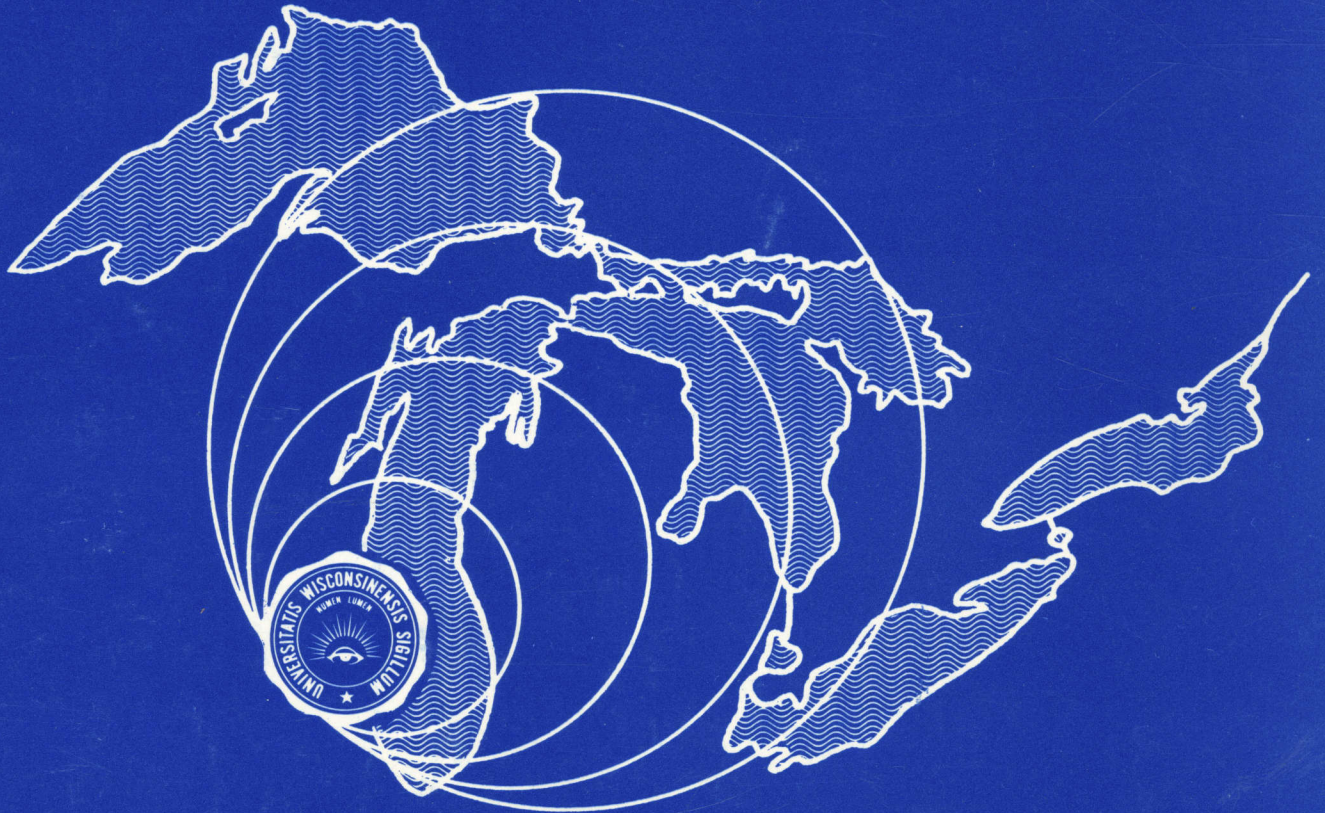
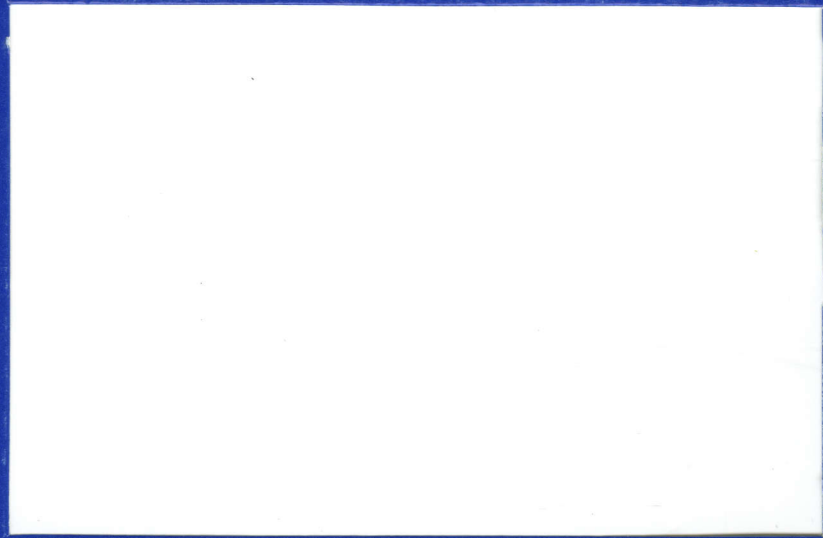


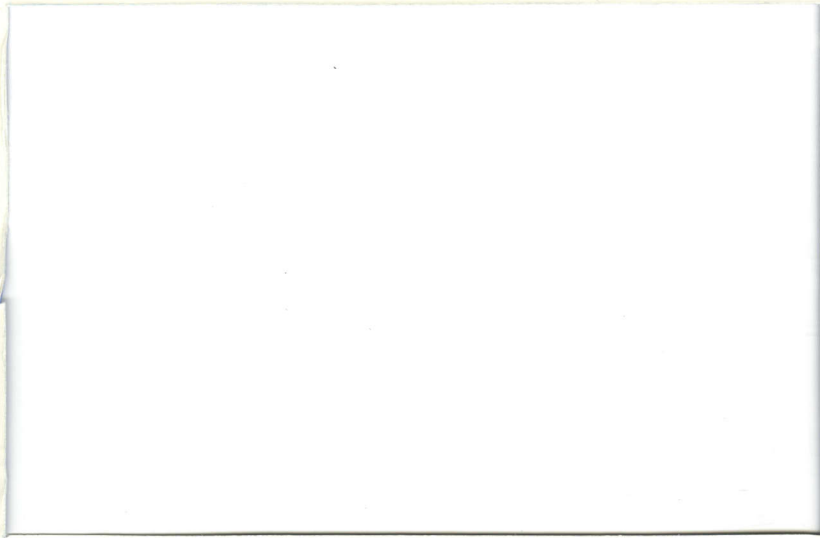
THE UNIVERSITY OF WISCONSIN—MILWAUKEE

CENTER
FOR
GREAT LAKES STUDIES

Brooks, Arthur



MILWAUKEE, WISCONSIN 53201 U.S.A.



Semi-Annual Research Progress Report

INVESTIGATIONS
OF THE EFFECTS OF CHLORINATING POWER PLANT
COOLING WATER ON THE BIOTA
OF LAKE MICHIGAN

October 1974 - May 1975

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Since the first semi-annual progress report was issued eight months ago, considerable progress has been made for completing the objectives of the research program. Advancements were made on all phases of the program from bioassay research to the field monitoring and modeling program. Each of these phases will be briefly discussed below.

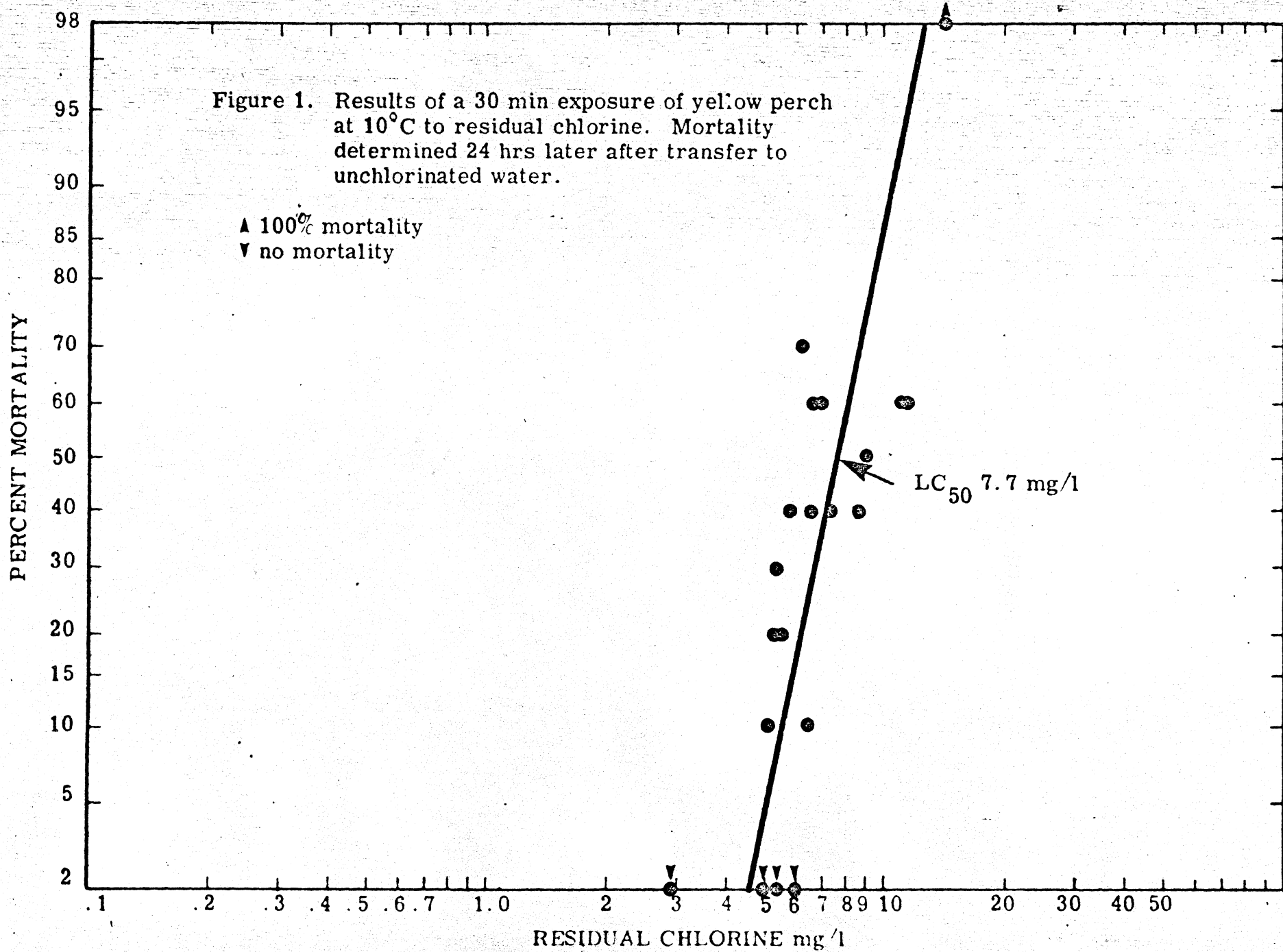
FISH STUDIES

Fullscale fish bioassays began in January 1975 and are now well underway. Work on yellow perch has been completed at all three test temperatures: 10°, 15° and 20°C. The 10°C studies on rainbow trout, coho salmon, spottail shiner and alewife have also been completed. The 15° and 20°C tests on these species are now starting with coho salmon currently being tested at 15°C.

RESULTS

All results reported are for 30 m exposure to the test concentration followed by transfer for 24 hours or 48 hours to unchlorinated water.

Figures 1-4 show the results of the perch bioassays. Young-of-the-year perch ranging in size from 60-120 mm were used at all three test temperatures. Figure 1 shows the results of the 10° bioassay. Fish were exposed to concentrations ranging from 3.0 to 15 mg/l. At 10° they were found to be highly resistant to chlorine. No mortality was found below 5 mg/l and it took 12-15 mg/l to affect 100% mortality. The LC_{50} was as determined by an eye fit curve was 7.7 mg/l. At 15°C perch were more sensitive to chlorine than at

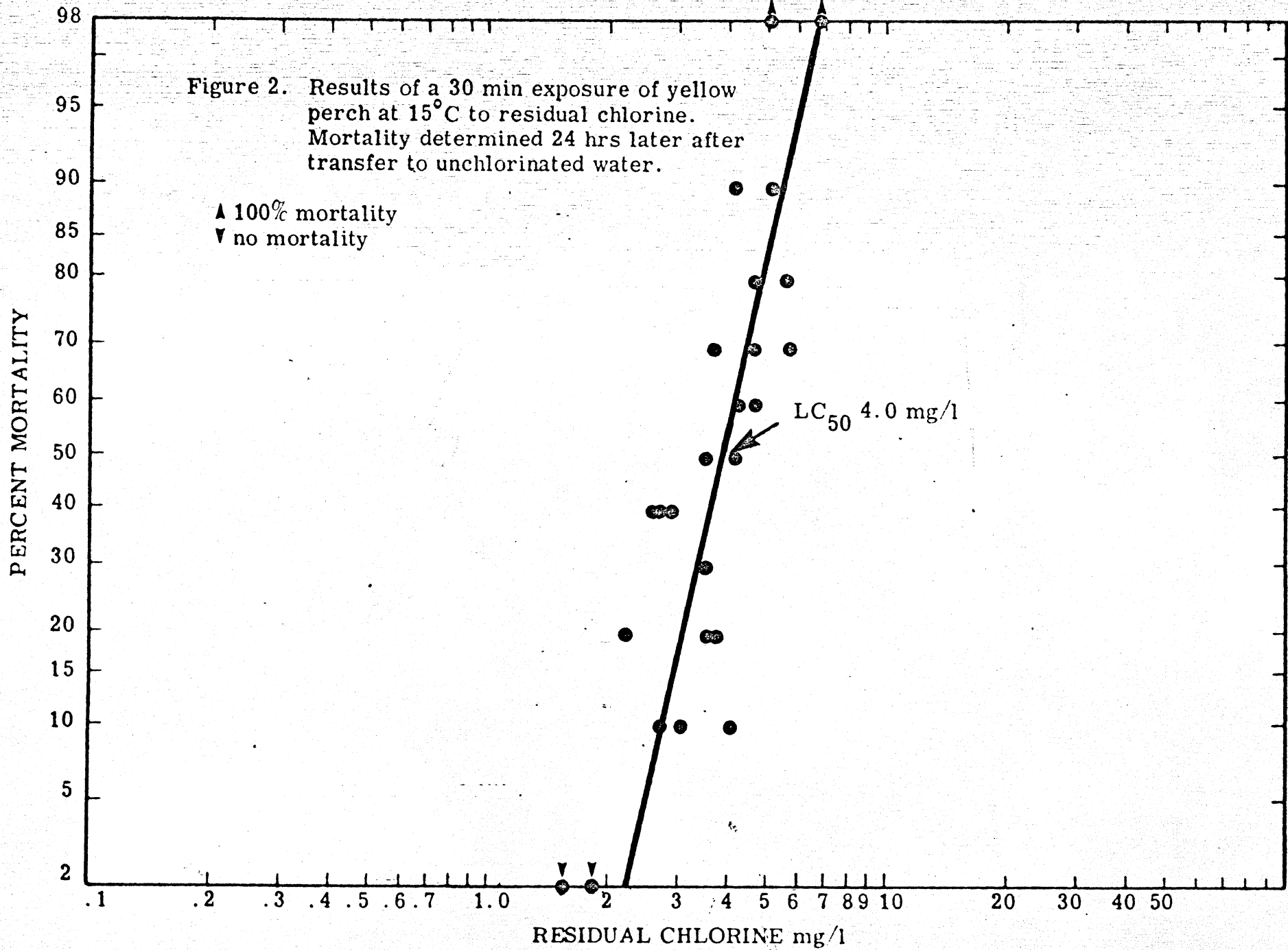


10°C. Concentrations tested ranged from 1.9 mg/l to 7.1 mg/l. No mortality was seen below 2.0 mg/l and the LC₅₀ was 4.0 mg/l (Figure 2). At 20°C perch were much more sensitive to chlorine than at 10°C or 15°C. Fish exposed to concentrations ranging from 0.5 mg/l to 4.6 mg/l had an LC₅₀ of only 1.1 mg/l (Figure 3). No mortality was seen below 0.5 mg/l and mortality was complete above 2 mg/l. Figure 4 compares the results of the 10°, 15° and 20°C perch bioassays. The trend towards increased sensitivity at higher temperatures is obvious. It was also found that mortalities were delayed at 20°C. Consequently, the observation period after the chlorine exposure was increased to 48 hours to properly assess this protracted mortality.

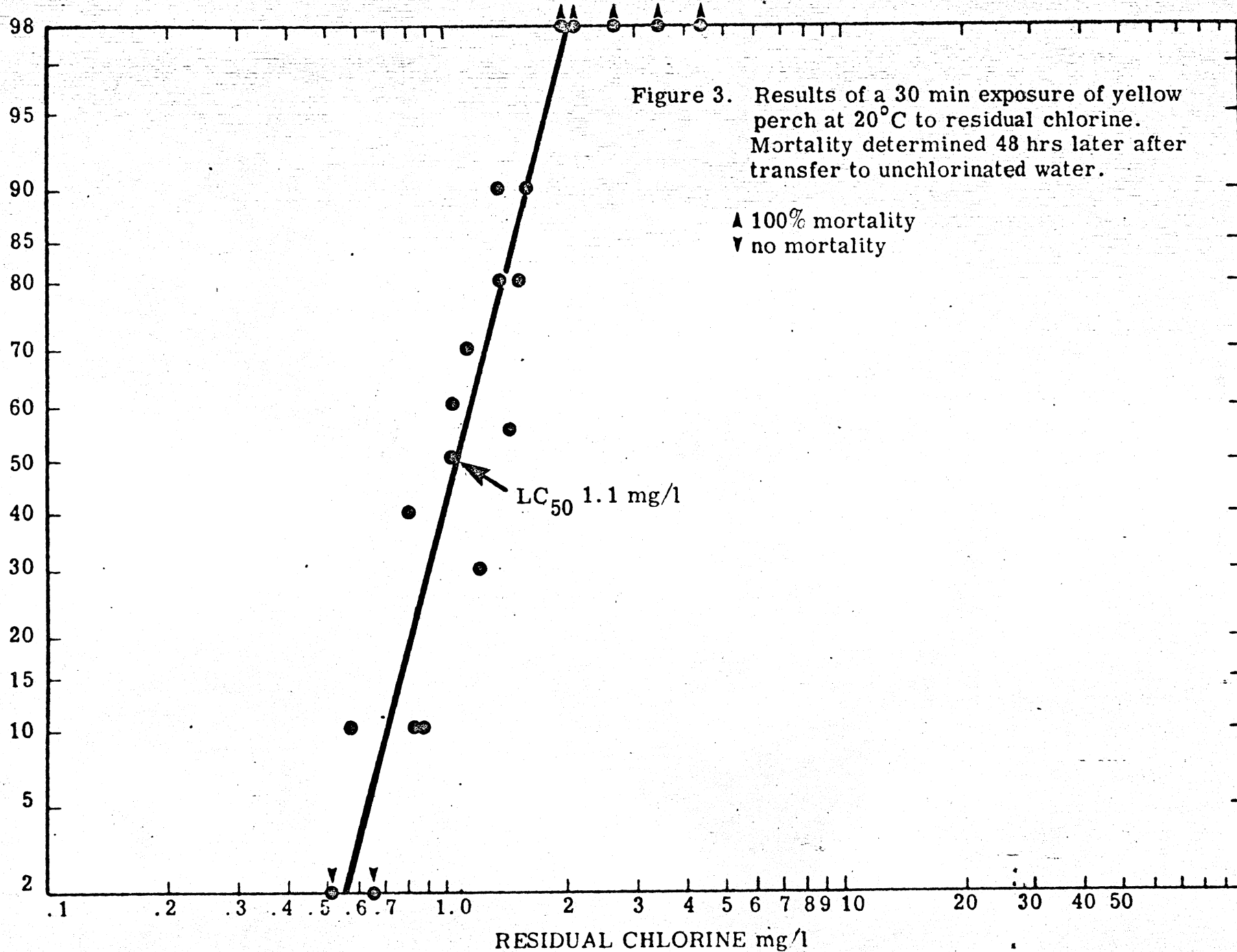
Fingerling coho salmon 13 - 17 cm proved much more sensitive to chlorine exposure at 10°C than did yellow perch at the same temperature. The LC₅₀ was 1.1 mg/l and the slope of the toxicity curve was very steep (Figure 5). Little or no mortality occurred at <1.0 mg/l while 100% mortality was seen at 1.5 mg/l.

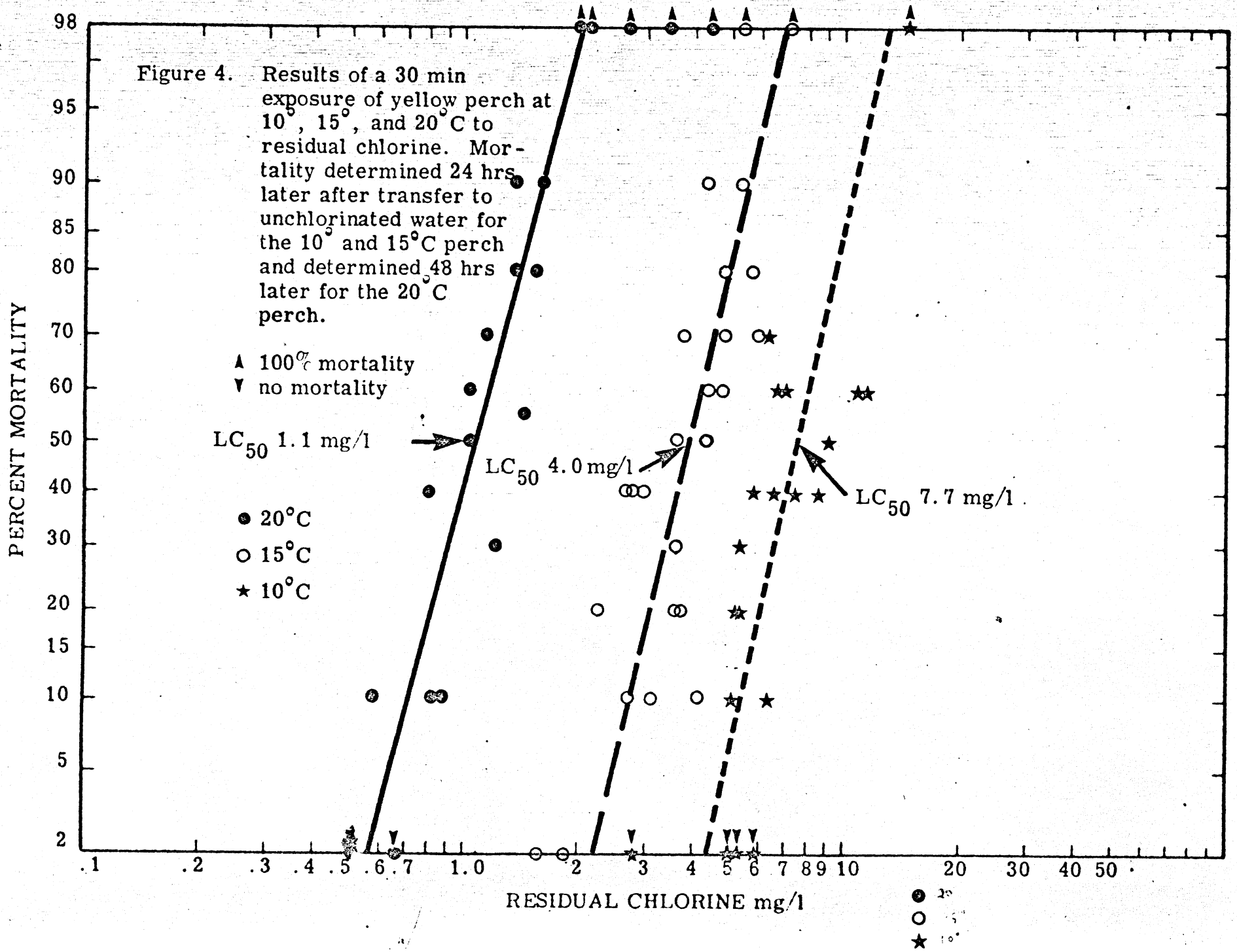
Yearling rainbow trout 23 - 28 cm exposed to chlorine reacted in a manner similar to the coho salmon. The LC₅₀ was 2.0 mg/l and the curve was even steeper than in the salmon (Figure 6). No mortality was seen below 1.6 mg/l and mortality was complete above 2.2 mg/l. In both the trout and salmon 10°C tests, mortality was complete within the first twenty-four hours after their exposure to chlorine.

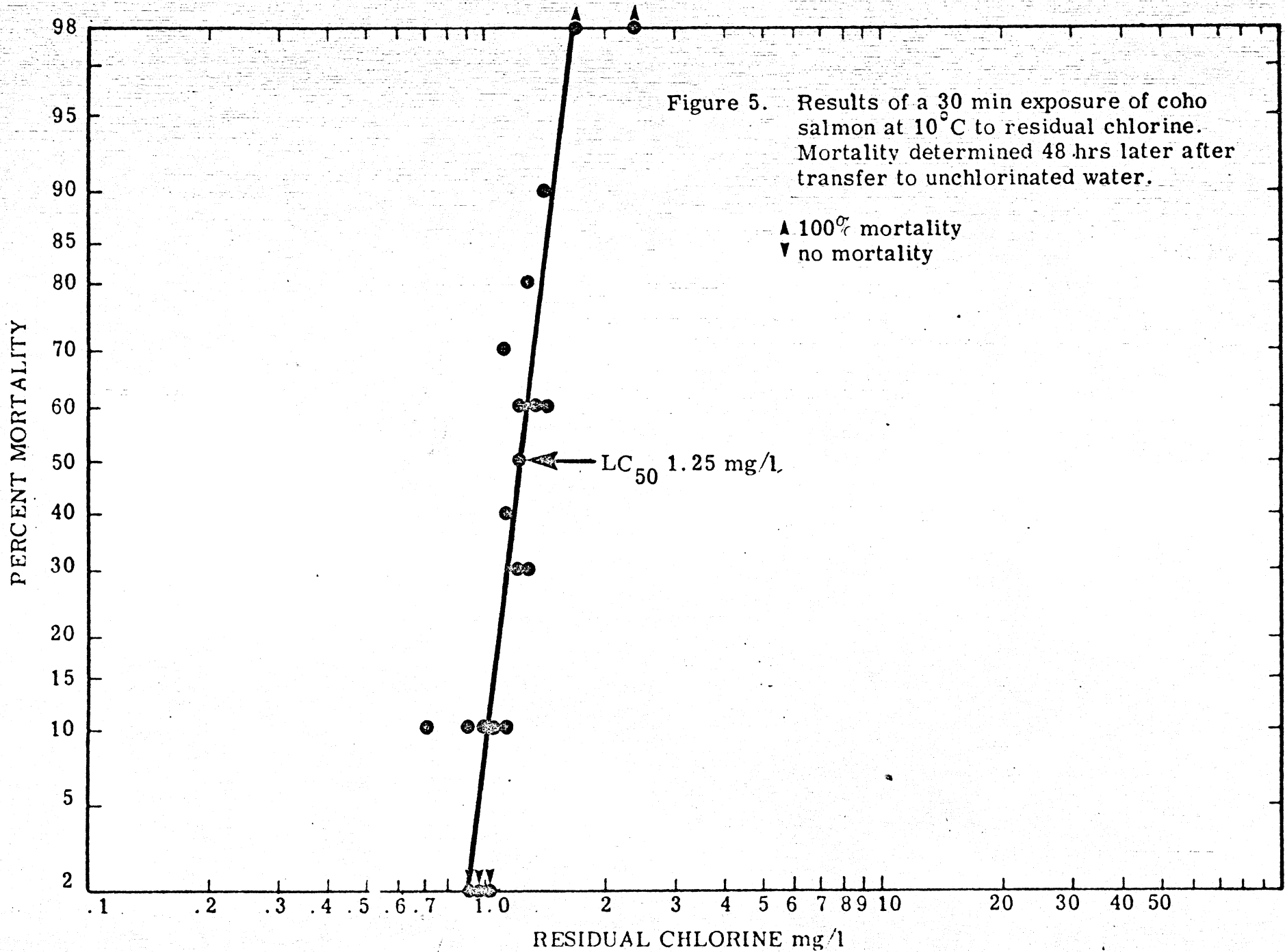
Alewives (80 - 120 mm) at 10°C were intermediate to the salmonids and yellow perch in their response to chlorine. Their LC₅₀ was 2.2 mg/l with no mortality <1 mg/l and complete mortality at >4 mg/l

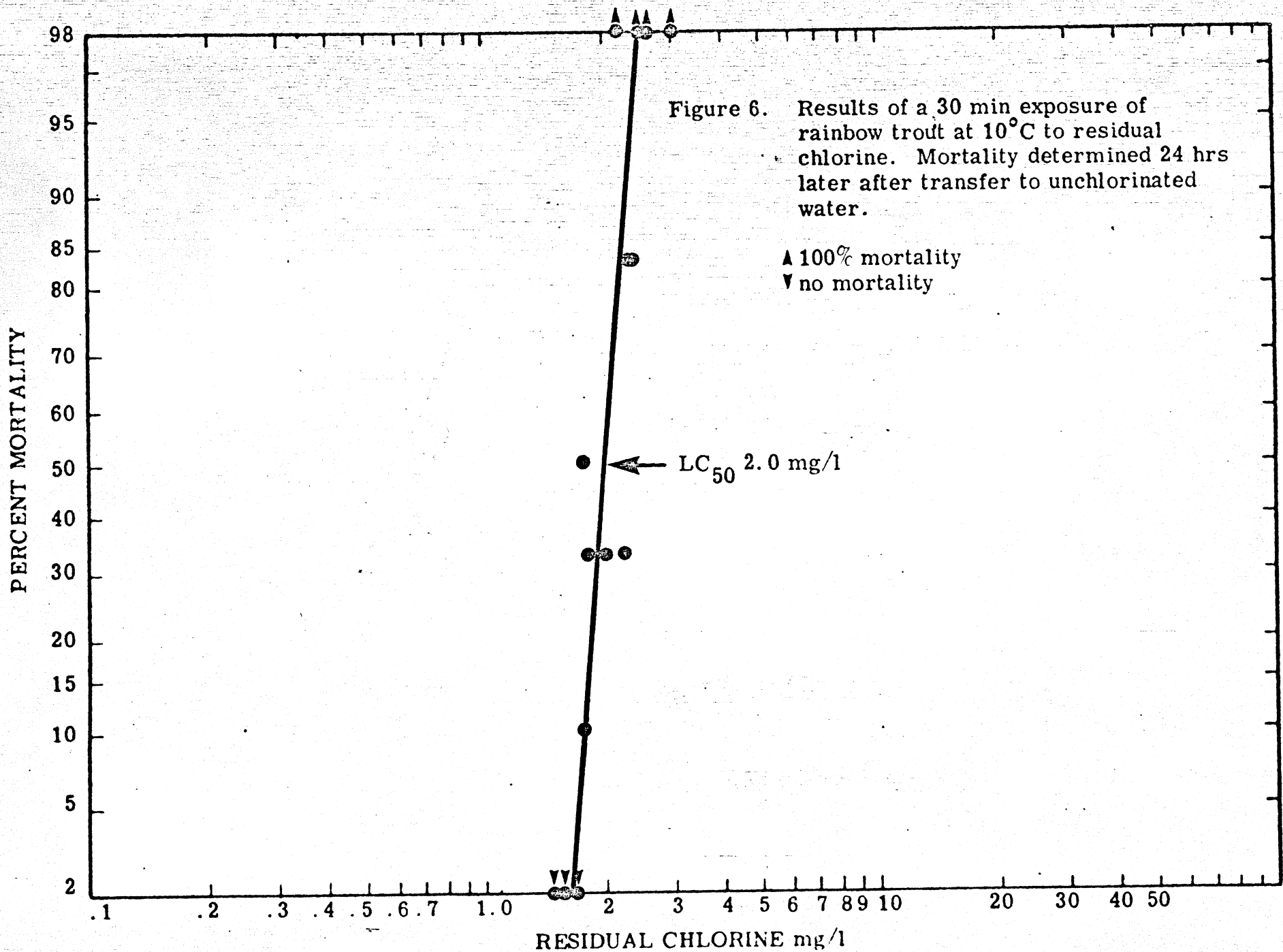


PERCENT MORTALITY





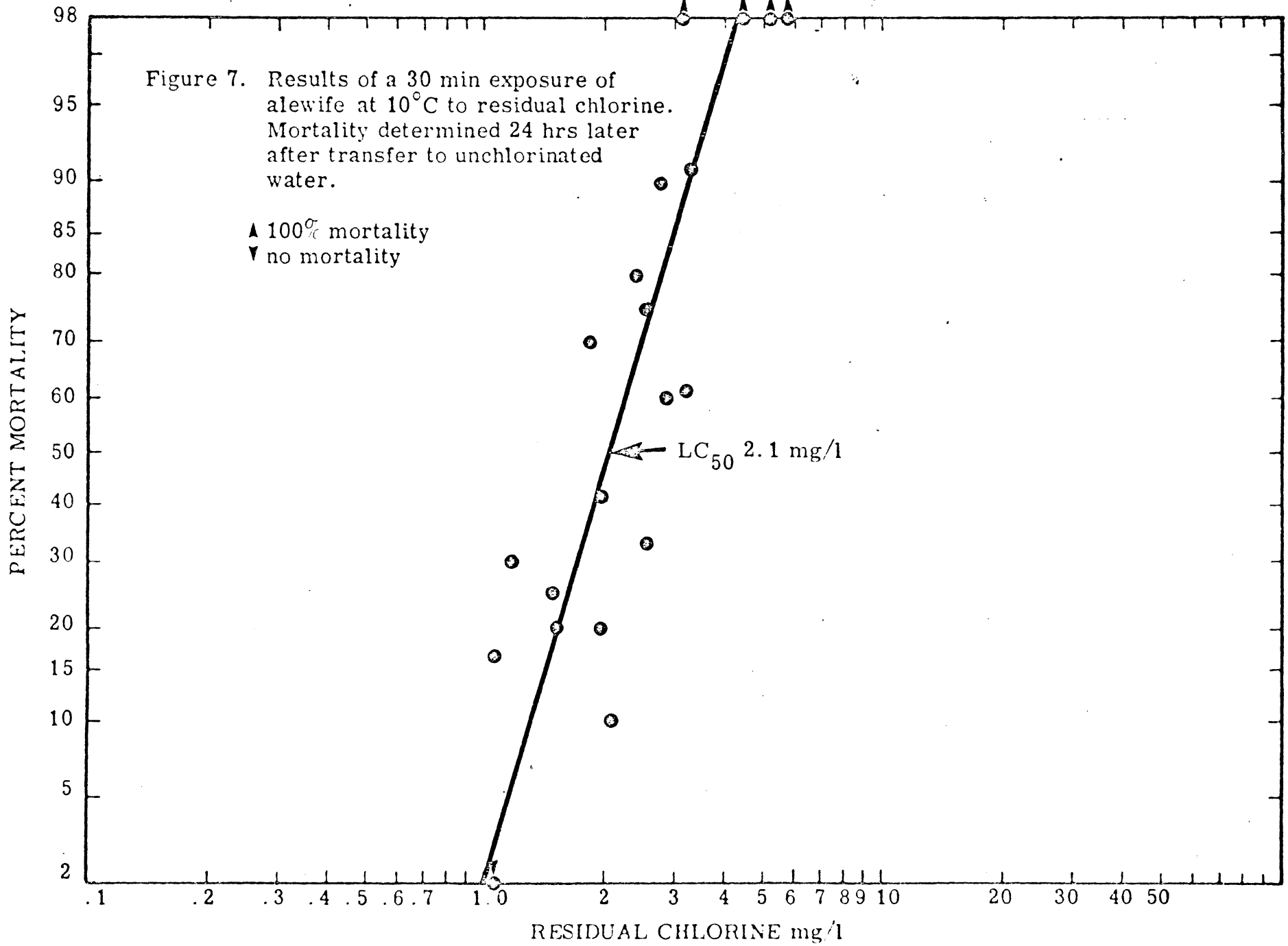


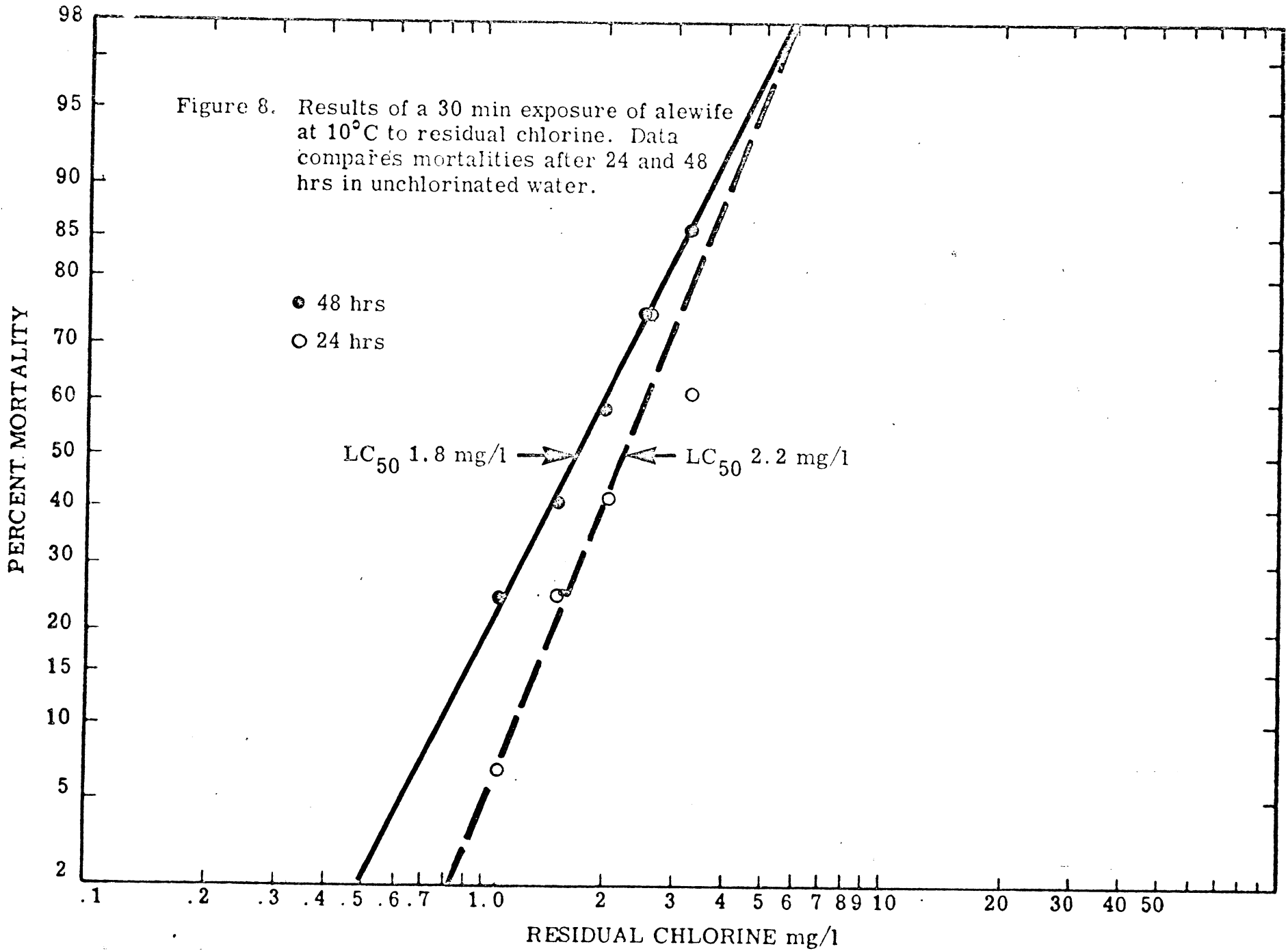


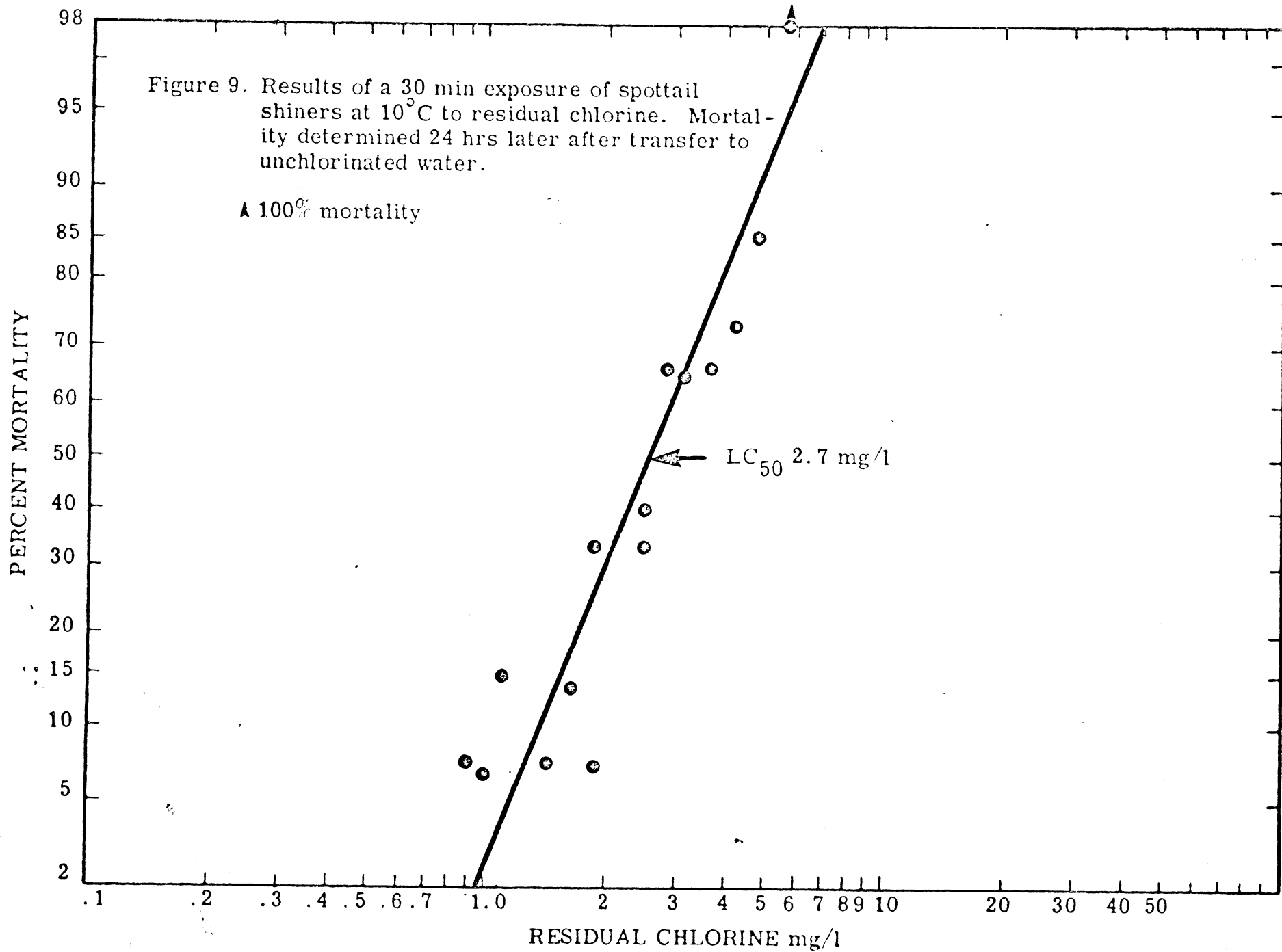
(Figure 7). Some delayed mortality did occur. Figure 8 compares for a single bioassay the mortalities after twenty-four and forty-eight hours. It can be seen that the forty-eight-hour curve is shifted slightly to the left lowering the LC_{50} from 2.2 to 1.8 mg/l. This indicates that the LC_{50} determined from Figure 7 is probably slightly inflated.

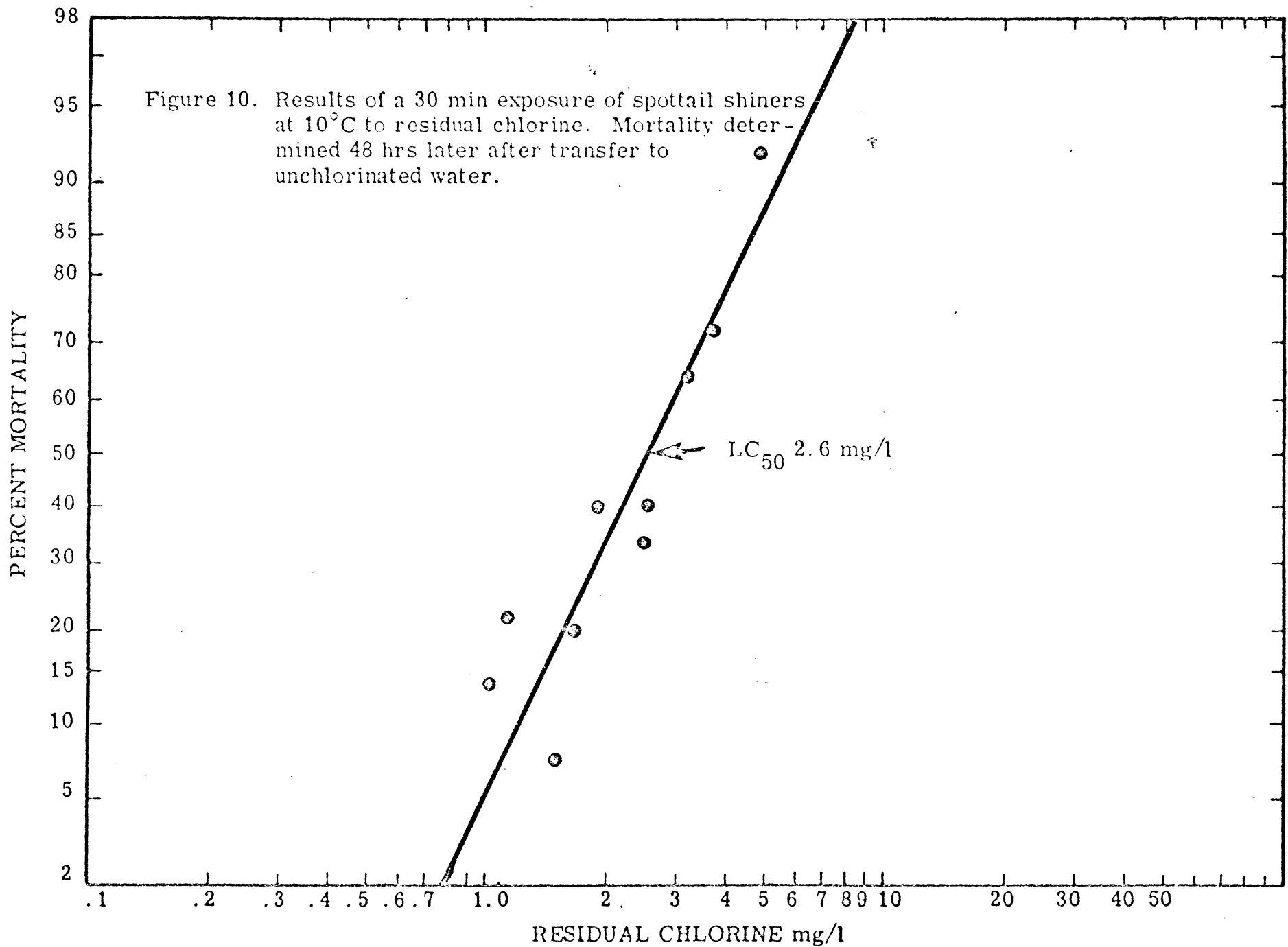
The reactions of 60-80 mm spottail shiners at 10°C to chlorine paralleled those of the 10° alewives. Like the alewives, little mortality was seen at <1.0 mg/l (Figure 9). At higher concentrations, however, the spottail were somewhat more resistant, requiring 5.8 mg/l for a complete kill. As a result of this increased resistance at higher temperatures, the slope of line was not as steep compared to the alewife curve. This resulted in a somewhat higher (2.7 mg/l) LC_{50} . When mortality data based on forty-eight-hour tests was plotted, the resultant LC_{50} was almost identical to the 24 LC_{50} , indicating little mortality after the initial twenty-four hours (Figure 10).

All species tested reacted similarly when exposed to chlorine. In concentrations too low to cause mortality the fish behaved quite normally during their 30 m exposure. At higher concentrations they typically exhibited exaggerated respiratory movements and occasionally a coughing response was seen. They frequently swam to the surface and gulped for air. Although their movements were generally random, they appeared to be seeking a way to escape the chlorine. At lethal concentrations, the above-mentioned pattern was seen,









followed by the fish sinking to the bottom and eventually losing their equilibrium. Throughout the course of their exposure, fish at high concentrations were very lethargic in their actions with little violent swimming being seen. After being transferred to the recovery tanks this lethargic behavior continued for 1 - 10 hours depending on the concentration they had been exposed to. Only at the highest concentrations did mortalities occur during the 30-minute exposure period. Most of the mortalities occurred during the first two hours in the recovery tanks. After four hours in the recovery tanks, 90-100% of the eventual mortality had already occurred. The 20°C perch and the 10°C alewives were exceptions to this trend. For these fish, little or no initial mortality was seen. Mortality largely manifested itself during hours 2 - 10 with some additional mortality scattered throughout the 48-hour test period.

Bioassay work with two species of Lake Michigan copepods has been completed and reported in a Master's thesis by Mr. David L. Latimer entitled, "The toxicity of 30-minute exposures of residual chlorine to the copepods Limnocalanus macrurus and Cyclops bicuspidatus thomasi. Complete copies of this thesis were mailed to each of you several weeks ago. A manuscript with a similar title has also been submitted for publication. A summation of this thesis along with appropriate figures and a table illustrating the results of this research are included below. (Figs. 11-13; Tbl. 1)

" 1) The toxicity of residual chlorine in 30-minute exposures at various temperatures to the freshwater copepods Cyclops bicuspidatus thomasi and Limnocalanus macrurus has been studied.

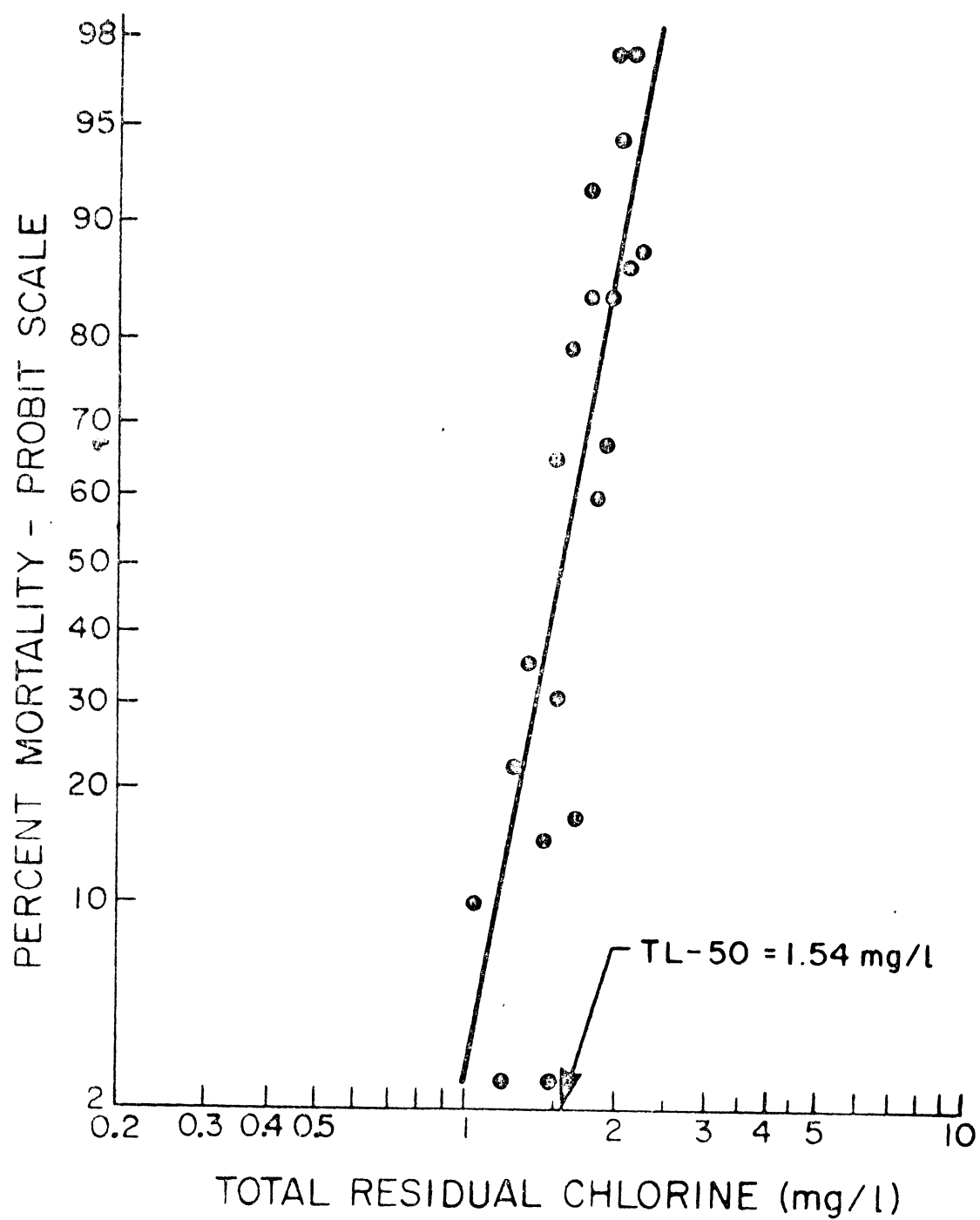


Figure 11. Dose-mortality plot for a 30-minute exposure of residual chlorine to Limnocalanus macrurus at 5°C.

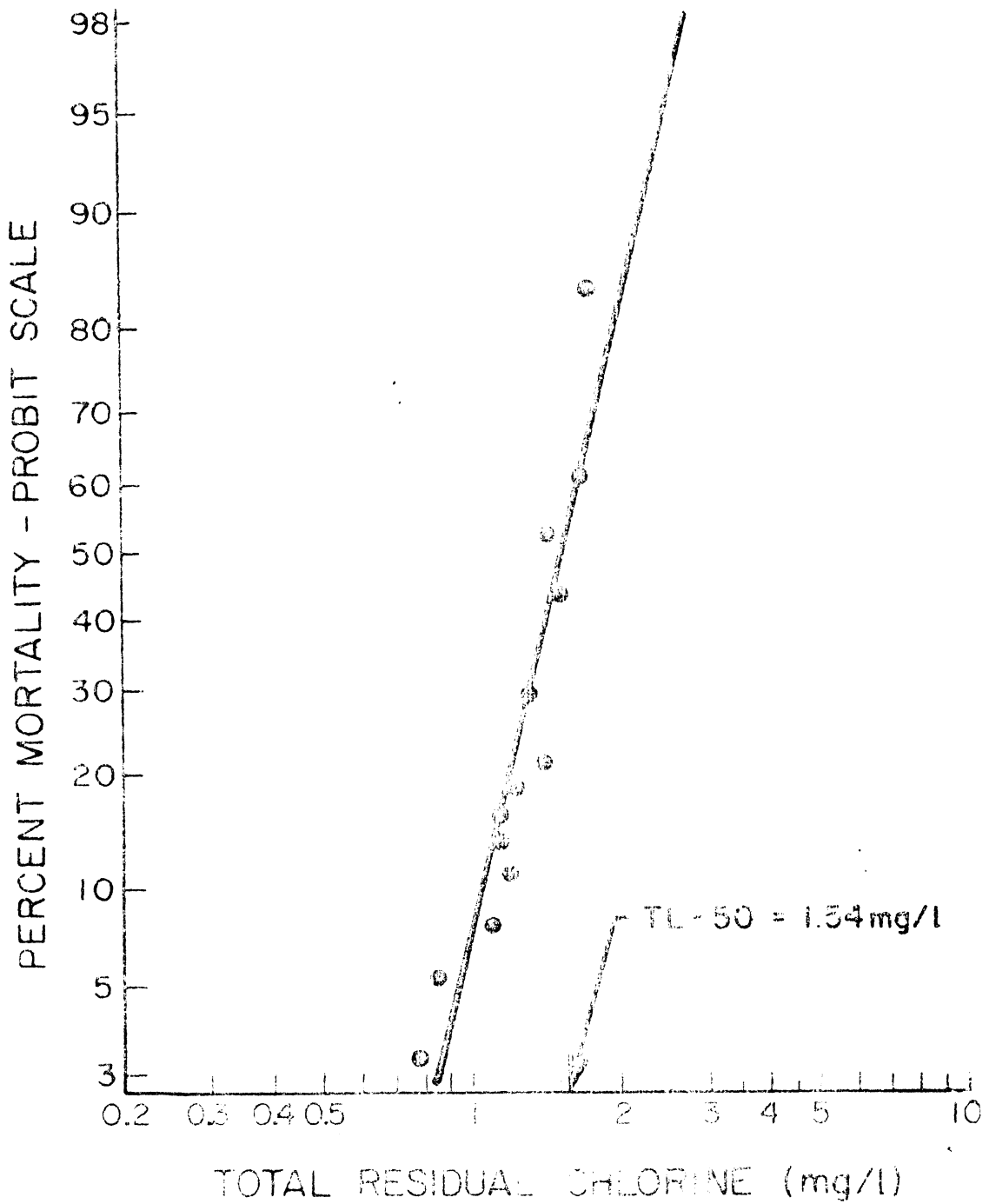


Figure 12. Dose-mortality plot for a 30-minute exposure of residual chlorine to *Limnocalanus macrurus* at 10°C.

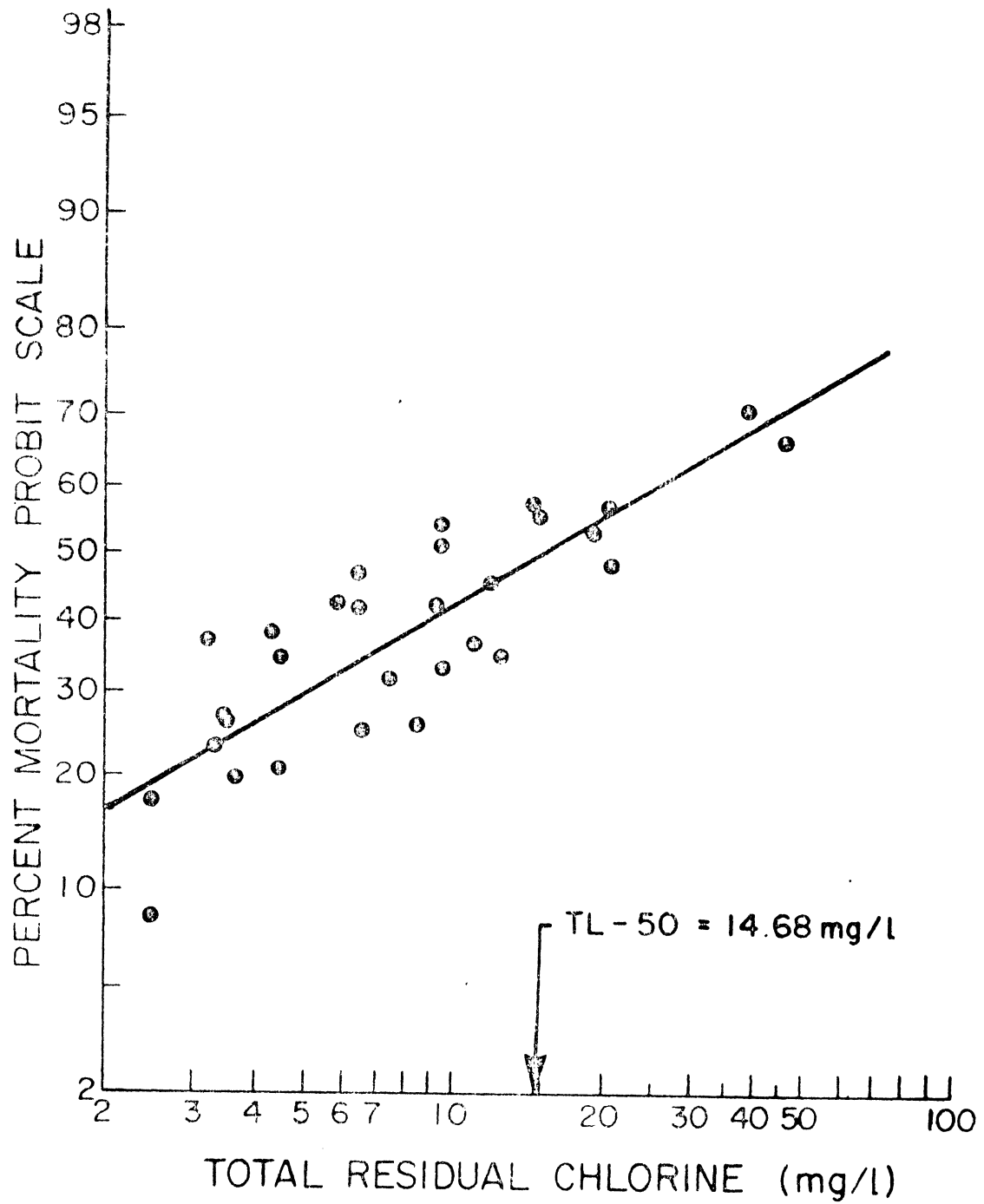


Figure 13. Dose-mortality plot for a 30-minute exposure of residual chlorine to *Cyclops bicuspidatus thomasi* at 10°C.

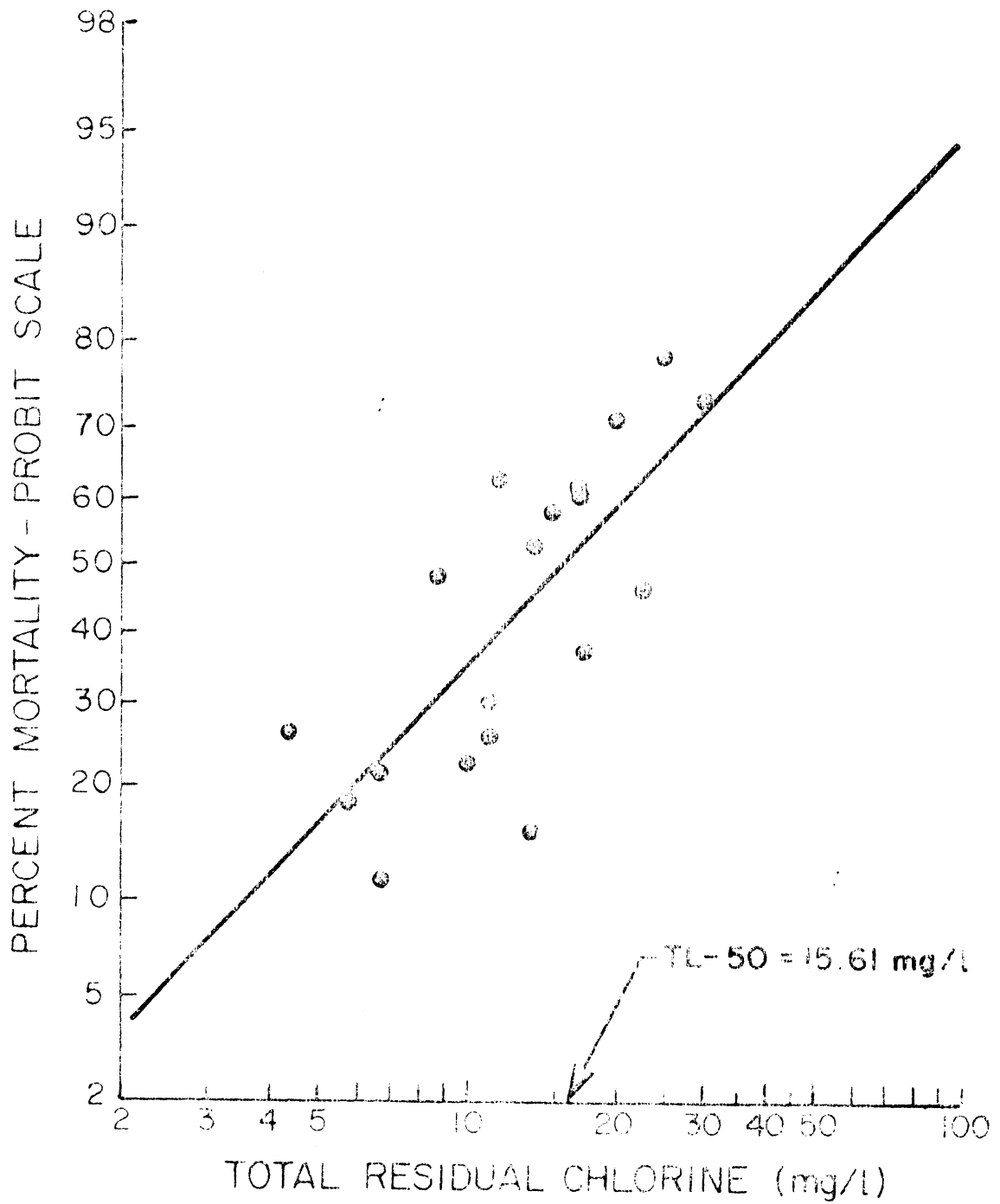


Figure 14. Dose-mortality plot for a 30-minute exposure of residual chlorine to *Cyclops bicuspidatus thomasi* at 15°C.

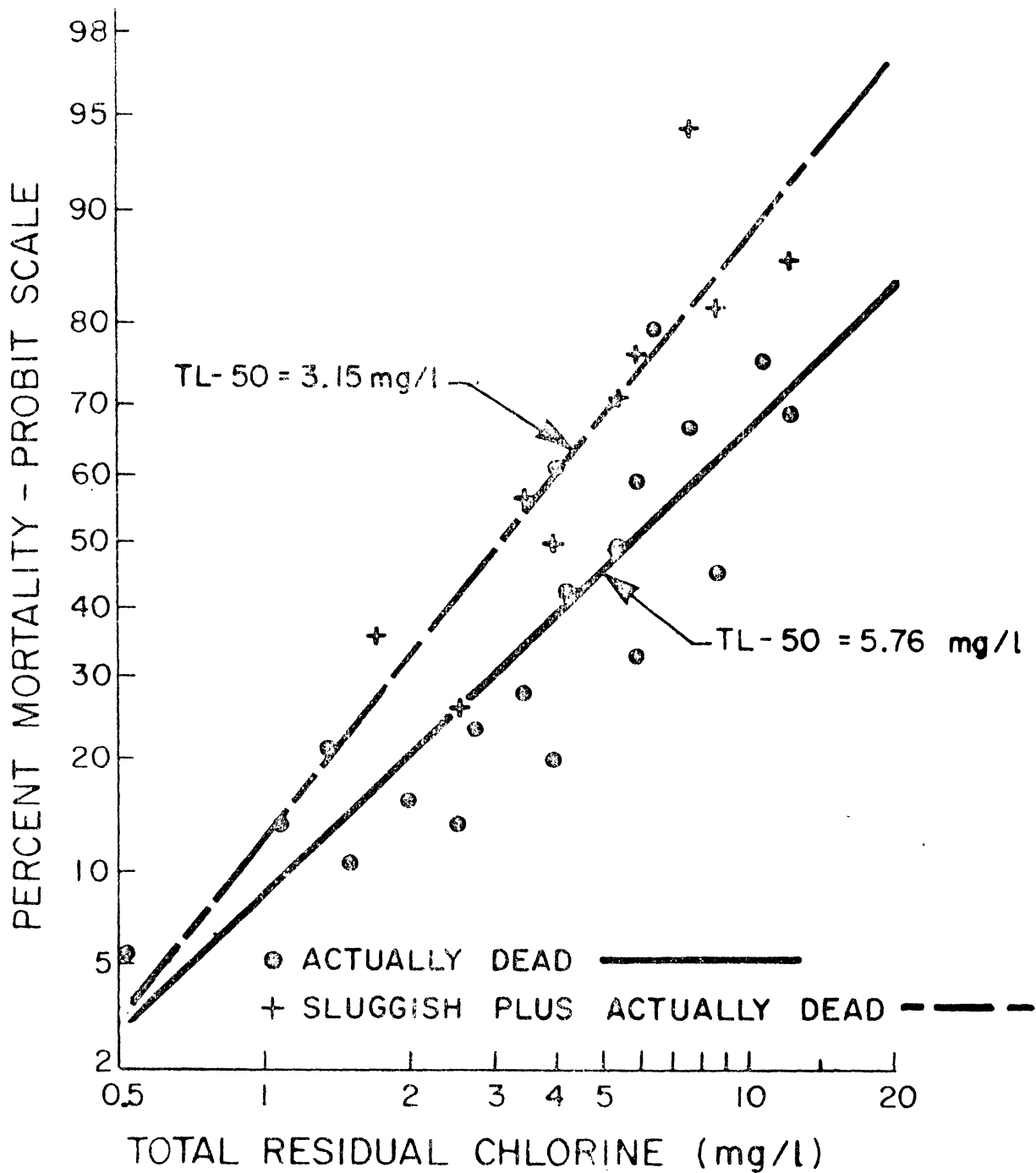


Figure 15. Dose-mortality plot for a 30-minute exposure of residual chlorine to Cyclops bicuspidatus thomasi at 20°C.

Table 1. Statistical results from bioassays in which Limnocalanus and Cyclops were exposed to residual chlorine for 30 minutes at various temperatures.

Species	Temperature (°C)	TL-50 (ppm)	95% Confidence limits for TL-50 (ppm)	Regression slope (b)	95% Confidence limits for 'b'
<u>Cyclops</u>	10	14.08	12.89 -- 15.29	1.142	0.888 -- 1.388
"	15	15.61	13.96 -- 18.17	2.006	1.386 -- 2.627
"	20	5.75	5.10 -- 6.99	1.814	1.221 -- 2.407
"	20*	3.15	2.29 -- 3.67	2.367	1.810 -- 3.897
<u>Limnocalanus</u>	5	1.89	1.5 -- 2.55	7.010	4.881 -- 9.128
"	10	1.81	1.56 -- 1.98	10.41	6.187 -- 14.64

*Temperature controlled by circulating tap water in the bioassay.

2) The calculated TL_{50} values of residual chlorine for Cyclops at 10°, 15° and 20°C were 14.68, 15.61, and 5.76 mg/l, respectively.

3) For Limnocalanus at both 5° and 10°C, the calculated TL_{50} was 1.54 mg/l.

4) The toxicity of chlorine to Cyclops was observed to markedly increase when temperature was increased from 15° to 20°C.

5) TL_5 and TL_1 statistics were calculated as estimates of safe levels for 30-minute exposures to residual chlorine.

6) Based on the TL_5 values, the proposed safe levels for 30-minute exposures to Cyclops and Limnocalanus were 0.5 and 0.9 mg/l, respectively.

7) Based on the TL_1 values, the proposed safe levels for 30-minute exposures to Cyclops and Limnocalanus were 0.1 and 0.7 mg/l, respectively.

8) These predicted safe levels roughly coincide with the levels of residual chlorine typically found in power plant effluents."

Bioassay work with other invertebrate species and with Lake Michigan phytoplankton is proceeding satisfactorily at the present time. The results of the invertebrate bioassay work will be reported as a Master's dissertation within the next year. Most of the phytoplankton work should be completed by the end of this summer.

The results of last summer's field surveys and the cruises to the Oak Creek plant have been tabulated and are presented in Tables 2 through 10. Figures 16 through 24 illustrate the locations from which samples were obtained. The numbers on these figures correspond to the sample numbers listed in the accompanying tables.

Table 2. RESULTS OF CHLORINATION FIELD SURVEY: MITCHELL

August 6, 1974

Sample	Mini Ranger		Time	°C Temperature	mg/l Chlorine
	A	B			
1	250	303	0840	23.5	0.015
2	339	309	0845	23.7	0.000
3	412	334	0849	21.6	0.000
4	461	365	0852	22.4	0.000
5	239	304	0900	23.6	0.052
6	232	300	0905	23.6	0.037
7	223	403	0908	21.4	0.000
8	325	305	0910	22.7	0.091
9	391	255	0912	22.7	0.068
10	418	248	0913	22.6	0.020
11	479	274	0915	22.7	0.037
12	302	382	0917	22.7	0.032
13	300	503	0918	22.3	0.008
14	224	467	0920	21.7	0.000
15	290	366	0921	21.4	0.000
16	525	287	0923	22.5	0.064
17	472	246	0925	22.6	0.070
18	347	279	0926	25.0	0.024
19	171	536	0930	21.2	0.000
20	260	277	0932	21.5	0.066
21	458	446	0936	25.6	0.033
22	226	316	0938	25.0	0.053
23	217	474	0940	21.5	0.000
24	523	313	0942	22.2	0.042
25	523	300	0943	22.5	0.054
26	480	448	0946	22.4	0.026
27	366	613	0948	21.8	0.000
28	151	458	0950	21.3	0.000
29	221	316	0951	22.5	0.002
30	369	219	0952	23.5	0.000
31	524	258	0954	25.0	0.057
32	348	368	0956	23.5	0.000
33	298	477	0957	22.3	0.001
34	370	612	0959	21.3	0.000
35	390	520	1000	21.4	0.000
36	587	425	1002	22.2	0.003
37	812	538	1004	22.9	0.042
38	631	530	1006	23.0	0.038
39	552	612	1008	22.0	0.010
40	530	700	1009	21.8	0.000
41	565	809	1010	21.5	0.000
42	599	780	1012	21.5	0.000
43	674	649	1014	21.7	0.000
44	757	639	1015	22.0	0.000
45	794	667	1016	22.0	0.000
46	878	755	1018	22.2	0.002
47	865	739	1019	22.1	0.000
48	743	805	1021	22.0	0.000

Table 2. (continued) RESULTS OF CHLORINATION
FIELD SURVEY:

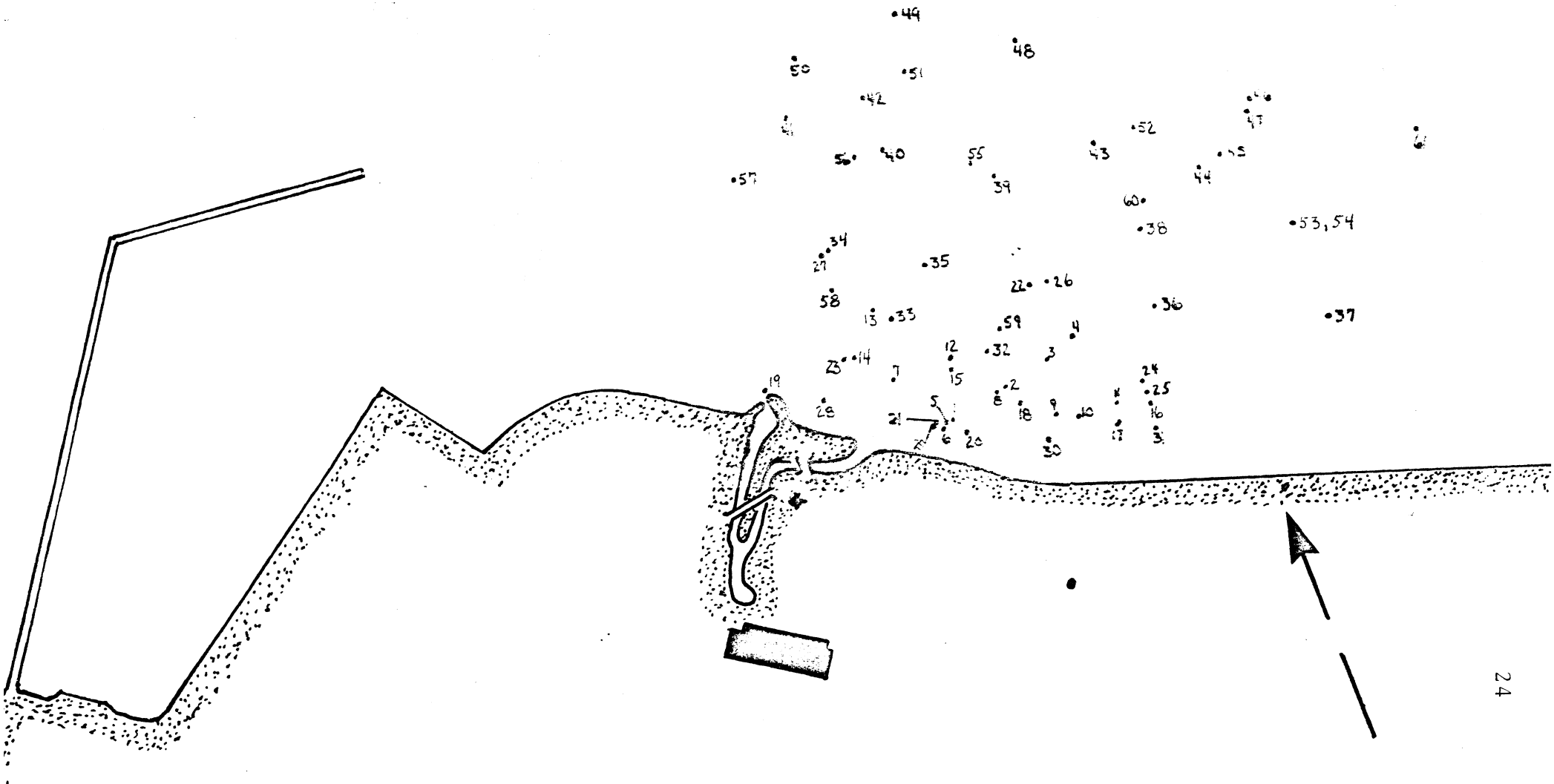
MITCHELL

August 6, 1974

Mini Ranger

Sample	Mini Ranger		Time	°C Temperature	mg/l Chlorine
	A	Yards B			
49	729	879	1022	21.7	0.000
50	651	877	1024	21.7	0.000
51	650	797	1025	21.5	0.000
52	730	677	1027	21.7	0.000
53	824	619	1030	22.0	0.000
54	824	619	1030	22.0	0.000
55	552	634	1033	22.0	0.000
56	511	707	1034	21.7	0.000
57	483	778	1035	21.5	0.000
58	314	564	1037	21.3	0.000
59	382	394	1039	22.0	0.000
60	661	571	1041	22.2	0.000
61	1046	831	1043	22.0	0.000

Figure 16. Station locations from which samples were collected at the DH Mitchell Station August 6, 1974.



August 6, 1974

Sample	Range	Bearing	Time	°C Temperature	mg/l Chlorine
1	134	4° 55'	1438	28.0	0.000
2	189	6° 45'	1439	28.0	0.000
3	270	6° 30'	1440	28.0	0.000
4	340	5° 12'	1441	28.0	0.000
5	418	4° 20'	1442	27.0	0.000
6	500	4° 00'	1443	27.0	0.000
7	473	348° 47'	1447	25.0	0.000
8	396	349° 15.5'	1449	25.0	0.000
9	348	349° 18'	1450	25.0	0.006
10	278	350° 4.5'	1451	24.0	0.004
11	210	355° 00'	1452	25.0	0.057
12	173	357° 55'	1453	26.5	0.113
13	148	4° 50'	1454	28.5	0.181
14	190	13° 29'	1455	27.5	0.105
15	247	17° 31'	1456	26.5	0.055
16	309	20° 21'	1457	26.5	0.010
17	411	25° 7.5'	1457	25.5	0.000
18	522	24° 36'	1459	25.0	0.000
19	507	11° 23.5'	1507	26.0	0.053
20	446	11° 25.5'	1508	26.0	0.049
21	383	9° 46.5'	1509	27.0	0.090
22	328	7° 53.5'	1510	27.0	0.129
23	295	7° 43.5'	1512	28.0	0.134
24	227	4° 55'	1513	28.5	0.001
25	149	7° 18'	1514	28.5	0.000
26	216	17° 2'	1516	27.0	0.000
27	315	16° 6.5'	1517	27.0	0.024
28	413	16° 7'	1518	26.5	0.045
29	480	16° 19.5'	1520	26.0	0.015
30	571	16° 33'	1522	26.0	0.004
31	450	348° 24.5'	1528	24.5	0.000
32	345	350° 55'	1529	24.5	0.000
33	275	351° 12'	1531	24.5	0.000
34	185	350° 00'	1532	22.0	0.000
35	132	4° 37.5'	1533	28.0	0.000
36	220	12° 00'	1535	27.0	0.000
37	300	22° 28.5'	1536	26.0	0.000
38	395	28° 5'	1537	25.5	0.000
39	480	32° 15'	1538	25.0	0.000
40	567	34° 35'	1539	24.5	0.000
41	530	25° 27'	1540	25.0	0.000
42	515	13° 22.5'	1542	26.0	0.000
43	477	5° 10'	1550	27.0	0.000
44	381	5° 46.5'	1551	27.0	0.000
45	324	6° 14'	1552	27.0	0.000
46	255	7° 23'	1554	28.0	0.000
47	179	6° 00'	1555	23.0	0.000

Figure 17. Stations locations from which samples were collected at the Bailly Station August 6, 1974.

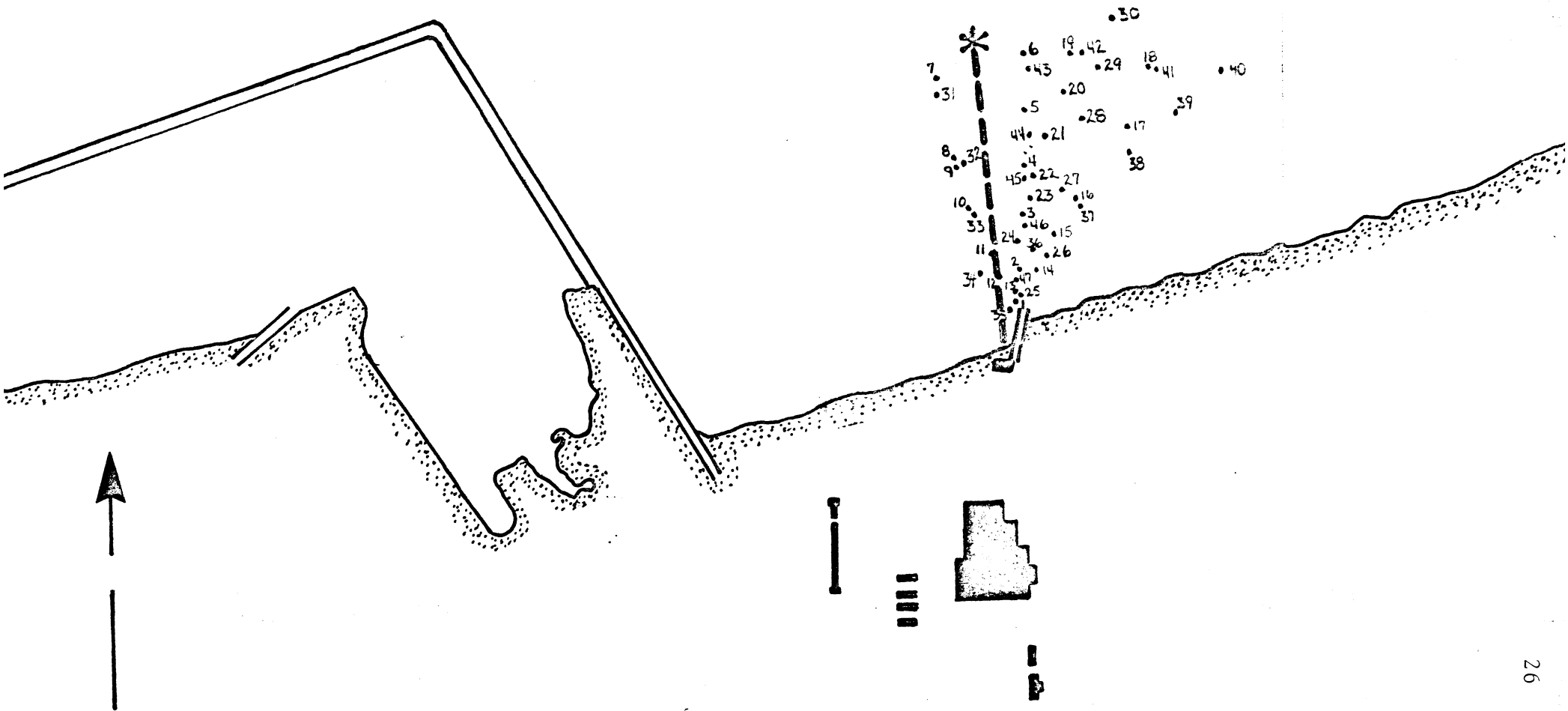


Table 4. RESULTS OF CHLORINATION
FIELD SURVEY:

MICHIGAN CITY

August 7, 1974

Sample	Mini Ranger		Time	°C Temperature	mg/l Chlorine
	A	B			
1	580	253	0857	21.6	0.000
2	593	255	0900	21.6	0.000
3	583	312	0903	22.0	0.000
4	545	358	0909	21.2	0.000
5	537	294	0911	24.0	0.000
6	543	284	0912	24.3	0.000
7	535	319	0914	22.1	0.000
8	381	559	0918	22.8	0.000
9	299	769	0920	22.4	0.000
10	375	687	0922	21.2	0.000
11	472	572	0923	21.3	0.000
12	589	497	0924	23.0	0.000
13	680	442	0925	22.7	0.000
14	789	434	0927	22.7	0.000
15	501	335	0947	23.4	0.000
16	506	325	0949	21.9	0.000
17	506	334	0950	21.7	0.000
18	504	339	0951	21.5	0.000
19	503	357	0953	21.8	0.000
20	507	369	0955	21.3	0.000
21	506	372	0956	21.4	0.000
22	505	319	1001	23.7	0.000
23	512	298	1003	23.9	0.000
24	513	294	1004	21.9	0.000
25	510	295	1005	23.3	0.000
26	508	319	1007	22.7	0.000
27	516	275	1012	23.6	0.000
28	517	275	1013	24.6	0.010
29	511	308	1016	22.2	0.000
30	514	320	1017	22.1	0.000
31	509	336	1018	21.7	0.000
32	522	337	1020	21.9	0.001
33	618	264	1021	21.8	0.000
34	687	231	1022	23.7	0.147
35	643	288	1024	22.2	0.000
36	525	375	1025	22.1	0.007
37	445	475	1026	22.9	0.028
38	495	471	1027	22.3	0.000
39	721	378	1029	22.6	0.000
40	759	408	1030	23.0	0.000
41	724	453	1031	22.9	0.000
42	505	600	1033	23.0	0.000
43	425	723	1034	22.8	0.000
44	479	793	1036	21.6	0.000
45	553	694	1037	21.7	0.000
46	658	610	1038	23.0	0.000
47	926	562	1040	22.9	0.000
48	1156	602	1042	23.1	0.000

Figure 18. Station locations from which samples were collected at the Michigan City Plant August 7, 1974.

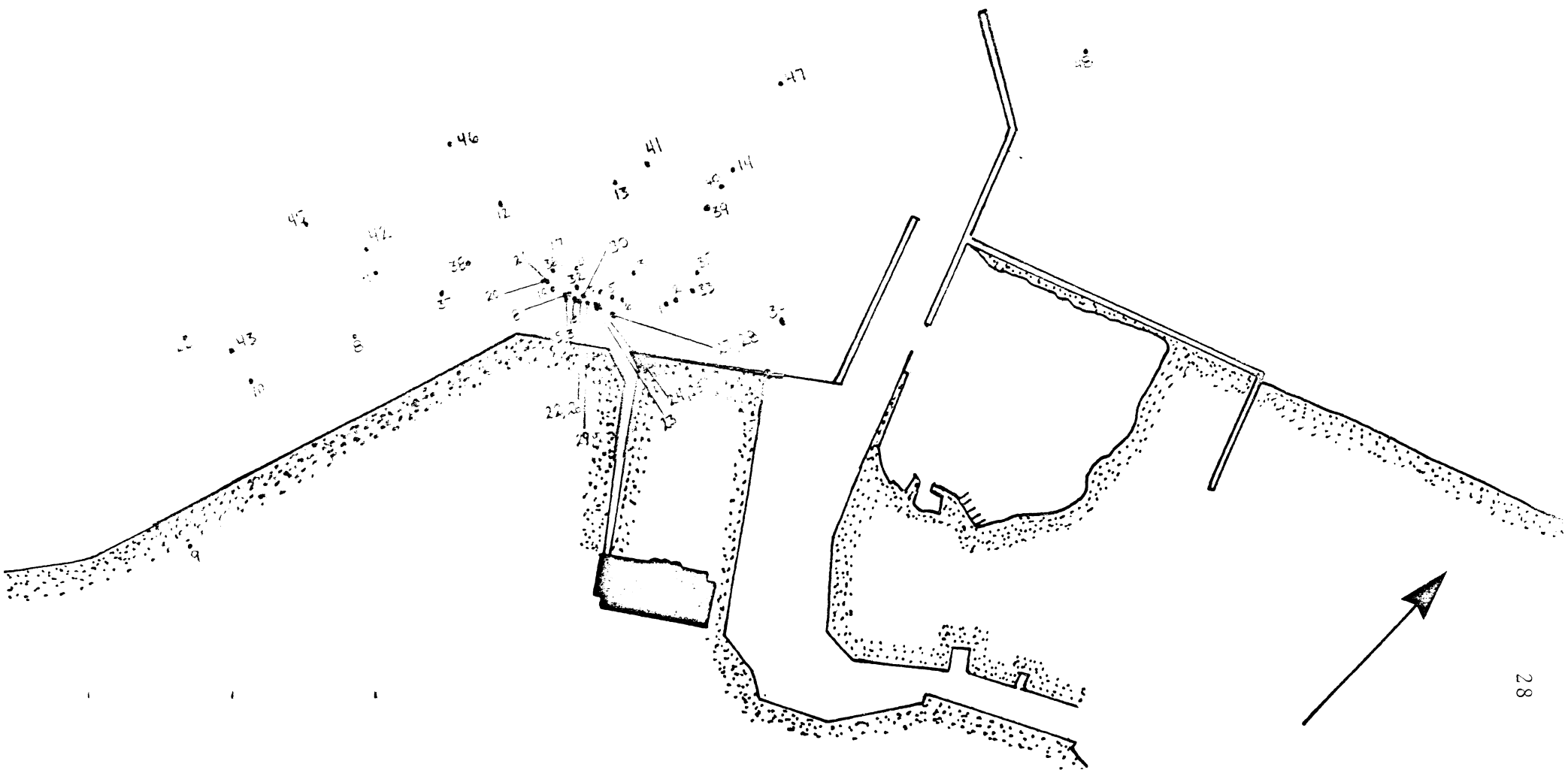


Table 5. RESULTS OF CHLORINATION FIELD SURVEY: DONALD C. COOK

Mini Ranger

August 7, 1974

Sample	Yards		Time	°C	mg/l Chlorine
	A	B		Temperature	
1	479	458	1321	22.0	0.000
2	501	450	1323	23.5	0.000
3	541	478	1325	23.8	0.000
4	467	447	1330	22.4	0.000
5	524	463	1334	22.2	0.017
6	546	489	1336	22.2	0.024
7	511	453	1338	21.7	0.027
8	455	443	1341	21.6	0.117
9	421	422	1342	21.6	0.129
10	487	438	1343	21.6	0.000
11	580	458	1347	21.6	0.063
12	613	508	1348	21.4	0.000
13	581	566	1349	21.4	0.080
14	484	670	1351	21.9	0.000
15	437	583	1352	22.0	0.000
16	517	468	1354	21.9	0.000
17	525	467	1355	21.5	0.126
18	521	475	1356	21.3	0.104
19	666	537	1358	21.3	0.095
20	663	642	1400	21.4	0.027
21	627	714	1401	21.6	0.000
22	741	776	1404	21.9	0.000
23	924	722	1407	21.7	0.029
24	868	664	1408	21.5	0.000
25	715	669	1410	21.5	0.000
26	676	738	1411	21.4	0.062
27	665	807	1412	21.8	0.000
28	658	880	1413	21.9	0.000
29	570	734	1415	21.9	0.000
30	662	612	1417	22.0	0.000
31	748	599	1418	21.9	0.000
32	853	613	1419	21.5	0.011
33	641	682	1420	21.5	0.000
34	998	690	1421	21.5	0.000
35	776	535	1423	21.6	0.000
36	649	504	1424	21.6	0.000
37	575	548	1425	21.6	0.004
38	527	713	1427	21.6	0.001
39	572	868	1428	22.0	0.000
40	872	1165	1430	22.0	0.000
41	1008	1238	1431	21.9	0.000
42	1045	1225	1432	21.7	0.000
43	1033	1170	1433	21.5	0.000
44	1065	1072	1435	21.5	0.000
45	1198	1061	1437	21.5	0.000
46	1255	1090	1438	21.5	0.005
47	1347	1131	1439	21.6	0.000
48	1336	1103	1440	21.6	0.000

Table 5. (continued) RESULTS OF CHLORINATION
FIELD SURVEY:

DONALD C. COOK

August 7, 1974

Sample	Yards		Time	°C Temperature	mg/l Chlorine
	A	B			
49	1042	810	1442	21.6	0.000
50	897	647	1443	21.7	0.000
51	699	563	1444	21.7	0.000
52	689	706	1447	21.5	0.000
53	809	868	1448	21.9	0.000
54	944	1021	1449	22.0	0.000
55	1097	1230	1451	21.6	0.000
56	1105	1289	1452	21.6	0.000
57	940	1200	1454	21.6	0.000
58	822	1042	1455	21.8	0.000
59	710	833	1456	21.9	0.000
60	593	723	1457	22.0	0.000
61	509	586	1458	22.0	0.000
62	563	367	1501	21.5	0.000
63	408	454	1503	21.7	0.000
64	656	967	1507	21.9	0.000
65	800	1127	1508	22.0	0.000
66	1035	1283	1510	21.9	0.000
67	953	1112	1512	21.8	0.000
68	936	1033	1513	21.9	0.000
69	942	969	1514	21.7	0.000
70	1037	931	1516	21.8	0.000
71	1100	939	1517	21.6	0.000
72	1421	1091	1520	21.7	0.000

Figure 19. Station locations from which samples were collected at the Donald C. Cook Plant August 7, 1974.

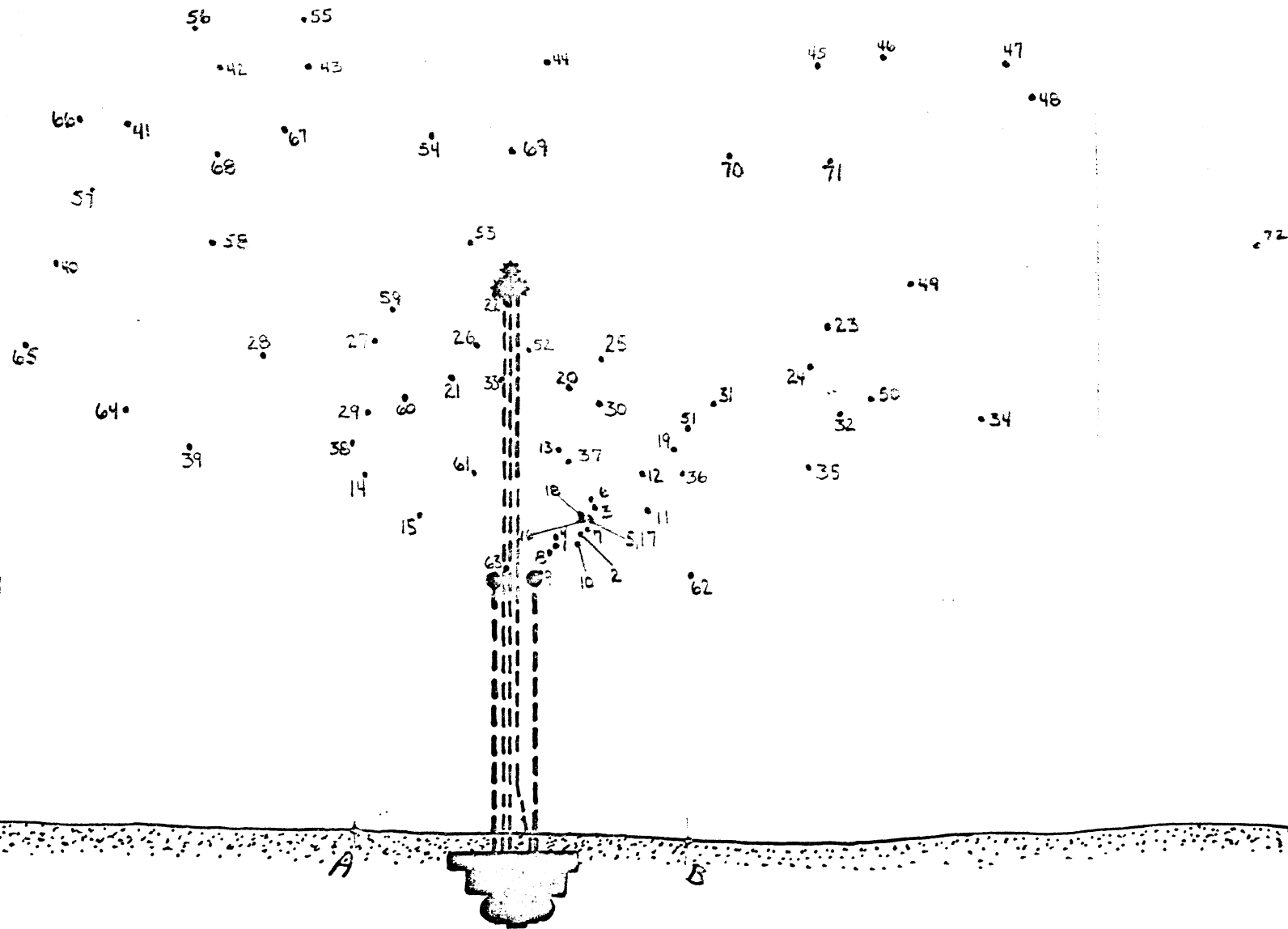


Table 6. RESULTS OF CHLORINATION
FIELD SURVEY:

CAMPBELL

August 8, 1974

Mini Ranger

Sample	Yards		Time	°C Temperature	mg/l Chlorine
	A	B			
1	1244	498	1148	26.0	0.000
2			1150	26.0	0.000
3			1151	25.5	0.000
4			1152	24.0	0.000
5			1222	26.0	0.055
6			1223	26.0	0.047
7			1224	26.0	0.013
8			1225	25.0	0.000
9	2025	1011	1226	25.0	0.000
10	1239	486	1235	24.5	0.007
11			1237	25.0	0.017
12			1238	25.0	0.042
13			1239	26.0	0.061
14			1240	25.5	0.100
15			1241	26.0	0.117
16			1242	26.5	0.214
17			1243	25.5	0.080
18			1244	23.5	0.012
19	1312	379	1245	24.5	0.000
20	1306	450	1247	24.0	0.000
21			1249	25.0	0.007
22			1250	24.5	0.007
23			1252	26.5	0.061
24			1259	25.5	0.055
25			1300	24.5	0.000
26	1204	473	1300	22.7	0.000
27			1301	24.0	0.000
28	1196	488	1302	23.0	0.000
29	1193	516	1307	22.5	0.000
30			1308	22.5	0.000
31			1309	23.5	0.000
32			1310	24.0	0.000
33	1196	533	1310	23.1	0.000
34			1313	26.5	0.001
35	1187	536	1313	23.0	0.000
36			1315	26.0	0.004
37			1316	26.0	0.000
38	1305	448	1317	25.5	0.017
39	1324	448	1318	24.9	0.000
40	1315	451	1323	25.0	0.000
41			1324	26.0	0.000
42			1325	25.0	0.000
43			1326	26.0	0.000
44			1327	26.5	0.000
45	1407	414	1335	24.1	0.000
46			1337	25.5	0.000
47			1338	24.5	0.000
48			1339	24.0	0.000

Table 6. RESULTS OF CHLORINATION FIELD SURVEY: CAMPBELL

August 8, 1974

Sample	Mini Ranger		Time	°C Temperature	mg/l Chlorine
	A	B			
49	1396	393	1340	23.5	0.000
50	1394	367	1344	24.0	0.000
51			1345	24.5	0.000
52			1346	24.5	0.000
53			1347	26.0	0.000
54			1348	26.5	0.000
55	1347	369	1349	23.5	0.000
56	1185	371	1350	24.5	0.003
57			1352	26.5	0.000
58			1353	26.0	0.000
59			1354	26.0	0.000
60	842	588	1355	25.0	0.000
61	846	522	1358	23.0	0.000
62	1238	326	1410	24.0	0.000
63	1310	337	1411	25.1	0.047
64	1302	340	1414	24.8	0.040
65	1253	357	1421	25.4	0.046
66	1387	382	1422	25.4	0.005
67	1853	705	1425	24.5	0.000
68	1931	770	1426	24.8	0.000
69	1320	312	1443	24.4	0.006
70	1178	317	1444	25.1	0.000
71	1517	399	1457	24.9	0.000
72	1524	575	1503	23.9	0.000
73	1029	593	1506	24.2	0.000
74	751	724	1508	24.7	0.014
75	1264	438	1516	24.3	0.000

Figure 20. Station locations from which samples were collected at the Campbell Plant August 8, 1974.

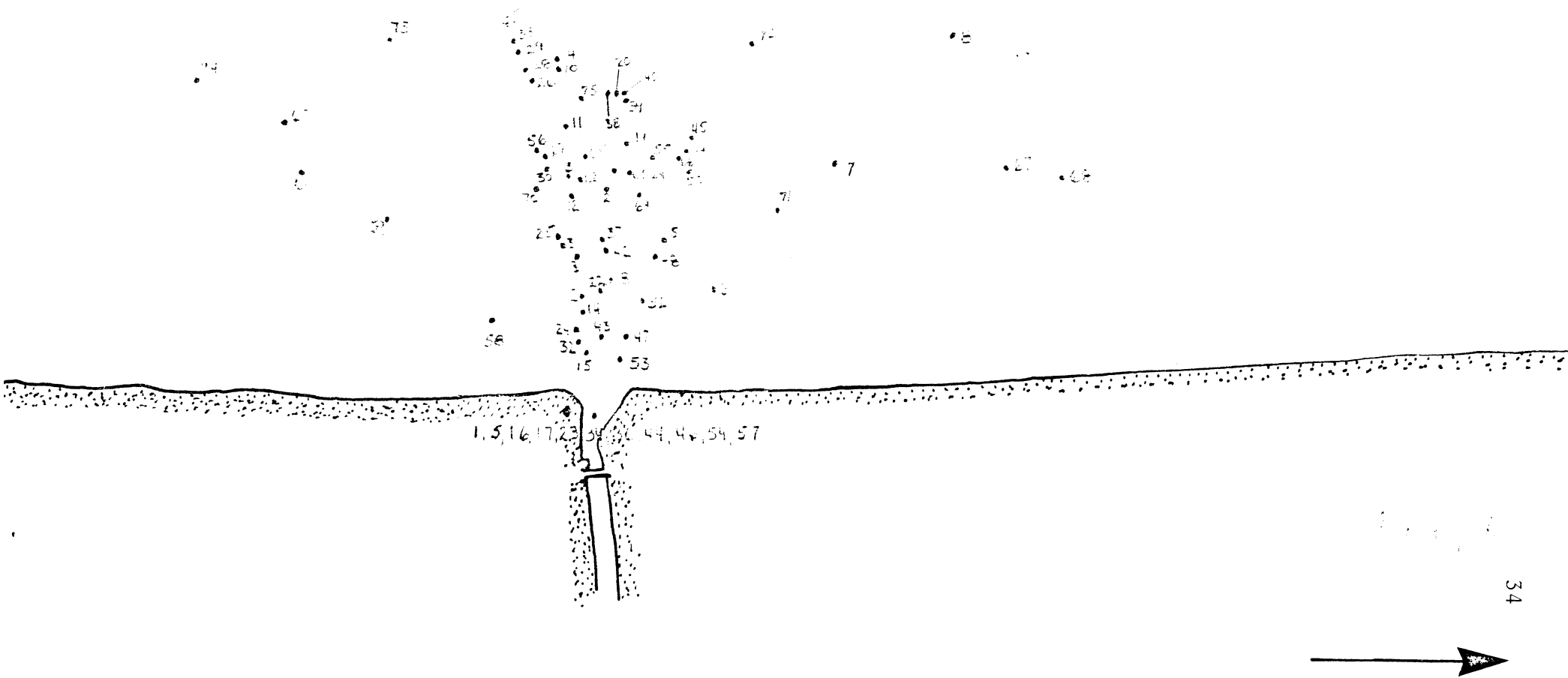


Table 7. RESULTS OF CHLORINATION FIELD STUDY: OAK CREEK

May 28, 1974

Sample	Mini Ranger		Time	°C Temperature	mg/1 Chlorine
	A	B			
1	184	510	11:00	14.0	0.000
2	216	443	11:02	14.0	0.016
3	248	417	11:04	10.3	0.089
4	268	393	11:06	10.7	0.075
5	356	315	11:08	11.5	0.031
6	494	185	11:10	12.0	0.080
7	605	115	11:13	12.8	0.085
8	719	120	11:16	12.9	0.065
9	824	197	11:18	13.0	0.050
10	904	267	11:20	11.3	0.000
11	1064	415	11:23	12.0	0.000
12	1224	571	11:26	11.7	0.000
13	1383	745	11:29	11.3	0.000
14	1477	834	11:32	11.3	0.000
15	1394	767	11:35	9.5	0.000
16	1180	589	11:38	10.0	0.000
17	976	512	11:41	11.5	0.000
18	1219	729	11:44	9.8	0.000
19	1329	835	11:47	9.6	0.000
20	1481	961	11:50	9.5	0.000
21	1656	1150	11:53	9.7	0.000
22	1652	1044	11:57	10.5	0.000
23	1366	736	12:00	10.8	0.000
24	1126	524	12:03	10.9	0.110
25	840	329	12:06	10.5	0.002
26	1038	641	12:09	10.5	0.000
27	1128	702	12:11	10.5	0.000
28	1229	778	12:13	10.8	0.000
29	1341	865	12:15	10.5	0.000
30	1438	953	12:17	10.0	0.000
31	1564	1068	12:20	10.3	0.000
32	1680	1178	12:22	10.3	0.000
33	1859	1329	12:24	10.5	0.000
34	1665	1306	12:26	10.6	0.000
35	1509	1225	12:28	10.8	0.000
36	1420	1199	12:30	10.8	0.000
37	1318	1192	12:32	10.9	0.000
38	1041	1092	12:35	11.0	0.000
39	636	815	12:37	11.1	0.000
40	299	642	12:39	11.0	0.000
41	156	557	12:41	10.3	0.000
42	215	441	12:43	10.3	0.000
43	258	498	12:45	11.0	0.000
44	321	819	12:48	10.5	0.000
45	569	1041	12:50	10.3	0.000
46	1028	1422	12:53	10.5	0.000
47	1523	1839	12:55	10.0	0.000
48	1838	2112	12:58	9.6	0.000
49	2134	2372	1:00	9.6	0.000
50	2300	2511	1:02	8.9	0.000
51	2552	2744	1:04	9.5	0.000
52	2851	3029	1:06	10.0	0.000
53	3027	3190	1:08	10.0	0.000

Figure 21. Station locations from which samples were collected at the Oak Creek Plant May 28, 1974.

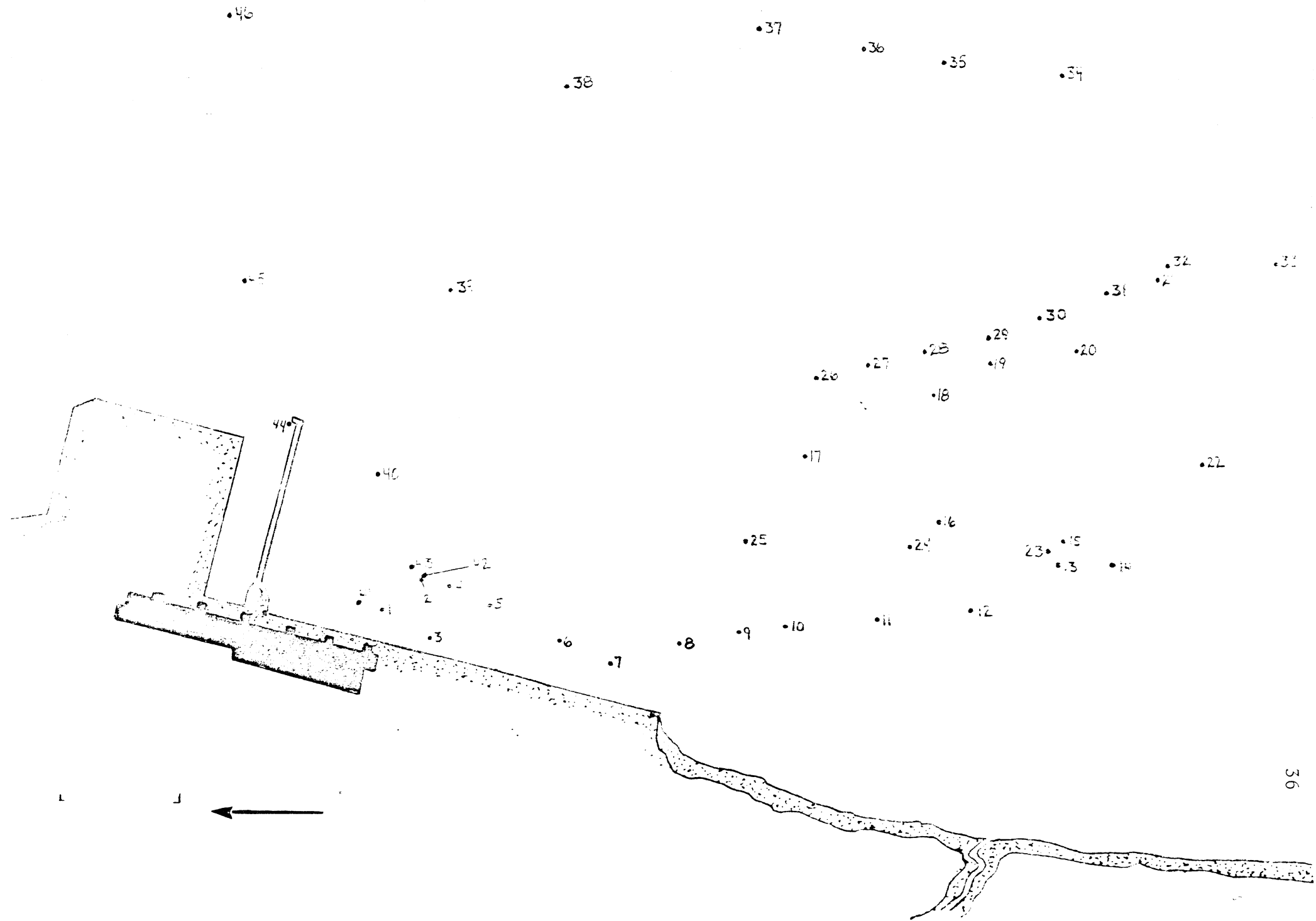


Table 8. RESULTS OF CHLORINATION FIELD SURVEY: OAK CREEK

September 11, 1974

Sample	Mini Ranger Yards		Time	°C Temperature	mg/l Chlorine
	A	B			
1	115	584	10:51	15.0	0.000
2	117	585	10:53	15.0	0.000
3	120	567	10:56	16.0	0.000
4	283	476	11:09	17.0	0.011
5	277	390	11:11	20.0	0.000
6	330	335	11:14	20.0	0.078
7	367	310	11:16	20.0	0.354
8	429	256	11:18	19.5	0.292
9	496	210	11:20	18.0	0.195
10	586	170	11:22	17.0	0.160
11	723	194	11:25	17.0	0.084
12	830	283	11:27	18.0	0.044
13	913	346	11:29	17.0	0.021
14	980	504	11:33	17.0	0.010
15	776	444	11:35	17.0	0.002
16	493	447	11:37	17.0	0.000
17	254	116	11:39	17.0	0.000
18	278	686	11:41	16.5	0.000
19	466	596	11:43	17.0	0.000
20	659	528	11:45	15.5	0.000
21	935	558	11:47	17.0	0.000
22	1219	729	11:49	17.0	0.000
23	1469	969	11:51	17.3	0.000
24	1812	1242	11:53	16.5	0.000
25	2077	1486	11:56	16.5	0.000
26	2423	1819	11:59	15.5	0.000
27	2403	1822	11:59	15.0	0.000
28	2241	1632	12:00	15.0	0.000
29	1918	1289	12:01	15.0	0.000
30	1591	991	12:03	16.0	0.000
31	1240	910	12:05	15.0	0.000
32	959	566	12:07	16.0	0.000
33	738	557	12:10	17.0	0.000
34	581	658	12:13	17.5	0.018
35	558	913	12:15	17.0	0.005
36	844	1083	12:16	17.0	0.000
37	1168	1284	12:18	16.0	0.000
38	1466	1540	12:20	15.0	0.000
39	1413	1503	12:23	16.0	0.000
40	1413	1503	12:25	15.0	0.000
41	1158	1249	12:27	15.0	0.000
42	713	882	12:27	16.0	0.000
43	434	643	12:30	16.0	0.000
44	310	571	12:32	15.0	0.000
45	194	515	12:36	16.0	0.000
45	233	438	12:38	16.5	0.000
			12:40	17.0	0.000

Figure 22. Station locations from which samples were collected at the Oak Creek plant
September 11, 1974.

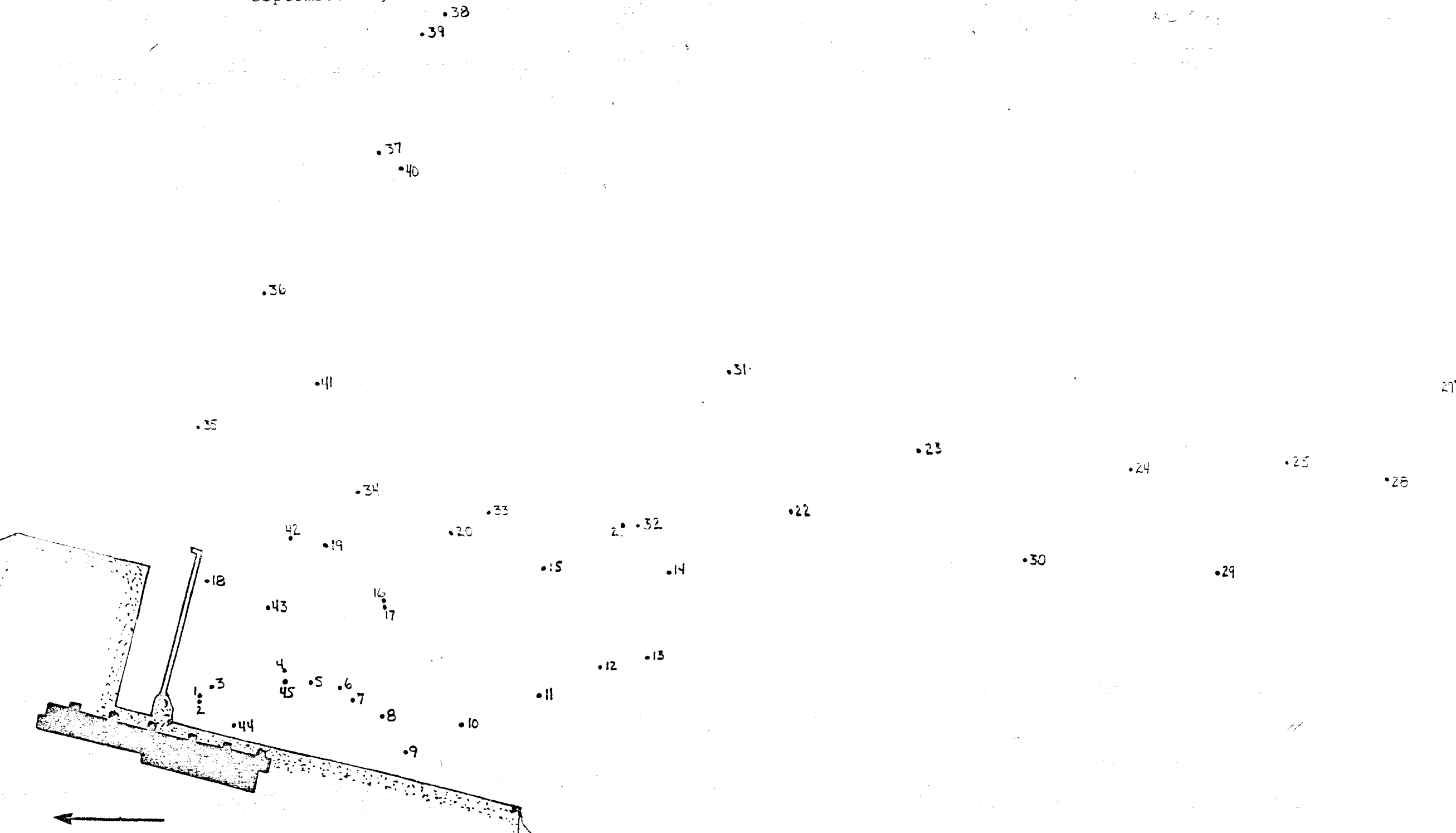


Table 9. RESULTS OF CHLORINATION FIELD SURVEY: OAK CREEK

November 12, 1974

Sample	Mini Ranger Yards		Time	°C	mg/1 Chlorine
	A	B		Temperature	
1	114	580	10:51	10.0	0.000
2	160	496	10:53	12.0	0.050
3	292	365	10:57	13.5	0.020
4	360	299	10:59	13.0	0.025
5	435	225	11:01	12.5	0.016
6	528	157	11:04	13.0	0.014
7	708	115	11:06	14.0	0.077
8	566	213	11:08	12.0	0.000
9	167	521	11:12	11.0	0.000
10	114	566	11:14	10.0	0.000
11	114	582	11:16	12.0	0.000
12	179	476	11:19	13.0	0.156
13	311	358	11:22	12.5	0.151
14	546	121	11:25	14.0	0.190
15	719	144	11:27	13.5	0.069
16	709	176	11:30	11.5	0.004
17	735	232	11:34	11.5	0.000
18	1167	580	11:38	11.0	0.000
19	1450	851	11:40	11.0	0.000
20	1158	596	11:42	10.5	0.000
21	706	357	11:45	10.5	0.000
22	397	450	11:47	10.0	0.000
23	263	589	11:50	10.0	0.000
24	452	550	11:52	10.0	0.000
25	904	523	11:55	10.0	0.000
26	1388	855	11:58	10.0	0.000
27	1793	1242	12:01	10.0	0.000
28	1860	1240	12:05	11.0	0.000
29	1330	764	12:09	10.5	0.000
30	459	412	12:15	10.0	0.000
31	256	638	12:18	10.0	0.000

Figure 23. Station locations from which samples were collected at the Oak Creek plant November 12, 1974.



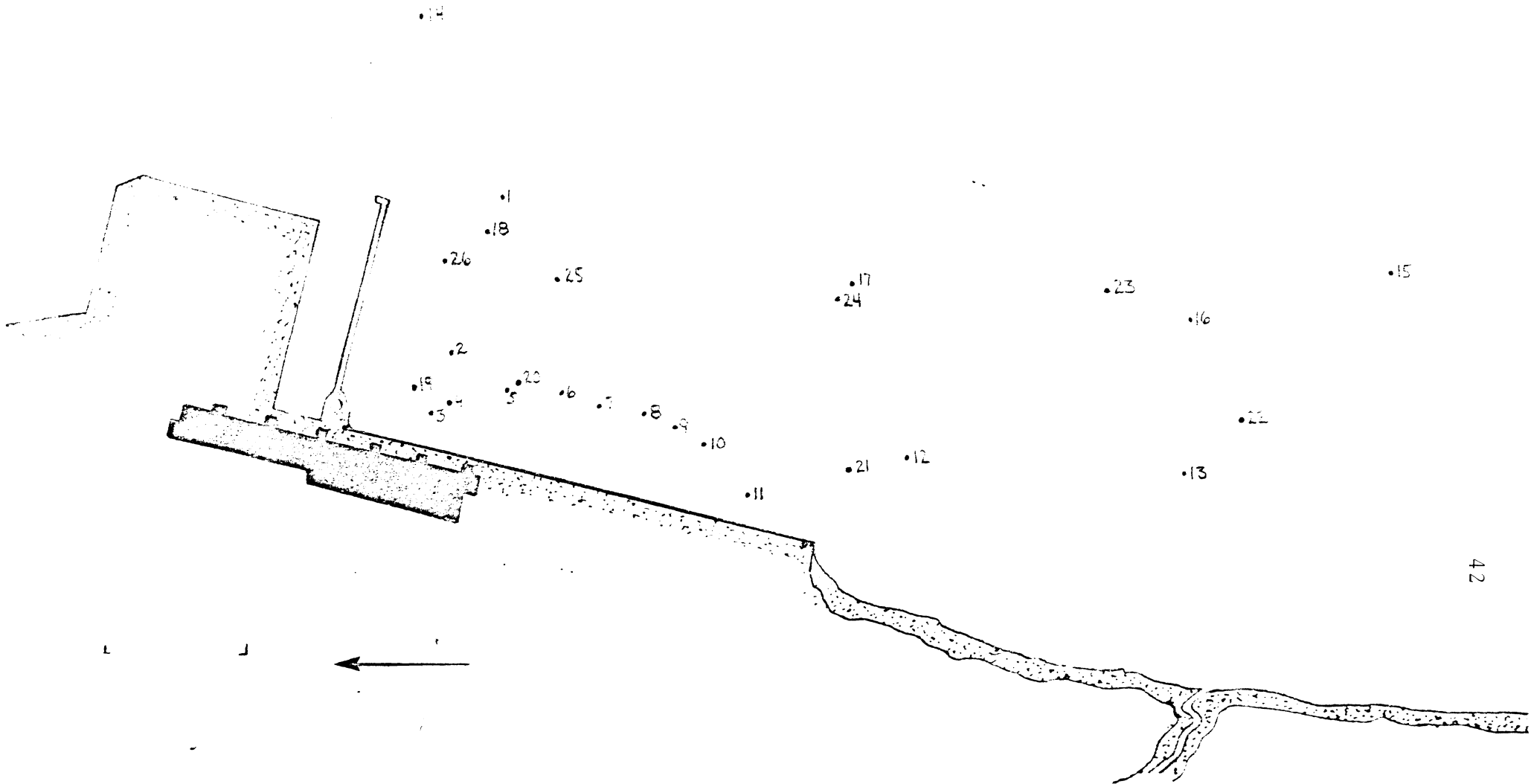
Table 10. RESULTS OF CHLORINATION FIELD SURVEY:

Oak Creek

December 10, 1974

Sample	Mini Ranger Yards		Time	°C Temperature	mg/l Chlorine	
	A	B			pH 7	pH 4
1	397	682	11:21	5.0	0.000	
2	175	603	11:23	5.0	0.000	
3	114	596	11:26	7.0	0.001	
4	114	570	11:28	7.0	0.012	
5	185	482	11:29	8.0	0.112	
6	264	397	11:31	8.5	0.240	
7	328	338	11:33	8.0	0.157	
8	397	264	11:36	8.0	0.345	
9	450	213	11:38	8.0	0.187	
10	502	167	11:40	8.5	0.376	0.025
11	595	115	11:43	9.5	0.343	0.020
12	821	183	11:45	9.5	0.069	
13	1231	556	11:48	9.0	0.000	
14	1602	964	11:50	9.0	0.000	
15	1549	938	11:54	7.0	0.000	
16	1245	641	11:57	5.0	0.000	
17	765	378	12:00	4.5	0.000	
18	341	662	12:03	4.5	0.000	
19	122	625	12:08	5.0	0.000	
20	192	467	12:13	6.5	0.000	
21	738	113	12:16	8.2	0.100	
22	1312	655	12:20	8.5	0.000	
23	1130	566	12:23	5.5	0.000	
24	739	354	12:26	4.7	0.000	
25	366	537	12:29	4.0	0.000	
26	268	682	12:32	4.5	0.000	

Figure 24. Station locations from which samples were collected at the Oak Creek plant
December 10, 1974.



Samples were collected at 2-5 minute intervals commencing approximately fifteen minutes after the start of chlorination and continuing until chlorine could no longer be detected. Samples were either obtained from the circulating water system of the ship which draws water from a depth of 2 m or dipped from the surface in shallow areas. The data indicate that chlorine levels measured at the point of discharge were relatively low and that the concentration of chlorine in the lake water diminished rapidly moving away from the plant. These data will be analyzed more completely this summer in conjunction with the development of a chlorinated plume model. Dr. Kwang Lee of the Department of Mechanics and the Center for Great Lakes Studies will be working with the project this summer in developing the chlorine model. His work should be completed by the end of the summer.

Another aspect of the field work related to the behavior of chlorine in an effluent plume concerns the rate of chlorine degradation in lake water exclusive of dilution processes. On each of the field surveys, samples of water were obtained from the discharge of the power plant and maintained on the deck of the ship for several hours. Periodic chlorine measurements were made on this water, the results of which are presented in Table 11. Laboratory studies designed to observe the same phenomena under more controlled conditions have also been undertaken. Samples of Lake Michigan water were collected, chlorinated and maintained at 10°, 15° and 20°C exposed to natural light at three light intensities. The results of the chlorine decay under these conditions is shown in Tables 12 to 14. It appears from these data that chlorine degrades more rapidly at higher temperatures and high light conditions whereas at low

temperatures and low light conditions the chlorine persists for several days. The apparent lower decay rate for the clear samples may have been caused by the presence of a tight cover installed to prevent debris from entering the sample container. This information will be incorporated into the design of the chlorinated effluent model along with other data collected on the field survey. Additional laboratory persistence studies will be conducted this summer to obtain additional data under summer conditions.

Table 11.

SHIPBOARD CHLORINE PERSISTENCE STUDY

Station	Date	Sample time	Elapsed time (min.)	Residual Cl ₂ mg/l	
Mitchell	8-6-74	0908	0	0.041	
		0924	16	0.028	
		0943	35	0.027	
		1005	63	0.032	
		1029	87	0.030	
		1131	149	0.034	
		1213	191	0.027	
		1417	315	0.010	
		1613	431	0.010	
		1646	464	0.000	
D. C. Cook	8-7-74	1359	0	0.071	
		1434	35	0.032	
		1459	60	0.053	
		1606	127	0.040	
		1925	199	0.032	
		2146	340	0.027	
		0815	971	0.000*	
Oak Creek	5-28-74	1112	0	0.043	
		1130	18	0.045	
		1155	43	0.046	
		1218	66	0.046	
		1231	80	0.045	
		1247	96	0.041	
		1305	114	0.031	
		1442	211	0.025	
		1505	234	0.011	
		1555	284	0.006	
	1632	321	0.007		
		repeat		0.006	
		1645	334	0.007	
		5-29-74	1700	30 hrs.	0.000
	Oak Creek	9-11-74	1123	0	0.184
			1203	40	0.150
			1302	99	0.104
1338			135	0.116	
1455			212	0.096	
1658			335	0.083	
2136			278	0.054	
		9-12-74	1025	23 hrs.	0.012
			1605	29 hrs.	0.004
			1950	33 hrs.	0.002

*rained in barrel overnight

Table 11. (continued) SHIPBOARD CHLORINE PERSISTENCE STUDY

Station	Date	Sample time	Elapsed time (min.)	Residual Cl_2 mg/l
Oak Creek	12-10-74	11:41	0	0.202
		12:35	54	0.205
		20:00	499	0.166
	12-11-74	10:45	23 hrs.	0.145*
		15:05	27 hrs.	0.118
		20:15	32 hrs.	0.122
	12-12-74	12:25	50 hrs.	0.078
		16:30	54 hrs.	0.062
		17:25	55 hrs.	0.050
	12-13-74	10:37	71 hrs.	0.019
		13:35	76 hrs.	0.008
		15:35	78 hrs.	<0.001

*Barrel with layer of ice on top

Table 12. CHLORINE PERSISTENCE STUDY STARTED 7 JANUARY 1975

10° Run

Elapsed time (min.)	Clock time	Date	Light Treatment				Weather conditions	Temperature
			L ₀	L ₁	L ₂	L ₃		
0	0904	1-7	.351	.331	.343	.351	Sunny	10.6
81	1025	1-7	.142	.175	.172	.293	"	-
172	1156	1-7	.122	.135	.115	.276	"	11.9
292	1356	1-7	.107	.098	.085	.232	Hazy	
428	1612	1-7	.097	.071	.065	.210	Cloudy	
645	1949	1-7	.088	.062	.055	.181	Dark	9.5
776	2200	1-7	.072	.036	.042	.164	Rain	
1366	0750	1-8	.056	.006	.006	.142	Foggy	11.2
1814	1518	1-8	.046	0	0	.115	Foggy	10.9
2221	2205	1-8	.035	0	0	.100	Dark	
2823	0757	1-9	.041	0	0	.101	Cloudy	9.2
3249	1503	1-9	0*	0	0	.076	Cloudy	9.1
3615	2109	1-9	0*	0	0	.069	Dark	10.0
5296	1310	1-11	0*	0	0	0		6.8

* = Covering blown off

L₀ = Clear containerL₁ = Container wrapped with 1 layer of cheeseclothL₂ = Container wrapped with 2 layers of cheeseclothL₃ = Container wrapped with opaque black plastic

Table 13. CHLORINE PERSISTENCE STUDY STARTED 7 JANUARY 1975

15° Run

Elapsed time (min.)	Clock time	Date	Light Treatment				Weather conditions	Temp- erature
			L ₀	L ₁	L ₂	L ₃		
0	0930	1-7	.320	.313	.310	.358	Sunny	14.6
86	1056	1-7	.130	.115	.122	.198	"	12.2
165	1215	1-7	.120	.094	.099	.173	"	15.9
289	1419	1-7	.100	.072	.072	.157	Hazy	
417	1627	1-7	.095	.052	.060	.140	Cloudy	
632	2002	1-7	.085	.035	.047	.123	Dark	15.0
766	2216	1-7	.065	.005	.025	.057	Rain	
796	2246	1-7	-	.008	-	.106		
1384	0834	1-8	.061	.000	.009	.103		14.9
1751	1521	1-8	.051	.000	.000	.090	Cloudy/fog	15.8
2155	2207	1-8	.031	.000	.000	.078	Dark	
2748	0800	1-9	.036	.000	.000	.060	Cloudy	15.2
3172	1504	1-9	.000*	.000	.000	.037	Cloudy	15.2
3588	2200	1-9	.000	.000	.000	.030	Dark	16.0
5223	1315	1-11	.000	.000	.000	.000		13.2

* = Covering blown off

L₀ = Clear containerL₁ = Container wrapped with 1 layer of cheeseclothL₂ = Container wrapped with 2 layers of cheeseclothL₃ = Container wrapped with opaque black plastic

Table 14. CHLORINE PERSISTENCE STUDY STARTED 7 JANUARY 1975

20° Run

Elapsed time (min.)	Clock time	Date	Light Treatment				Weather conditions	Temperature
			L ₀	L ₁	L ₂	L ₃		
0	0952	1-7	.295	.285	.306	.250	Sunny	19.1
104	1136	1-7	.120	.106	.136	.191	Sunny	12.2
170	1242	1-7	.107	.090	.118	.177	Sunny	19.9
283	1435	1-7	.092	.065	.088	.158	Hazy	
410	1642	1-7	.085	.040	.070	.145	Cloudy	
645	2037	1-7	.065	.026	.040	.120	Dark/rain	20.2
759	2231	1-7	.054	.009	.025	.121	Rain	
1390	0902	1-8	.055	.000	.002	.100	Fog/mist	20.0
1779	1523	1-8	.035	.000	.000	.085	Cloudy/fog	20.0
2467	2211	1-8	.011	.000	.000	.046	Dark	
3059	0803	1-9	.014	.000	.000	.043	Cloudy	19.9
3481	1505	1-9	.000	.000	.000	.025	Cloudy	20.2
3898	2202	1-9	.000	.000	.000	.026	Dark	18.1
5538	1320*	1-11	.000	.000	.000	.000		13.2

* = Covering blown off

L₀ = Clear containerL₁ = Container wrapped with 1 layer of cheeseclothL₂ = Container wrapped with 2 layers of cheeseclothL₃ = Container wrapped with opaque black plastic

