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Persistence of Chlorine in Cooling Water from Electric Generating Station

By G. Fred Lee,[1] M. ASCE

Introduction

The Eddystone Generating Station of the Philadelphia Electric Company is a 650-MW station located on the Delaware River estuary 12 miles (19 km) downriver from the city of Philadelphia. At the time of this study this station consisted of two coal-fired electric generating units, each utilizing approx 200,000 gal/min (760 m^3/min) of cooling water from the Delaware River. The cooling water is heated 6° C–7° C during condenser passage and discharged to Crum Creek. Fig. 1 presents an overall map of the area showing the sampling stations used in this study.

As a condition for the permit to essentially double the electrical output from the Eddystone Station (the addition of Units 3 and 4), the Delaware River Basin Commission (DRBC) required that a study be conducted on the persistence of chlorine in the once-through cooling thermal discharge plume. The DRBC also required that the Philadelphia Electric Company add 5,000 lb/day (2,300 kg/day) of dissolved oxygen (DO) to the river to compensate for the DRBC estimated loss in BOD assimilative capacity in the Delaware River estuary arising from loss of DO due to elevated temperatures in the thermal plume. In order to comply with this requirement Philadelphia Electric sponsored a study to determine the persistence of chlorine and the changes in dissolved oxygen in the thermal discharge plume from Units 1 and 2 of the Eddystone Station. This paper presents a summary of the results of the chlorine persistence studies; the dissolved oxygen studies are being published elsewhere.

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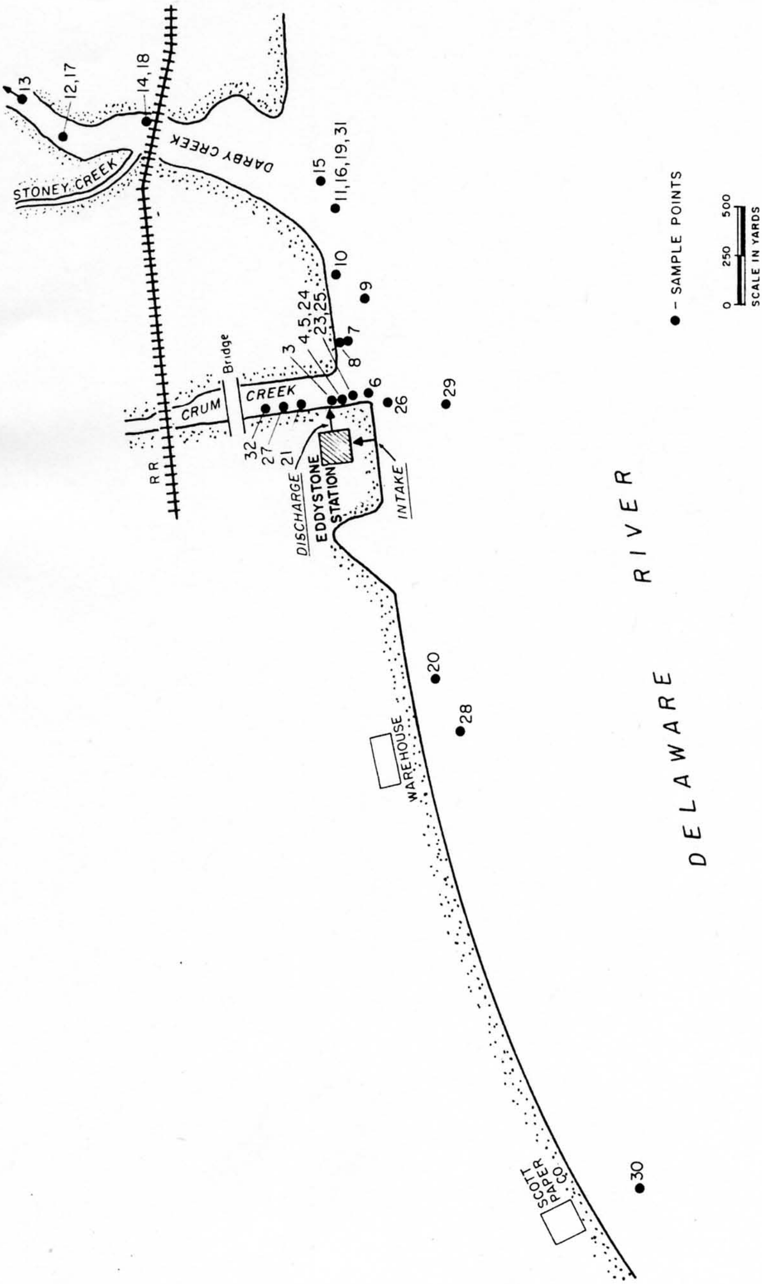

FIG. 1.—Map of Study Area and Sampling Points

Experimental Procedure

The study was conducted on October 8 and 9, 1973. The first day of the study concentrated on sampling of the plant's discharge plume to determine the actual persistence of chlorine in the Delaware River system. Sampling on the second day was conducted to evaluate the fluctuations in chlorination procedures and changes in effluent chlorine concentrations through one complete chlorination cycle. Chlorine demand and dissolved oxygen studies were carried out on both sampling days.

Sampling and Analytical Techniques.—The sampling program was to be carried out with the plant operating under normal procedures of load and chlorination schedule. Sampling of the discharge plume was accomplished with a rope and bucket from a boat provided by Ichthyological Associates. This method of sample collection was adequate for this study since the heated effluent floated on top of the Delaware River estuary water. The surface samples were collected at locations dictated by the movement of drogues (see Fig. 1). Each drogue consisted of two 0.6-m square slotted aluminum panels joined perpendicularly along their vertical center lines. The drogues were suspended from plastic bottle floats using 0.6 m of nylon cord. The length of the line was such that the drogues would indicate the movement of water in the upper meter of the water column; the drogues provided an indication of the direction and rate of movement of the discharge waters. Rope and bucket samples of water were also taken in the intake and discharge wells for the station circulating (cooling) water; inlet pump and condenser samples were collected through sampling ports located on these structures.

Chlorine demand studies were conducted on intake and discharge waters. Four-liter samples were taken to the Eddystone Station laboratory, stored in the dark, stoppered, and sampled at various time intervals. The samples were shaken at periodic intervals to suspend any settled solids. Total residual chlorine was determined on these samples versus time. For total residual chlorine analysis, the pH of the samples was first adjusted to 4.0 ± 0.5. Since free chlorine was not detected on the discharge side of an operating chlorinator, only total residual chlorine was measured in the samples.

The amperometric titration procedure was modified from the manufacturer's recommendations in order to improve the sensitivity and precision of this equipment. The modification included replacing the titrator's burette with a 5-ml microburette. Instead of using a dead stop approach for end point detection, the reading on the instrument's microamp meter was plotted on graph paper in accordance with normal amperometric titration procedures. Whenever the meter needle went off scale the resistance knob on the titrator was turned to adjust the current reading to near full scale and the titration continued. The end point was chosen to be the intersection of two straight lines arising from the plot of current versus milliliters of titrant.

Samples were analyzed for dissolved oxygen, temperature, specific conductance, pH, and total chlorine at Eddystone. Selected samples were analyzed for ammonia and chloride; the analytical methods employed are tabulated in Table 1.

The Delaware River at the location of the Eddystone Plant is highly polluted and as shown in a subsequent section, the dissolved oxygen levels are often less than 1 mg/l. The ammonia levels at this location are frequently between 0.5 mg/l and several milligrams per liter of ammonia nitrogen. The minimum of the dissolved oxygen sag from the wastewater inputs from Philadelphia and the industries of the area occurs near the point where the Eddystone Plant is located on the shore of the river. Table 2 presents a list of the sample numbers and locations used in this study.

Circulating Water System (1)

The location of the intake and discharge for Eddystone Units 1 and 2 is shown in Fig. 1. The intake tunnels are located on the Delaware River at the downriver end of the Eddystone property. Water is drawn in between El. −18.6 ft (−5.7 m) (the bottom of the intake tunnel), and El. −6.35 ft (−1.9 m) (the bottom of the apron wall). There are four intake tunnels each equipped with trash racks, stop logs, traveling screen, river water pump suction, and circulating water pump section. Each circulating water pump is rated at 100,000 gal/min (380 m^3/min) and each river water pump at 10,000 gal/min (38 m^3/min).

TABLE 1.—Analytical Methods

Analysis (1)	Method (2)
Dissolved oxygen	Yellow Springs Instruments Corporation Dissolved Oxygen and Temperature Meter and Probe
Temperature	Yellow Springs Instruments Corporation Dissolved Oxygen and Temperature Meter and Probe
pH	Corning Model 7 Laboratory pH Meter
Specific conductance	Leeds & Northrup Wheatstone Laboratory Conductivity Bridge
Total residual chlorine	Wallace & Tiernan Amperometric Titrator
Ammonia	American Public Health Association, et al. (6) Bausch & Lomb Spectronic 20 Phenate Procedure
Chloride	American Public Health Association, et al. (6) Mercuric Nitrate Titration Procedure

One 78-in. (2,000-mm) ID inlet pipe leaves underground from each circulating water pump. A separate chlorinator feeds chlorine into the discharge side of each circulating pump, e.g., chlorinators 1A and 1B add chlorine in accord with a previously determined schedule to the discharge pipe for circulating water pumps 1A and 1B. The sampling point for chlorinators 1A and 1B is just downstream of the point where the chlorine is mixed with the circulating water. Two of the pipes terminate at the steel inlet pipes to the Unit 1 condenser that has split water boxes. The two 78-in. (2,000-mm) ID inlet pipes for Unit 2 each split into two 54-in. (1,400-mm) ID pipes. Unit 2 has two condensers with split water boxes so that one 54-in. (1,400-mm) pipe from each inlet pipe feeds one water box on each condenser. Each condenser is located above the mean high water level. The condenser inlet and tail pipes are vertical to connect the condenser with the lower intake and discharge piping. Analysis of the circulating water hydraulic and energy gradients shows that the condenser tail pipes are always at less than atmospheric pressure. The vacuum is a function of river water level with the greater vacuum occurring at the lowest river water level.

TABLE 2.—Key to Sampling Locations: Eddystone Study of October 9 and 10, 1973

Sample[a] (1)	Location (2)	Time (3)
1	Discharge side of 1B chlorinator	0815
2	Discharge crib adjacent to Crum Creek	1006
3	Below turbulent area in Crum Creek	1009
4	50 yd[c] below sample 3, Crum Creek	1013
5	Off Boeing Corporation plant near mouth of creek	1020
6	Mouth of Crum Creek	1023
7	200 yd upstream from mouth of Crum Creek and 30 yd offshore	1032
8	200 yd upstream and 15 yd[c] offshore	1034
9	350 yd upstream and 150 yd offshore	1045
10	450 yd upstream and 30 yd[c] offshore	1048
11	Mouth of Darby Creek	1110
12	Darby Creek just above 1st Marina	1133
13	Darby Creek just below Driftwood Marina	1136
14	Darby Creek at railroad bridge	1145
15	Mouth of Darby Creek 50 yd up creek from sample 11	1148
16	Mouth of Darby Creek; same as sample 11	1306
17	Just below 1st Marina on Darby Creek	1317
18	Darby Creek under Railroad bridge	1320
19	Mouth of Darby Creek	1324
20	Delaware River 100 yd[c] offshore and 1,250 yd below Crum Creek	1332
21	Crum Creek above effluent outfall 100 yd	1458
22	Discharge crib adjacent to Crum Creek	1520
23	Crum Creek 75 yd below discharge	1523
24	Crum Creek 50 yd below discharge and nearer sea wall than sample 23	1525
25	Crum Creek off Boeing Corporation plant near mouth of creek	1532
26	Delaware River 100 yd offshore and 100 yd from Crum Creek mouth, downstream	1555
27	Crum Creek 200 yd above Discharge crib	1553
28	Delaware River 150 yd offshore and 1,500 yd downstream from Crum Creek	1635
29[b]	Delaware River 300 yd offshore	1640
30	Delaware River 3,500 yd downstream from Crum Creek and 200 yd offshore	1707
31	Mouth of Darby Creek	1720
32	Crum Creek opposite entrance gate	1758
33	Discharge side of chlorinator 1A	0715
34	Discharge well into Crum Creek	0725

[a]Samples 1–32 are from October 9; samples 33 and 34 are from October 10.
[b]Ambient sample.
[c]Measured distance; all other distances are approximated.

The Unit 2 condenser tail pipes discharge into a discharge tunnel that flows in an upriver direction under the plant where the discharge from the Unit 1 condenser joins this same tunnel. Flow continues on and then discharges to the Crum Creek approx 300 yd (270 m) upstream from the Delaware River.

There is a discharge well where circulating water can be sampled just before the bulkhead at the Crum Creek. The common discharge tunnel for Units 1

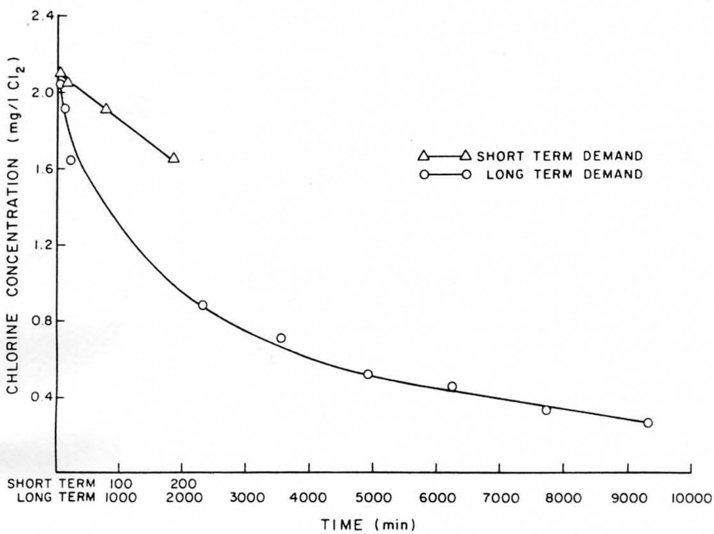

FIG. 2.—Chlorine Demand of Cooling Water Sample 1 from Discharge Side of Chlorinator 1B (Sample Taken on October 9, 1973, at 0815 hr)

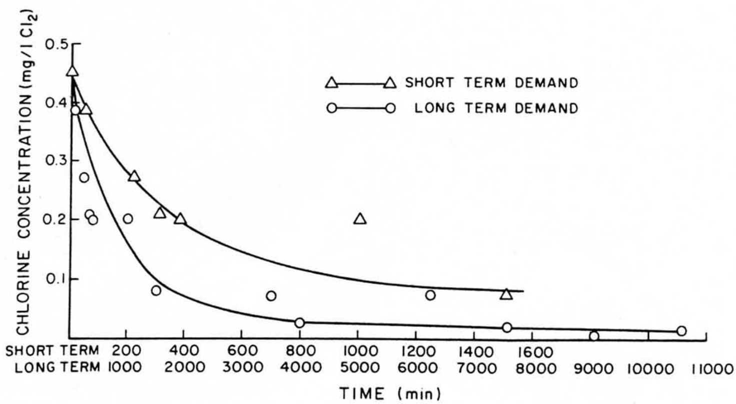

FIG. 3.—Chlorine Demand of Cooling Water Sample 2 from Discharge Crib Adjacent to Crum Creek (Sample Taken on October 9, 1973, at 1006 hr)

and 2 is vented to the atmosphere near its origin by means of a 24-in. (600-mm) vent. Since chlorine is added to the discharge of only one circulating pump at a time, the chlorine present in the discharge crib has been diluted 3:1 with unchlorinated cooling water. Typically, the concentration of chlorine in the circulating water is in the range of 1 mg/l–2 mg/l.

Results

Laboratory Studies of Chlorine Demand.—Four separate chlorine demand studies were carried out in order to determine the rate of chlorine disappearance

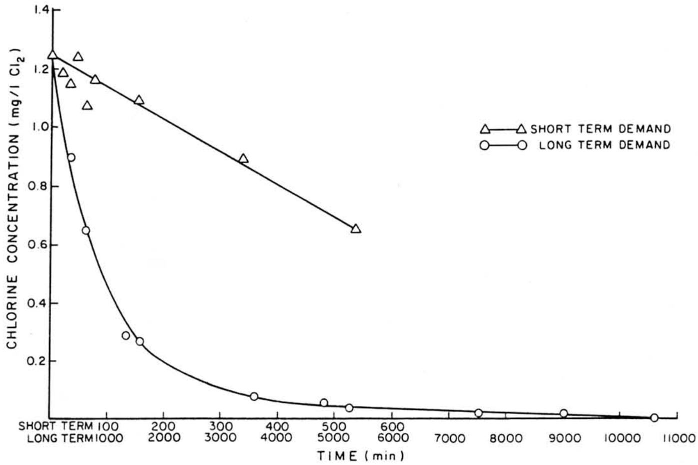

FIG. 4.—Chlorine Demand of Cooling Water Sample 33 from Discharge Side of Chlorinator 1A (Sample Taken on October 10, 1973, at 0715 hr)

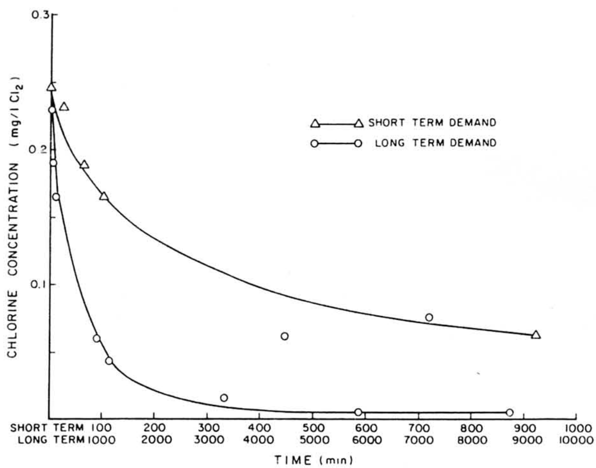

FIG. 5.—Chlorine Demand of Cooling Water Sample 22 from Discharge Crib Adjacent to Crum Creek (Sample Taken on October 9, 1973, at 1520 hr)

in the plant cooling waters: two samples were collected at the discharge crib; and the other two were taken at the intake works just after chlorination. (Refer to Table 2 for sampling times and locations.)

No attempt was made in these studies to maintain the temperature of the sample at the temperature of the water at the time of collection. Instead, all samples were allowed to adjust to room temperature. For the October, 1973 studies, all temperatures were in the range of 20° C for the samples taken from the discharge side of the chlorinators prior to condenser passage and from the discharge crib of Crum Creek after condenser passage and in the laboratory where the samples were stored for the chlorine demand studies.

Examination of Figs. 2–5 shows that initially there is a fairly rapid chlorine demand from the waters taken on the discharge side of the chlorinators, followed by a much slower chlorine demand. As shown in Fig. 6, the initial uptake rates fit a first order relationship where the rate of chlorine decrease is proportional to the chlorine concentration. The first-order rate constants for these studies are presented in Table 3.

The variability in these rate constants is probably attributable to the variability in composition of the river water and the temperature dependence of k.

In March, 1973, several chlorine demand studies were conducted on the Eddystone Station intake and discharge cooling waters. The initial rate constants

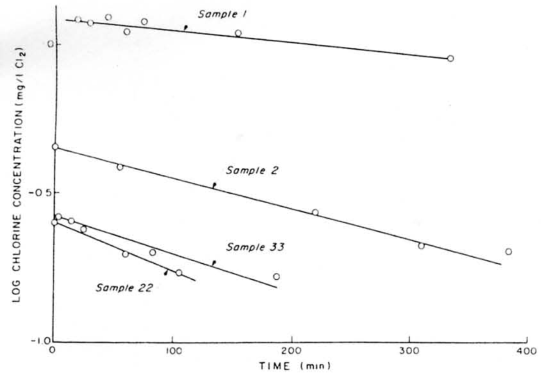

FIG. 6.—Initial Chlorine Demand of Samples 1, 2, 22, and 33

for the March, 1973 study were in the order of -0.3×10^{-3}. Values for the October, 1973 study as presented in the aforementioned are generally in excess of -1.0×10^{-3}/min. This increase in the rate of chlorine demand is probably the result of increased ambient river water temperature and changes of the characteristics of demand materials in the water. The initial temperatures obtained in March, 1973 were in the order of 12° C–18° C.

The typical chlorination schedule at the Eddystone Plant involved chlorinating for a period of 20 min, three times a day. For example, chlorinator 1A would be on at 7:00 a.m., 3:00 p.m., and 11:00 p.m., while chlorinator 1B would be on at 8:00 a.m., 4:00 p.m., and 12:00 midnight. Chlorinator 2A was on at 9:00 a.m., 5:00 p.m., and 1:00 a.m., while 2B was on at 10:00 a.m., 6:00 p.m., and 2:00 a.m. This means that chlorine is being discharged to the Delaware River for 20 min of each hour from 7:00 a.m. until 10:30 a.m. A similar sequence occurs from 3:00 p.m. until 6:30 p.m., and from 11:00 p.m. to 2:30 a.m. At the time of the study, chlorinator 1A was adding chlorine at a rate to give slightly over 2 mg/l immediately after mixing. The chlorinator 1B residual after mixing was on the order of 1 mg/l; 2A was slightly over 2 mg/l; and 2B was just under 1 mg/l. As indicated in the foregoing, there was a 3:1 dilution of any cooling water that was receiving chlorine before discharge to Crum Creek.

Generally, these studies showed that there were a few tenths of a milligram per liter of chlorine consumed during passage through the plant. Based on this chlorination schedule, for 4 hr out of each day there are a few tenths of a milligram per liter of chlorine being discharged to the Delaware River from the Eddystone Plant. Studies on the chlorine content during a chlorination cycle showed that it could vary several tenths of a milligram per liter during the chlorination cycle immediately downstream from the point of chlorine addition.

Field Measurements of Chlorine Persistence.—The discharge chlorine persistence field study was conducted in two parts: one part in the morning of October 9 near maximum flood tide; and the other part that afternoon near minimum ebb tide. The weather during the course of the 2 days of the study was predominantly overcast with occasional periods of sunshine. Air temperatures ranged from 60° F–70° F (16° C–21° C). Barometric pressure increased over the period from 768 mm to 775 mm of mercury.

TABLE 3.—Chlorine Demand Study

Sample number (1)	Rate constant, k, per minute (2)
1	-0.36×10^{-3}
2	-1.0×10^{-3}
22	-1.6×10^{-3}
33	-1.3×10^{-3}

Note: Temperature approx 20° C.

TABLE 4.—Tide Stage at Chester, Pa.

Date (1)	Time (2)	Height, in meters (3)
October 9, 1973	0530	0.12
	1036	1.8
	1721	1.6
	2254	1.9
October 10, 1973	0549	0.12
	1119	1.9
	1812	0.09

The load on the Eddystone Station during the course of the study was 338 MW–340 MW for Units 1 and 2 on October 9, 1973 from 6 a.m.–6 p.m.

The drogues were dropped into Crum Creek at the beginning of a chlorination period at a point approx 20 yd downstream from the plant discharge after an orthotolidine residual was detected in the waters in the discharge crib. The drogues then tended to follow the discharge water flow into the Delaware River,

TABLE 5.—Summary of Chemical Discharge Parameters: Drogue Study, October 9, 1973

Sample number (1)	Elapsed time, in minutes[a] (2)	In-situ temperature, in degrees celsius (3)	Dissolved oxygen, in milligrams per liter (4)	pH (5)	Specific conduction at 25° C, in micromhos per centimeter (6)	Total residual Cl_2, in milligrams per liter (7)	Dilution factor (8)
(*a*) Flood Tide Period							
2	—	29.5	2.3	6.6	274	0.470	—
3	3	29.1	1.8	6.4	274	0.237	0.053
4	7	29.1	1.8	6.6	271	0.090	—
5	14	—	—	6.6	271	0.080	—
6	17	29.0	1.4	6.8	274	0.147	0.067
7	26	28.0	1.7	6.8	269	0.152	0.173
8	28	27.0	1.7	6.8	270	0.148	0.333
9	39	24.0	0.7	6.8	276	<0.005	—
10	42	25.0	1.5	6.8	273	0.066	0.600
11	64	24.5	1.8	6.7	272	0.010	0.667
12	87	22.9	1.4	6.8	270	<0.005	—
13	90	22.8	2.2	6.8	265	0.008	—
14	99	23.0	2.1	6.8	271	0.060	—
15	102	23.1	1.7	6.8	275	0.010	—
16	180	22.4	1.9	6.8	271	0.010	—
17	191	21.9	1.6	6.8	279	<0.005	—
18	194	22.1	1.6	6.7	270	<0.005	—
19	198	22.3	1.6	6.7	270	0.005–0.010	—
20	206	24.9[b]	2.0	6.7	274	<0.005	—
Ambient	—	22.0	0.7	—	—	—	—
(*b*) Ebb Tide Period							
21	—	28.4	2.4	7.2	270	0.020	—
22	—	30.2	2.2	6.7	276	0.255	—
23	3	29.1	2.0	6.8	276	0.198	0.129
24	5	29.4	1.9	6.8	269	0.170	0.094
25	12	29.3	2.1	6.8	254	0.106	0.106
26	35	26.7	3.0	6.8	265	0.025	0.412
27	33	26.8	2.9	6.8	270	0.025	—
28	75	22.3	2.8	6.7	265	0.010	0.929
29[c]	80	21.7	1.5	6.8	266	0.015	—
30	107	21.9	1.6	6.8	268	0.025	—
31	120	21.8	2.5	6.8	278	0.010	—
32	158	18.1	10.0	7.3	207	<0.005	—

[a] From point of discharge.
[b] Sample shows effect of "reheating" as it passed mouth of Crum Creek.
[c] Ambient Sample.
Note: Dashes indicate no sample taken or it is inappropriate to calculate dilution factor for this sample.

and then either upstream or downstream, depending on tide conditions. Rates of movement were approx 1,700 yd/hr (1,600 m/hr) upstream during flood tide and approx 2,200 yd/hr (2,000 m/hr) downstream during ebb tide. Tide stage at Chester, Pa., near the Eddystone Station is presented in Table 4. Drogue positions in the river system were assumed to indicate the position of the discharge water mass. Samples were taken at these points (see Fig. 1). In addition to sampling at the drogue position, other samples were taken in surrounding water

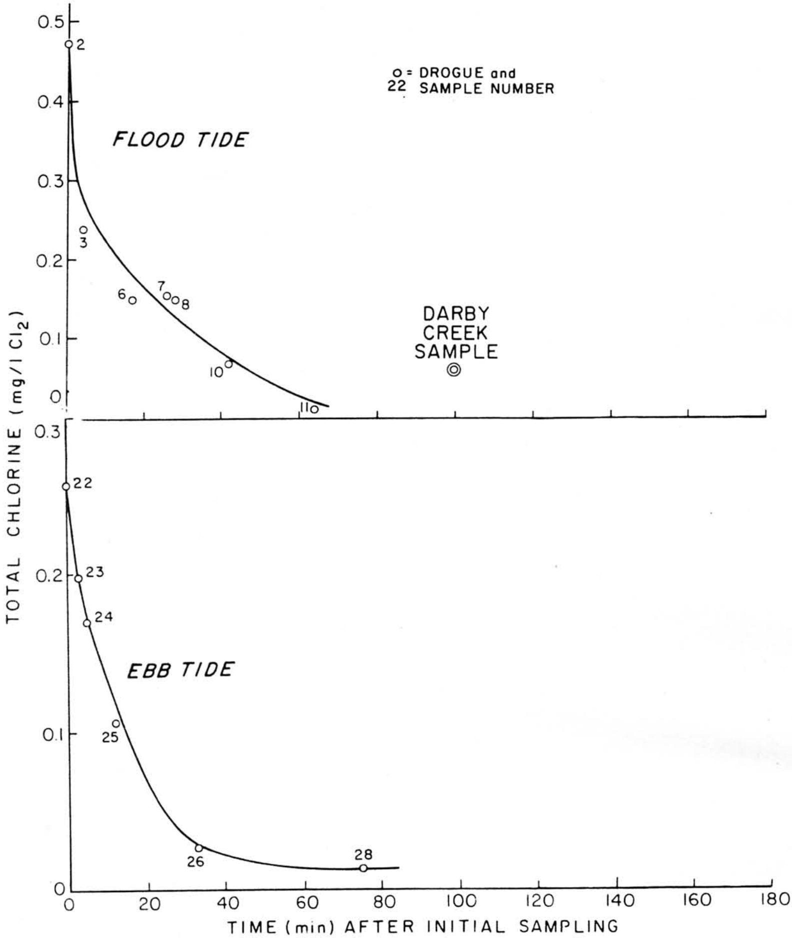

FIG. 7.—Persistence of Chlorine in Delaware River Estuary (October 9, 1973)

to determine if there were other sources of chlorine in the area. Dissolved oxygen and temperature were determined on board the sampling boat. Samples were collected and rushed back to the laboratory for further analysis. Generally, the maximum time between sample collection and chlorine analysis was 15 min. Because there was a time delay between sample collection and chlorine analysis, total residual chlorine values were corrected on the basis of the rate of loss of chlorine as determined in the laboratory chlorine demand studies.

The results of this study are tabulated in Table 5. Specific conductance values were corrected to 25° C using the correction factors provided in Ref. 6, p. 324. The dilution factor is derived from the temperature data applying the formula

$$\text{dilution factor} = \frac{T_D - T_S}{T_D - T_A} \quad \text{(1)}$$

in which T_D = temperature at the discharge crib; T_S = temperature of the sample; and T_A = ambient river temperature outside the thermal discharge plume of the Eddystone Plant.

This equation assumes that the temperature of the water is a conservative property in which the only significant way the temperature can change during the period of study is by dilution of the discharge waters with ambient water in the region of the discharge. This assumption will be in error to the extent

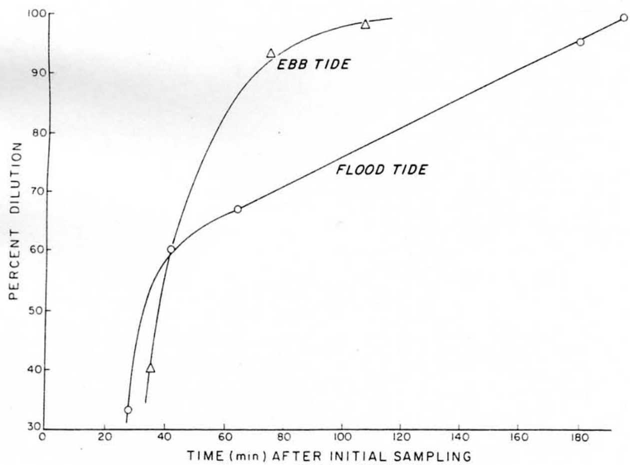

FIG. 8.—Dilution of Eddystone Thermal Discharge on October 9, 1973

that there is some heat loss to the atmosphere. Numerous studies on thermal discharge plumes have shown that in a period of a few hours with an Eddystone-type discharge, the primary cause of cooling of the discharge is dilution and not heat exchange with the atmosphere.

The drogue path during the flood tide studies was out the mouth of Crum Creek past Stations 2, 3, 6, 7, 10, and 11, and then into Darby Creek towards Station 14 [Table 5(*a*)]. At that time the drogue then reversed direction with a change in tide and moved downriver toward Station 30.

For the ebb tide study, the drogue followed a path from Stations 22, 23, 24, 25, 26, and 28 towards Station 30 [Table 5(*b*)].

Fig. 7 presents the persistence of chlorine in the Delaware River for flood and ebb tides. Chlorine apparently persists in the river system for about 2 hr after it is initially discharged. It requires an excess of 1 hr for chlorine concentration to fall to a level of approx 0.01 mg/l during both flood and ebb tides. Fig. 8 shows that dilution, as calculated from temperature changes, proceeds more rapidly during ebb tide. The difference in the rate of dilution between the two tide conditions is probably related to the higher velocities that occur in the region of the Eddystone Station during ebb tide.

The rate of chlorine disappearance in the Delaware River system is presented in Fig. 9. The theoretical concentrations were calculated based on dilution of the discharge crib waters using the dilution factors presented in Table 5. These concentrations represent the chlorine concentrations to be expected if dilution were the only mechanism acting to reduce chlorine residual concentrations.

Rate constants were calculated from the slopes in Fig. 9. Rate constants

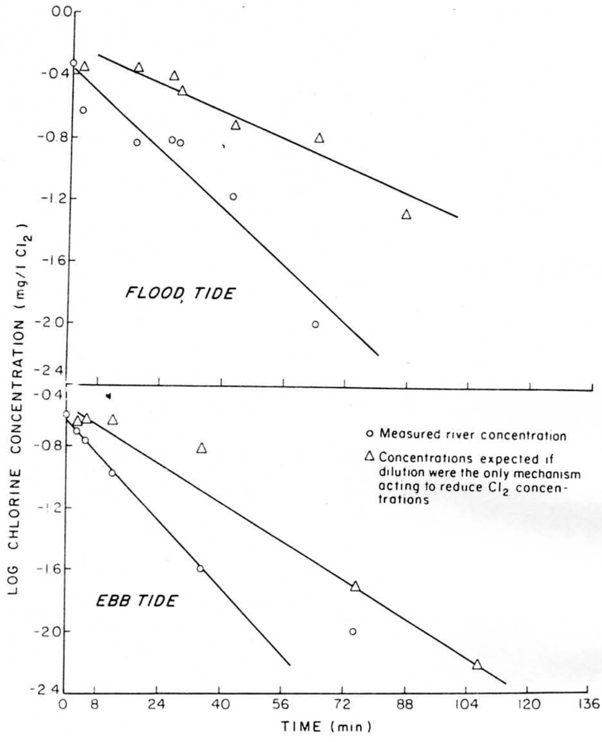

FIG. 9.—Chlorine Persistence in Delaware River on October 9, 1973

were determined for both measured chlorine concentrations and calculated concentrations based entirely on dilution. These rate constants are presented in Table 6. The rate constants show that approx 48% of in-river chlorine disappearance during flood tide and approx 60% during ebb tide is attributable to dilution. The in-river chlorine demand rate constant is approx -1.1×10^{-2}/min–-1.6×10^{-2}/min (roughly 10 times the rate constant determined from laboratory demand studies). It is not surprising to find that the chlorine disappearance in the river is somewhat faster than predicted based on laboratory chlorine demand studies as noted in another section of this paper. There are a number of factors that would cause chlorine to disappear faster in the field than under laboratory conditions.

Approximate dilution ratios are given in Table 7. The 40:1 dilution found for sample 30 occurred approx 2 miles downstream from the plant. A potentially significant area of the river could be adversely affected by excessive concentrations of chlorine if dilution were the only mechanism available for dissipation of the residual chlorine in the plant discharge. The area of chlorine influence during flood tide is less clearly defined, but it is apparent that total chlorine concentrations in excess of 0.010 mg/l are carried into and up Darby Creek.

TABLE 6.—Rate of Chlorine Disappearance in Delaware River System, October 9, 1973

Tide conditions (1)	Rate constant, *k*, based on measured chlorine residual, per minute (2)	Rate constant, *k*, based on concentrations if dilution were only factor influencing chlorine disappearance, per minute (3)
Flood	-2.3×10^{-2}	-1.1×10^{-2}
Ebb	-2.7×10^{-2}	-1.6×10^{-2}

TABLE 7.—Dilution of Thermal Discharge Plume: Drogue Study, October 9, 1973

Sample number (1)	Elapsed time, in minutes (2)	Percentage of dilution (3)	Dilution ratio, river:effluent (4)
		(*a*) Flood Tide Conditions	
8	28	33.3	1:2
10	42	60.0	3:2
11	64	66.7	2:1
16	180	94.7	18:1
19	194	98.7	75:1
		(*b*) Ebb Tide Conditions	
26	35	40.0	2:3
28	75	92.9	13:1
30	107	97.6	40:1

It is possible that the chlorine concentrations found in the Delaware River near the Eddystone Station could, to some extent, arise from the chlorination of domestic wastewaters that are discharged to this area of the river. The apparently anomalous data point for the mouth of Darby Creek could potentially be due to chlorine from other sources. However, the local wastewater treatment plant operators indicated that no chlorine was being used on the day of the field study, and therefore it appears that the data point may arise from interferences or errors in the analytical procedure.

The dilution ratio at the mouth of Darby Creek 3 hr after the initial discharge was 18:1. No information was collected to determine how far across the Delaware River the thermal plume extended. However, temperature profiles were taken at several points during ebb tide to determine the vertical extent of heated discharge. The discharge water from Crum Creek flows over the colder Delaware River water when the two systems first meet. But as the discharge waters move downstream, mixing results in lower surface temperatures but increases in temperatures at depths up to 5 m below the surface. These profiles show that except in the region where the thermal plume touches the shore, there would be a minimum of interaction between the chlorine in the thermal plume and benthic organisms.

There are two principle mechanisms by which chlorine may be dissipated in a thermal discharge plume. One of these is dilution, which has been examined previously. The other is by physical loss or chemical reactivity. While chlorine compounds have some volatility, their loss to the atmosphere under the conditions that exist at the Eddystone discharge plume would be expected to be relatively small. Another possible means by which chlorine can be lost is by interaction with sunlight. The relatively high turbidity of the Delaware River water would greatly reduce sunlight penetration and therefore minimize this means of loss.

The other principle mechanism of chlorine loss is chemical reactivity, which is manifested in the form of chlorine demand where the chlorine or chloramino compounds react with other chemical constituents in the water. Examination of the data taken in the October 9 studies shows that the primary mode of chlorine dissipation in the thermal discharge plume was dilution rather than physical or chemical reactivity. The chlorine in the discharge plume is present in the form of chloramines that are highly persistent, based on the drogue and laboratory demand studies.

Review

This study has shown that chlorine added to the Eddystone Station cooling water for condenser fouling control is present in the discharge during periods of chlorination at concentrations on the order of 0.2 mg/l–0.5 mg/l of Cl_2. Based on the chlorination practice used at that time, chlorine concentrations of this magnitude would be expected in the discharge for approx 4 hr each day. Laboratory and field studies of chlorine persistence show that the chlorine in the discharges is in the chloramine form and that this form of chlorine persists for a period of about an hour after discharge at concentrations above 0.01 mg/l under the conditions of the study on October 8, 1973.

As of this writing it is difficult to judge the significance of these chlorine residuals. The U.S. Environmental Protection Agency (EPA) (5) has recently established a maximum safe level of chlorine of 10 μg/l for freshwater organisms other than salmonid fish and all marine organisms. It is presumed that these values are applicable for extended exposure conditions. Brungs (2) reported that aquatic organisms may tolerate short term exposure to higher levels of chlorine than the concentrations that have adverse chronic effects. According to the EPA (5), Basch and Truchan have shown that repeated daily exposures at these levels will have an adverse effect on aquatic life.

Mattice and Zittel (4) conducted a review on chlorine toxicity to aquatic organisms in association with cooling waters used at electric generating stations. They found an apparent concentration threshold in which increased time of exposure had no additional toxicity in freshwater of 0.003 mg/l. For salt water, the safe chronic exposure concentration of 0.02 mg/l was found. For the concentration of chlorine ranges found in this study they report that freshwater organisms would show no effect for exposures to chlorine at 0.1 mg/l for 30 min or less. Several hour exposures should show no effect in freshwaters for concentrations of 0.01 mg/l or less. In marine waters the safe period of exposure for 0.1 mg/l chlorine is on the order of 3 min–4 min.

At the time of the study, specific conductance data showed that the Delaware River waters in the region of Eddystone were fresh and therefore the critical time of exposure for the concentrations of chlorine found in the thermal discharge plume from the Eddystone station is on the order of several hours. Because of the intermittent nature of the discharge and the dilution and decay of chlorine in the thermal discharge plume, it may be concluded that the use of chlorine for condenser fouling control at the Eddystone Station in October, 1973, was not having an adverse effect on fish or other aquatic life in the Delaware River in association with organisms entrained in the thermal discharge plume. Further, no significant adverse effects would be expected on fish populations that swim into the plume. It should be noted that fish may show a significant avoidance reaction to chlorine and therefore tend to minimize exposure in situations such as the Delaware River estuary, where the total volume of water affected by the thermal discharge is small compared to the total volume of water in that area. Some of the organisms that experience condenser passage, however, would be killed by the chlorine because of the much higher concentrations present in the circulating water system.

From the point of view of the design of the cooling water discharge system, the situation at Eddystone Station of the Philadelphia Electric Company represents something approaching the worst case. An examined by Lee and Martin (3), much higher degrees of dilution can readily be attained by utilizing an offshore, high velocity, jet discharge. The expansion of the Eddystone Station will involve construction of a cooling water discharge pipe to essentially the middle of the Delaware River where the cooling water from Units 1 through 4 will be discharged. It is expected that no significant adverse effects on aquatic life present in the region of the discharge should be experienced due to the use of chlorine for condenser fouling control at the expanded Eddystone Station.

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Appendix.—References

1. "Adding 5,000 lbs/day of Dissolved Oxygen to the Delaware River at the Eddystone Generating Station," Philadelphia Electric Company, *Report to Delaware River Basin Commission,* Apr., 1974.

14777 CHLORINE IN WATER FROM ELECTRIC STATION

KEY WORDS: **Chlorine; Cooling water; Delaware Basin; Fish conservation;** Plumes; Powerplants; **Thermal pollution;** Thermal water; **Toxicity**

ABSTRACT: A study of the persistence of chlorine in the cooling water discharged to the Delaware River estuary by the Philadelphia Electric Company Eddystone Generating Station showed that potentially toxic levels of chlorine were present 1 hr to 2 hr after discharge for organisms (plankton) entrained in the thermal discharge plume. Based on consideration of chlorine persistence-time of exposure relationships that exist in cooling water thermal plumes, little or no toxicity would be expected to fish in the Delaware River due to the use of chlorine for condenser fouling control at the Eddystone Electric Generating Station.

REFERENCE: Lee, G. Fred, "Persistence of Chlorine in Cooling Water from Electric Generating Station," *Journal of the Environmental Engineering Division*, ASCE, Vol. 105, No. EE4, **Proc. Paper 14777**, August, 1979, pp. 757-773