0.01		

[a] All characteristics except temperature [C (F)] and pH (standard units) are expressed as mg/liter.

Appendix 33. Chemical characteristics of water samples collected from each aquarium before (B), during (D), and 48 hr after (A), chlorination, July 16-20, 1973.

Item	Temperature [17 C (63 F)]						[21 C (70 F)]					
	0.99[a]	0.93	0.78	0.71	0.58	0.0	1.02	0.86	0.78	0.67	0.58	0.0
DO (mg/liter)												
B	8.0	8.5	7.6	8.2	9.0	8.0	9.0	8.0	8.2	7.6	6.5	9.2
D	6.8	6.8	7.0	7.6	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
A	6.6	6.2	6.6	6.6	6.6	6.6	6.8	6.4	7.0	7.0	7.0	7.0
DO (percent saturation)												
B	81	83	77	82	92	81	99	88	90	82	71	102
D	69	69	72	77	72	72	76	76	76	76	76	76
A	67	62	67	67	67	67	74	71	76	76	76	76
pH (standard unit)												
B	7.6	7.4	8.4	8.3	8.7	7.7	8.9	7.9	8.0	8.1	7.9	8.7
D	8.9	9.1	9.0	9.1	9.3	8.8	9.1	8.5	9.1	9.2	9.2	8.7
A	9.3	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alkalinity (mg/liter)												
B	86	86	86	68	68	68	68	68	68	68	68	68
D	68	68	68	68	68	68	68	68	68	68	68	68
A	68	68	68	68	68	68	68	68	68	68	68	68
Hardness (mg/liter)												
B	86	86	86	86	86	86	86	86	86	86	86	86
D	86	86	86	86	86	86	86	86	86	86	86	86
A	86	86	86	86	86	86	86	86	86	86	86	86

[a] Mean total residual chlorine concentration (mg/liter).

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Studies were conducted during 1972 at five Michigan power plants in which caged brown trout (Salmo trutta) and fathead minnows (Pimephales promelas) were held for 96 hr in the intake and condenser cooling water discharge channels and in condenser cooling water dechlorinated with sodium thiosulfate. Total residual chlorine levels as low as 0.05 mg/liter were lethal to brown trout below four of the five plants. Total residual chlorine concentrations lethal to 50 percent (ILC-50) of the caged brown trout at two plants averaged from 0.02 to 0.18 mg/liter during the chlorination periods. Fathead minnow deaths in all studies could not be attributed to the total residual chlorine.

Resident fish were observed in distress at two plants during 1972. These behavioral symptoms were noted at maximum total residual chlorine concentrations ranging from 0.2 to 0.5 mg/liter.

Studies were repeated in 1973 at one plant with brown trout and other salmonid species. No deaths of test fish occurred during these tests that could be attributed to chlorine concentrations. The inconsistent results may be related to interactions between chlorine, temperature, and dissolved oxygen saturation in the discharge channel.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Bioassay Chlorination Electrical industry Fishes Toxicity	Toxicity tests Condenser cooling water Median lethal concentration	6F

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