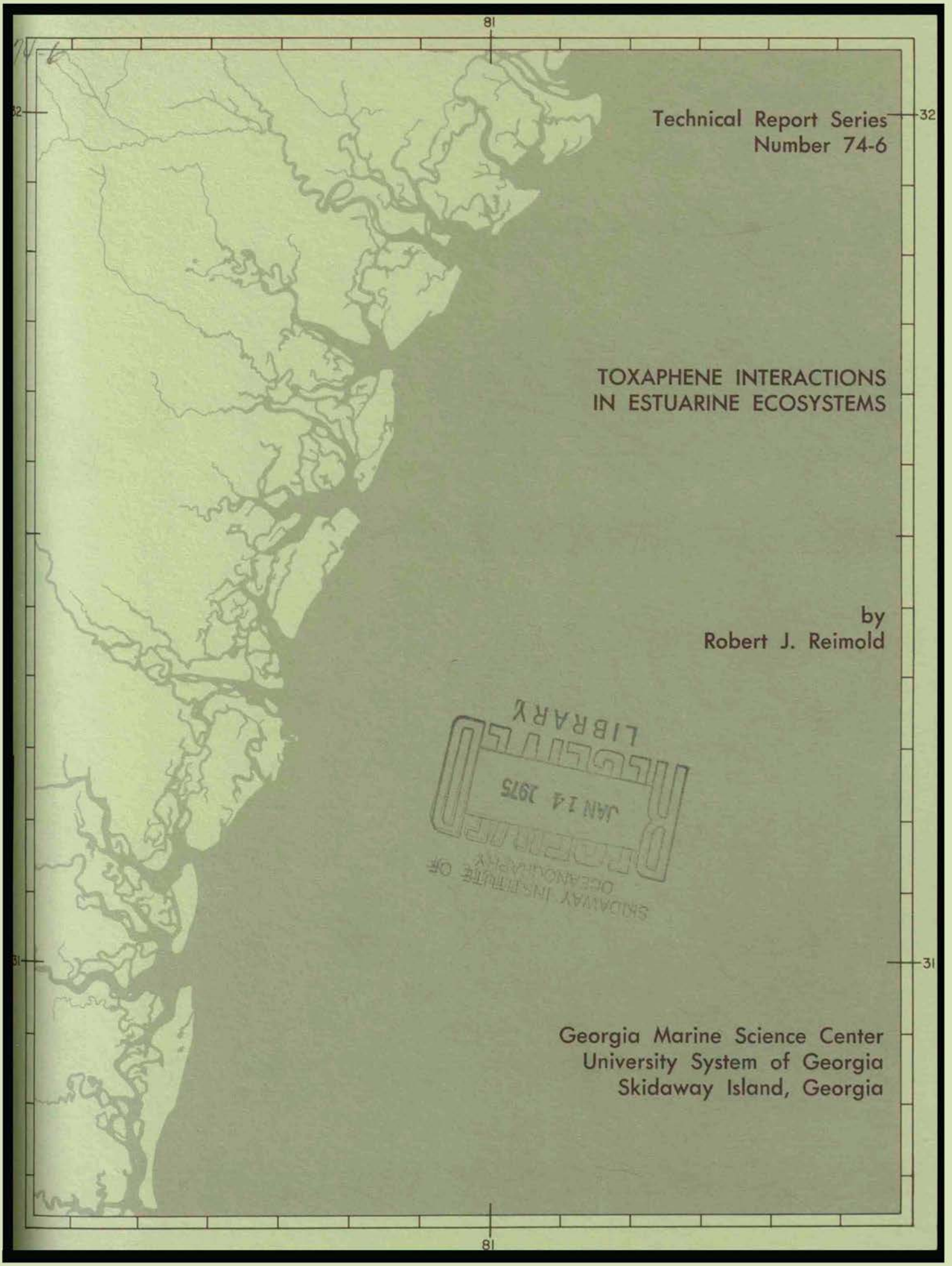

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TOXAPHENE INTERACTIONS IN ESTUARINE ECOSYSTEMS

by
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Georgia Marine Science Center
University System of Georgia
Skidaway Island, Georgia

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ABSTRACT

During 1973-1974, the toxaphene concentration in effluent from the Brunswick manufacturing plant continued to decrease from around 30 ppb to near 6 ppb. Concurrent with this was an increase in the species diversity of organisms in waters receiving the effluent. During 1973-1974 the diversity index, H Bar, was 1.9977 in the Duplin Estuary (considered to be undisturbed and free from any toxaphene contamination) contrasted with a higher index of 2.2577 in Terry Creek (which receives effluent containing toxaphene).

During the four year period, 1970-1974, the species diversity index, H Bar, in Terry Creek has increased from 0.70 to 2.26. This has coincided with a decrease in the apparent toxaphene concentration in plant effluents from a maximum monthly average of 2332 ppb (August, 1970) to 6.4 ppb (July 1974). Two other measures of diversity, J and NM Index, show a similar pattern based both on number of individuals and on biomass.

Experiments to follow the movement of toxaphene from the substrate into the salt marsh cordgrass, Spartina alterniflora, using ^{36}Chlorine labeled toxaphene were initiated. Spartina alterniflora was grown in sea water media for 26 and 100 days in a controlled environmental chamber. The greatest uptake (20%) of toxaphene and ^{36}Cl label was found in the roots and rhizomes. The least uptake was found in the leaves (1%).

Continued monitoring of toxaphene in the fauna of Terry Creek suggests as before that the oyster is not as good a biological monitoring organism as is the common anchovy. Toxaphene concentrations in the

white shrimp are higher in the head and thorax than in the abdomen (edible portion) although the concentrations are much lower than found in preceding years.

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During 1973-1974, there has been constant communication between officials from Hercules, Inc. and the principal investigator. In relation to the conduct of the field work, appreciation is extended to Mr. Fred Huebner and Mr. Millard Dusenbury, Brunswick Operations, Hercules, Inc. The financial support of Hercules, Inc. is also acknowledged.

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A sincere expression of appreciation is also extended to the Sapelo Island Research Foundation, Inc. for providing support facilities necessary for the conduct of this research project.

The outstanding contribution of Ms. Sarah Robinson and Ms. Cynthia Vernon, Zoology Department, DePauw University is also acknowledged. The winter term project conducted by these two ladies (Appendix I of this report) is an outstanding example of yet another cooperative effort to help us better understand the movement of toxaphene through the estuary.

INTRODUCTION

Over the past several years, research efforts have focused on the relationships between toxaphene contamination and estuarine ecology. Specifically, species diversity indices of the nekton in an estuary into which toxaphene wastes (from a manufacturing plant) were discharged were compared with those in an undisturbed salt marsh-estuarine system. Additionally, environmental samples have been analyzed for toxaphene. Changes in species diversity in the two systems and toxaphene concentrations in the fauna and flora were related to changes in the average daily toxaphene concentration of the toxaphene manufacturing plant effluent (Durant and Reimold, 1972; Reimold and Durant, 1972 a; Reimold and Durant, 1972 b; Reimold, Adams and Durant, 1973; Reimold and Durant, 1974 in press).

As toxaphene concentrations in manufacturing plant effluents decreased over one order of magnitude, the species diversity has increased. By the third year there was no significant difference between the diversity in the contaminated and the pristine estuary.

Toxaphene concentrations in organisms collected in the contaminated estuary also decreased during the three year period. One of the more interesting findings was the presence of toxaphene in the salt marsh cordgrass, Spartina alterniflora. In salt marsh sediments containing 32.5 ppm toxaphene, Spartina alterniflora was found containing 36.3 ppm ppm in the leaves, 4.9 ppm in the seed heads, and 1.9 ppm in the roots.

Based on the above, a two year research program was initiated to study the movement of toxaphene through the salt marsh sediment into Spartina alterniflora. Nekton sampling in the control and contaminated estuaries has continued to further evaluate changes in species diversity and to relate these to natural variation and to the release of toxaphene containing effluents.

METHODS

SPECIES DIVERSITY

At bimonthly intervals, nekton in the Duplin Estuary (control) and the contaminated Brunswick East estuary (Figure 1) were sampled. The specifics of sample collection, location, collection gear, etc. are described by Reimold et al. (1973). The only change was that during 1973-1974, samples were collected at bimonthly intervals rather than at monthly intervals as was the case during 1970-1973. Species diversity was calculated using an IBM 360-65 computer programmed as described by Reimold et al. (1973) and are based both on the number of individuals and biomass. The three indices chosen were: 1) Shannon-Wiener index, $\bar{H} = -\sum P_i \log P_i$, where P_i = proportion of the number of individuals in the i-th species to the total number of individuals; 2) Index of evenness, $J = \bar{H}/\log S$, where S is the maximum possible value of $\bar{H}$ and $\bar{H}$ is the Shannon-Wiener index discussed earlier; 3) Number of moves index, $NM = \frac{N\ (S+1)}{2} - \sum R_i N_i$ where N = total number of individuals, N_i = number of individuals in the i-th species, S = total number of species, and R_i = rank of species i. The diversity indices were compared by the

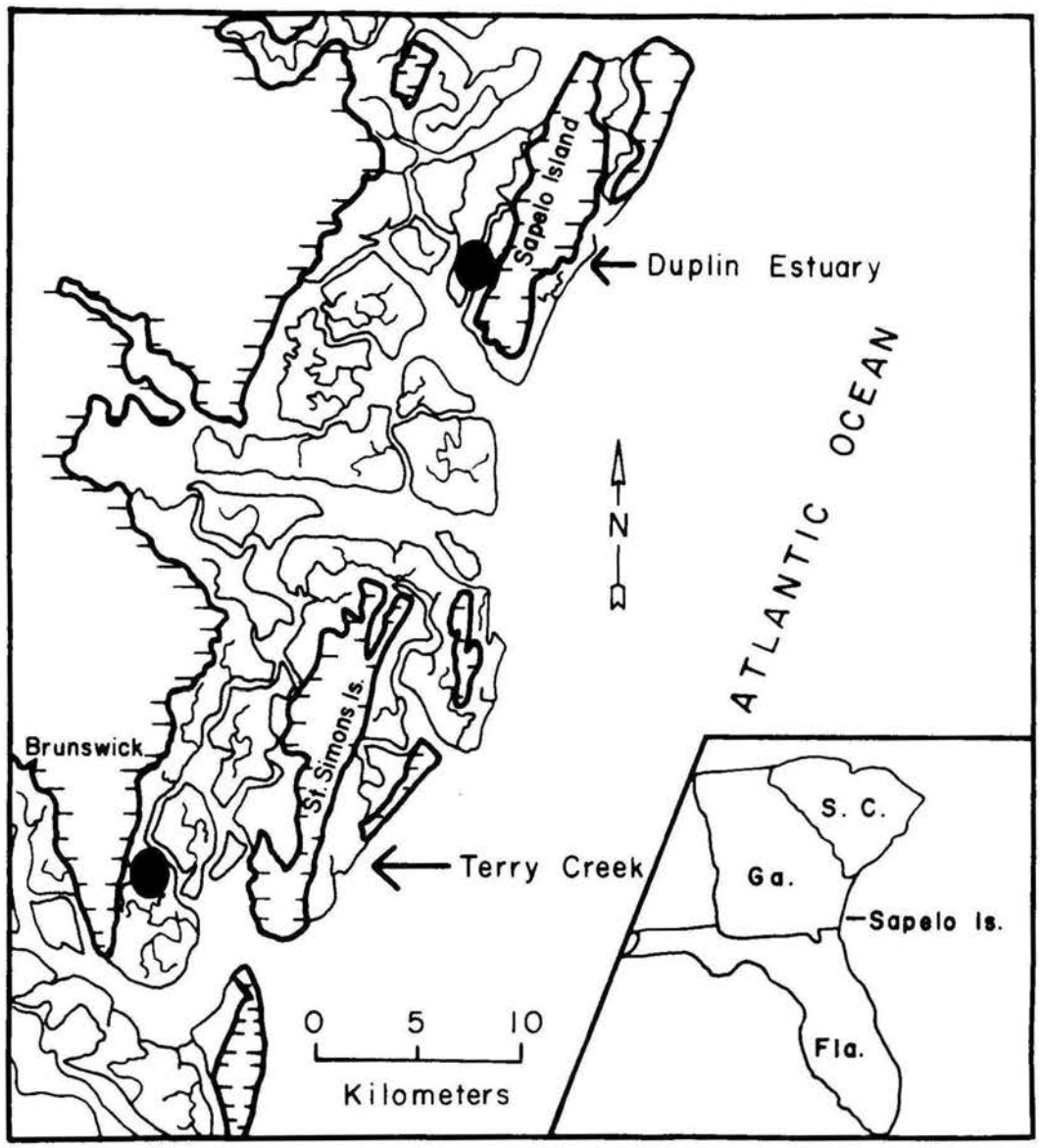

Figure 1. Geographic location of collection sites in coastal Georgia.

methods of Hutchinson (1970) and significant differences are reported for the 95.0%, 99.0%, and 99.9% confidence interval.

^{36}Cl LABELED TOXAPHENE

Several controlled laboratory experiments were initiated to follow the movement of toxaphene through the substrate and into the flora. Spartina alterniflora sprigs were grown for 20 days under controlled conditions in a sea water medium. All sprigs were collected from a marsh in the Duplin Estuary. Control samples were analyzed for toxaphene and ^{36}Cl after a twenty day acclimation period. Toxaphene containing a ^{36}Cl label with a specific activity of 52 microcuries per gram was then introduced into the sea water culture medium. Each plant (short form Spartina alterniflora) was placed in water containing 100 ppm toxaphene and 4.316 microcuries of ^{36}Cl. Incubation periods were 26 days and 100 days under controlled environmental conditions ($30^{o}C$ daytime temperature; $20^{o}C$ nighttime temperature; 14 hours daylight; 10 hours darkness; 5000 ft. candles light intensity). Eight replicates were run for each experimental and control set for each of the incubation periods.

Following incubation, the plants were removed from the media, blotted dry, and the leaves, stems, and roots and rhizomes were separated and then dried at $90^{o}C$ until a constant weight was obtained. Plant tissues were then ground in a Wiley mill using a 40 μ mesh screen.

Toxaphene was analyzed by methods described by Reimold and Durant (1974). Toxaphene concentrations were expressed in parts per million (dry weight of plant), milligrams of toxaphene per plant, and percent uptake of available toxaphene.

Thirty milligrams of plant tissue for ^{36}Cl analyses were weighed into a 20 ml glass vial to which 1 ml of Unisol® was added. After mixing, this was allowed to stand 48 hours when 0.5 ml of water free methanol was mixed into each vial followed by 10 ml of Unisol Compliment® and two drops of 30% hydrogen peroxide. The samples were then heated at 60°C for one hour. After standing for five days, an additional 2.0 ml of Unisol® was added to clear the cloudy precipitate. Samples then were counted using a Packard Liquid Scintillation Counter. Standards were prepared in the same cocktail in the same manner as above. Counts were corrected for background but not for quenching since counting efficiency was 93.25% and sample size was equal. All samples were counted twice.

Unisol® and Unisol Compliment® are a two component system designed for tissue solubilization and radioassay. Unisol® is a quaternary ammonium hydroxide compound in aqueous solution that effectively dissolves faunal and floral tissues at ambient temperature. Unisol Compliment® is a toluene based solution containing flours and sufficient quantities of a balancing acid solubilizer to accommodate over 10% (volume/volume) of Unisol® solubilized tissue.

GREENHOUSE EXPERIMENT

To follow the flux of toxaphene through sediment, a greenhouse study has been initiated. A box 16 ft long, 4 ft wide, and 4 ft deep was placed on a 4% slope inside the greenhouse. Marsh sediment from a nearby area was used to fill the box to within two inches of the top after which sprigs of Spartina alterniflora were transplanted into the box.

Three times every week the plants were watered with fresh water. A period of one year was allowed to pass to insure that the plants would survive a normal growing season. At the time of this writing, an experimental design is being developed to permit the addition of ^{36}Cl toxaphene at the "upstream" end of the box. Plant, substrate, and interstitial water samples will be collected at biweekly intervals for one year to help follow and quantify the flux of toxaphene through the system.

ENVIRONMENTAL MONITORING

To monitor changes associated with toxaphene effluent, fauna collected from the Brunswick-East estuary were analyzed by methods reported by Reimold and Durant (1974). Concentrations less than 0.25 ppm are considered undetectable.

RESULTS AND DISCUSSION

SPECIES DIVERSITY

The results of the species diversity computations based on numbers of individuals (1973-1974) are listed in Appendix I (1-4). A statistical comparison of the diversity index H Bar (based on the number of individuals) reveals that during 1973-1974, the Duplin Estuary (the control area receiving no toxaphene) was significantly different from the other areas considered (Table 1). In 1973-1974, the H Bar diversity of the Duplin Estuary was 1.9977 contrasted with 2.4118 for all Brunswick collection sites, 2.3875 for all Brunswick sites except Terry Creek (stream receiving the toxaphene manufacturing plant effluent), and 2.2577 for Terry Creek. A comparison of the H Bar diversity index of Terry Creek

Table 1. t-test of cumulative H BAR diversity indices (based on number of individuals) for 1973-1974 contrasting differences between collection sites. (* = significant at 95% confidence interval; ** = significant at 99% confidence interval; *** = significant at 99.9% confidence interval; NS = not significant).

	Duplin Estuary	Brunswick minus Terry Creek	Brunswick	Terry Creek
Brunswick minus Terry Creek	***			
Brunswick	***	NS		
Terry Creek	***	*	*	

and the Duplin Estuary for the four years considered (Figure 2) shows an increase in the diversity in Terry Creek. A similar increase in diversity (based on number of individuals) is also found for J and NM indices (Figures 3 and 4).

Diversity indices based on biomass (Appendix I, 5-8) show a significent difference between all areas considered in 1973-1974 (Table 2). The index, J, was 0.6797 for the Duplin Estuary, 0.7382 for all Brunswick collection stations combined, 0.7447 for all Brunswick stations except Terry Creek, and 0.7001 for Terry Creek. Another measure of diversity is a comparison of the number of species with the number of individuals. Figure 5 compares yearly changes in the Duplin Estuary while Figure 6 portrays similar information for Terry Creek. During 1973-1974, collections were at bimonthly intervals rather than at monthly intervals during 1970-1973. The variations in number of individuals and species in the Duplin Estuary are indicative of natural variations in populations.

Appendix I (1-8) lists the organisms responsible for changes in the diversity. In the Duplin Estuary, the most abundant organism was the star drum, while in Terry Creek, the most abundant organism was the common anchovy. In all instances, the diversity of the Duplin Estuary was less than that of Terry Creek. Lower diversity indices of the Duplin Estuary can be attributed to natural variation. Table 3 summarizes annual diversity indices (based on number of individuals) for all collection areas for the entire four year period considered. For each index computed, there is consistent increase in diversity in Terry Creek. During 1973-1974, the diversity (based on three different indices) of Terry Creek exceeded the diversity of the Duplin Estuary.

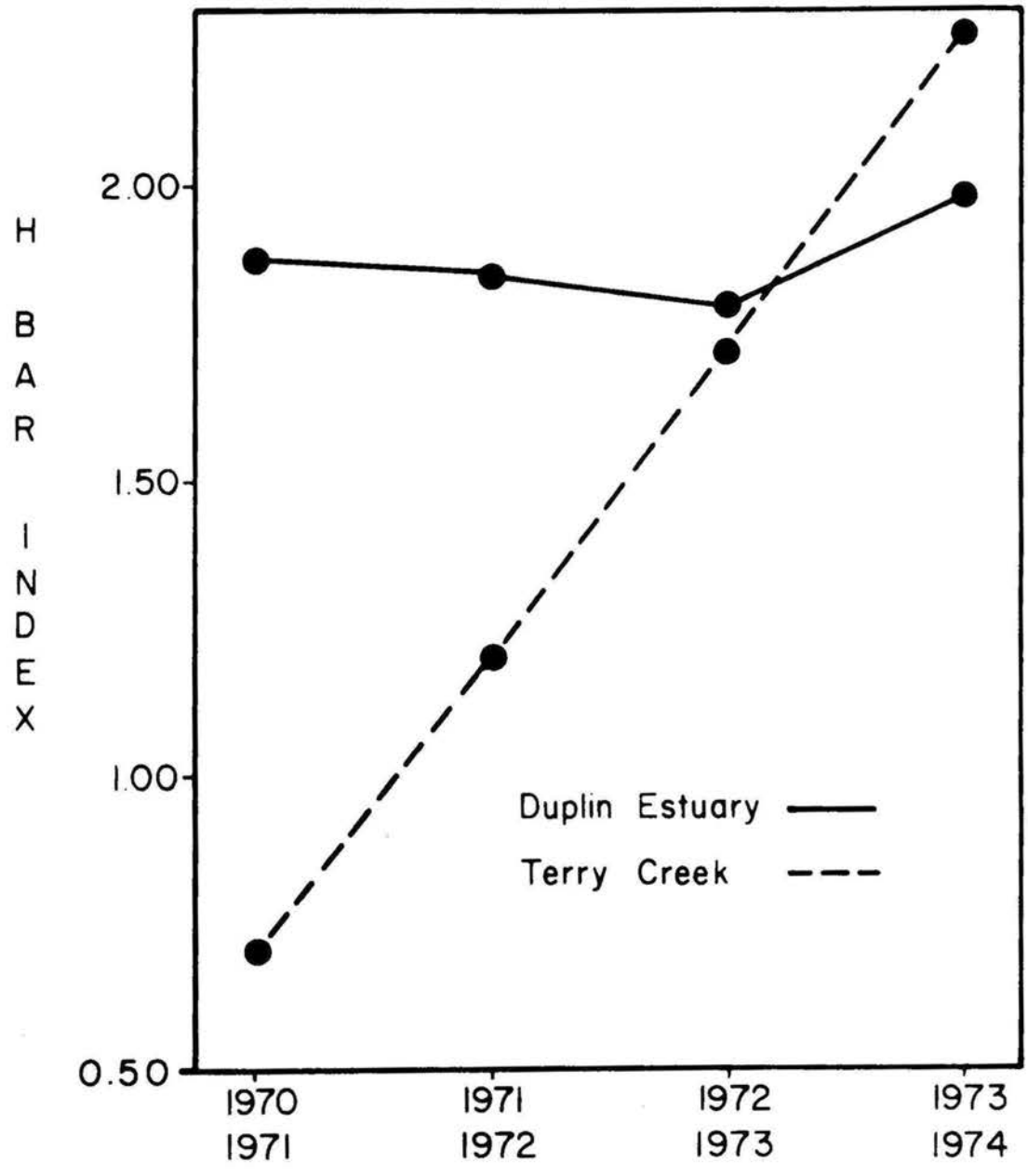

Figure 2. H BAR diversity index for the Duplin Estuary and Terry Creek, (based on the number of individuals) 1970-1974.

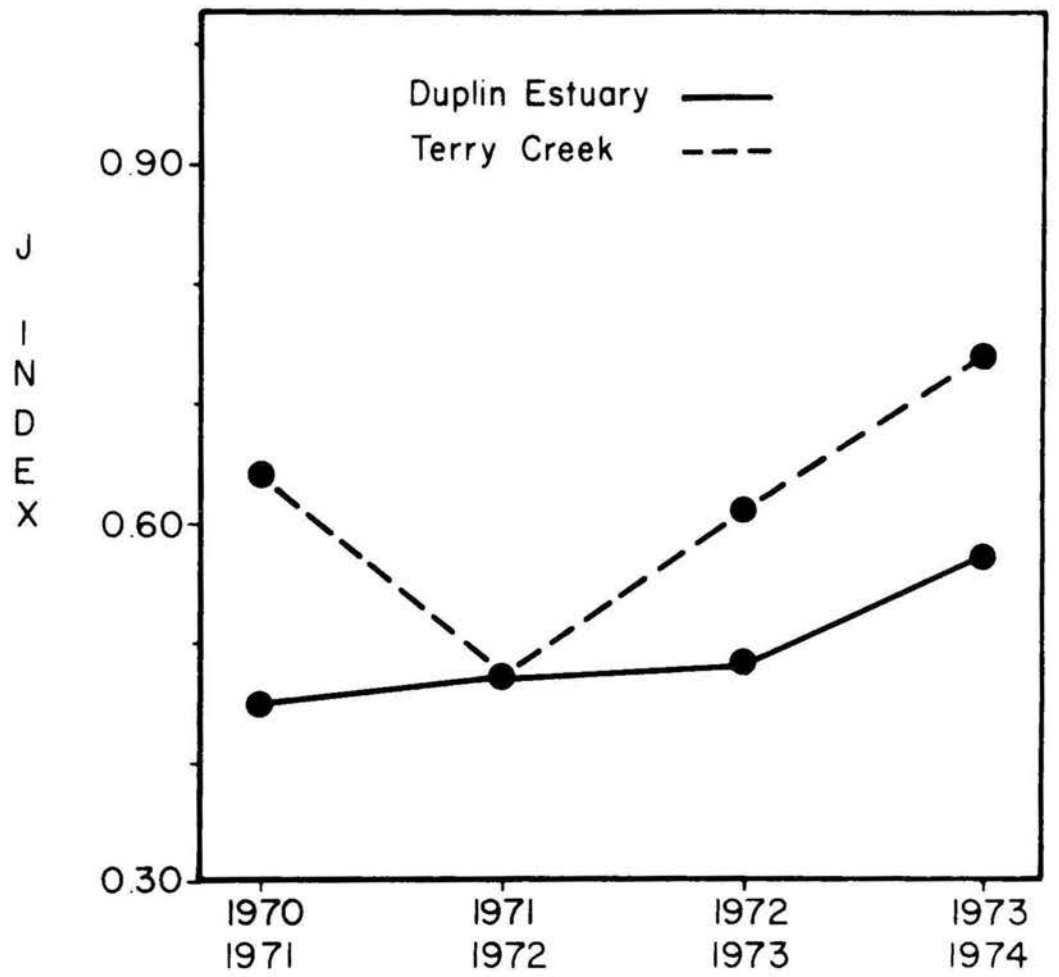

Figure 3. Diversity index, J, based on the number of individuals, for the Duplin Estuary and Terry Creek, 1970-1974.

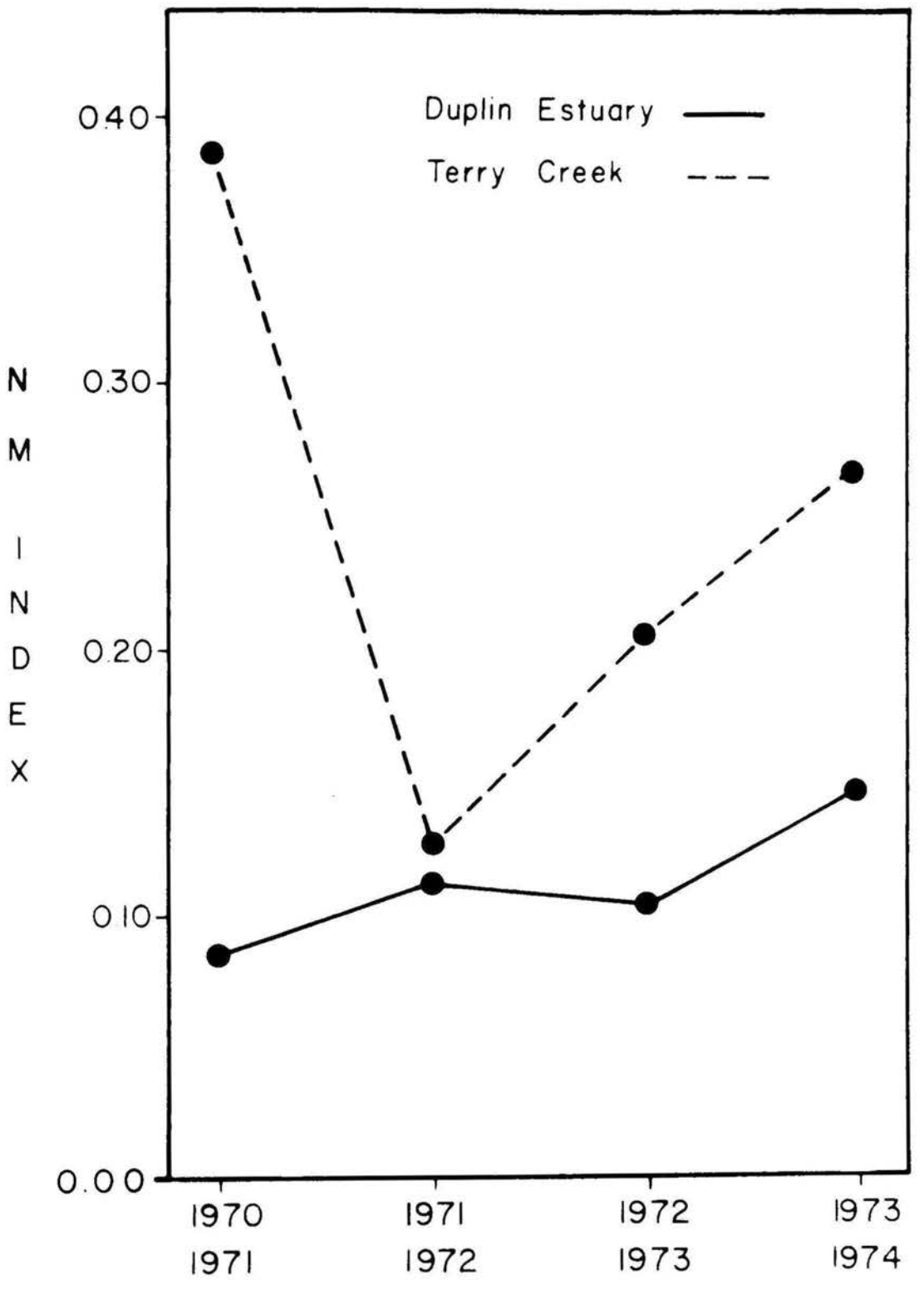

Figure 4. Diversity Index, NM index, based on the number of individuals, for the Duplin Estuary and Terry Creek, 1970-1974.

Table 2. t-test of cumulative H BAR diversity indices (based on biomass) for 1973-1974 contrasting differences between collection sites. (* = significant at 95% confidence interval; ** = significant at 99% confidence interval; *** = significant at 99.9% confidence interval; NS = not significant).

	Duplin Estuary	Brunswick minus Terry Creek	Brunswick	Terry Creek
Brunswick minus Terry Creek	***			
Brunswick	***	***		
Terry Creek	***	***	***	

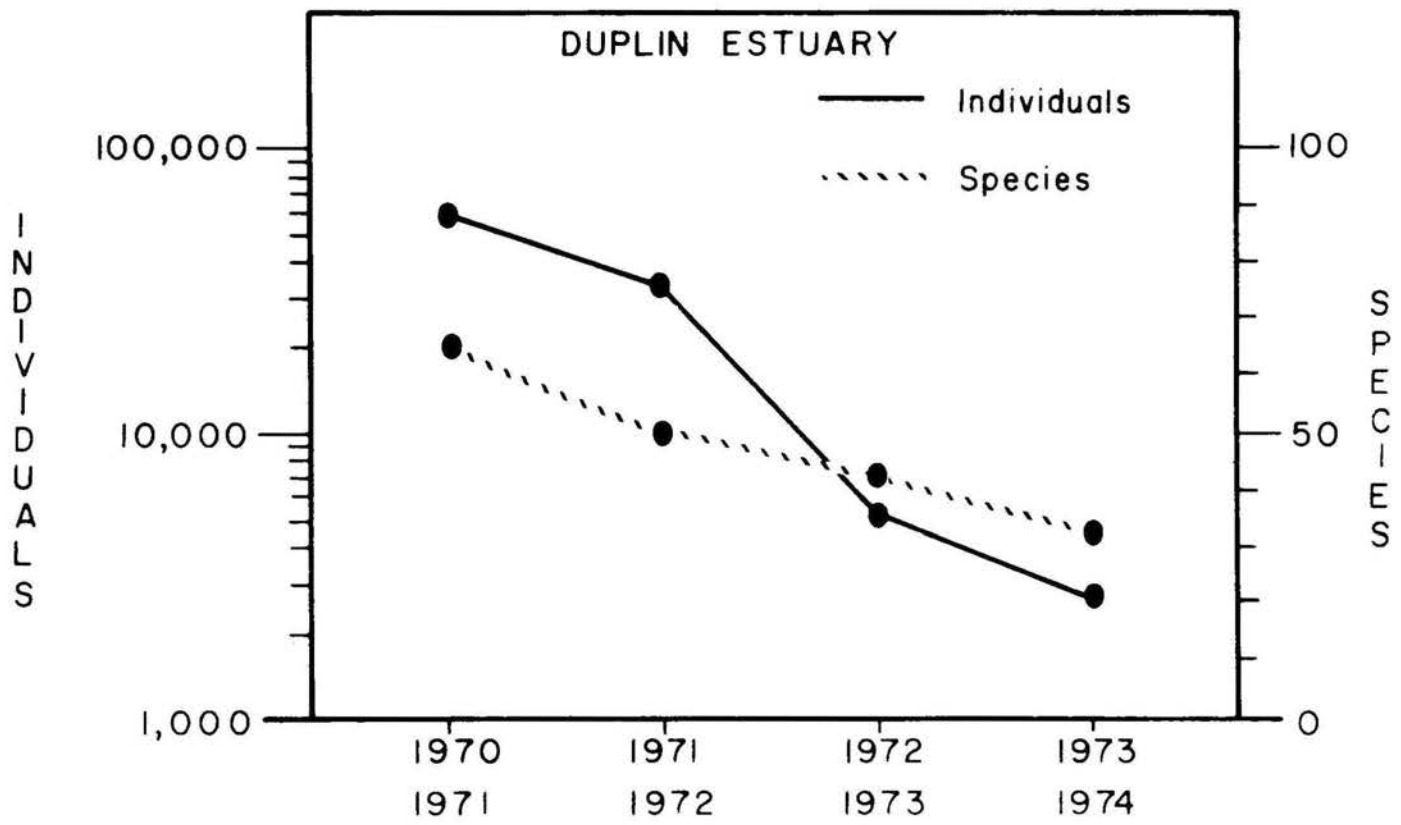

Figure 5. Diversity expressed as the number of species and number of individuals, for the Duplin Estuary, 1970-1974 (1970-1973, 12 collections per year; 1973-1974, 6 collections per year).

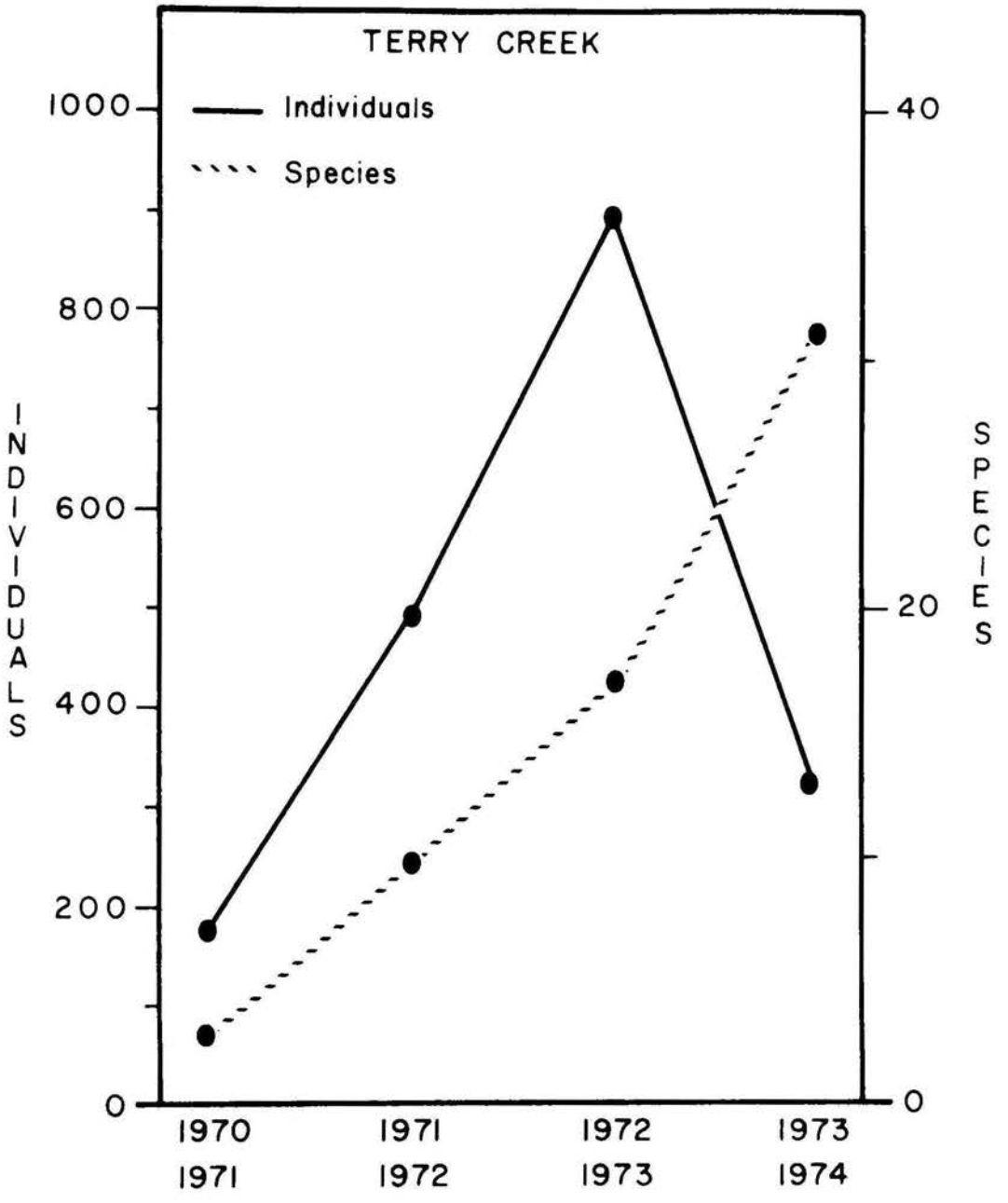

Figure 6. Diversity expressed as the number of species and number of individuals for Terry Creek, 1970-1974 (1970-1973, 12 collections per year; 1973-1974, 6 collections per year).

Table 3. Annual diversity indices based on number of individuals for all collection sites, 1970-1974.

Index	Year	Duplin Estuary	Terry Creek	All Brunswick Sites	Brunswick Sites Except Terry Creek
H					
	1970-1971	1.88	0.70	2.49	2.53
B	1971-1972	1.85	1.20	1.90	1.85
A	1972-1973	1.80	1.72	1.97	1.95
R	1973-1974	1.99	2.26	2.41	2.38
	1970-1971	0.45	0.64	0.69	0.70
J	1971-1972	0.47	0.47	0.52	0.51
	1972-1973	2.48	0.61	0.54	0.54
	1973-1974	0.57	0.74	0.67	0.69
N					
M					
	1970-1971	0.085	0.387	0.206	0.218
I	1971-1972	0.111	0.126	0.104	0.101
N	1972-1973	0.102	0.205	0.118	0.115
D	1973-1974	0.144	0.265	0.195	0.215
E					
X					

The decrease of toxaphene in effluents from the manufacturing plant can be considered the primary cause of the dramatic increase of diversity in Terry Creek. The apparent toxaphene content of the manufacturing plant effluent during the period 1 August 1970 to 30 June 1974, which decreased from 2332 ppb to 6.4 ppb, statistically correlates with the increase in diversity of Terry Creek (Table 4, Figure 7).

^{36}Cl LABELED TOXAPHENE

The flux of toxaphene through Spartina alterniflora was followed using ^{36}Cl labeled toxaphene. Uptake was more rapid in 26 days than in 100 days of incubation (Table 5). The roots and rhizomes (combined) had greater uptake rates of both the ^{36}Cl label and toxaphene than did the stems or leaves with one unexplained disparity in one plant (Figure 8).

Toxaphene and ^{36}Cl (Table 6) after 26 days incubation reached 62 ppm in the roots and rhizomes. Similarly, after 100 days, toxaphene (60.56 ppm) and ^{36}Cl (19.65 pc/mg) concentrations were highest in the roots and rhizomes.

Earlier work (Reimold and Durant, 1972a) showed that the highest concentrations of toxaphene occurred in leaves. In that study, the samples were collected from the field and the length of time of exposure or the concentration of toxaphene in the tidal waters was unknown. In the study reported here, data from eight replicate experiments were pooled to yield the results (Tables 5 and 6). The differences between the two observations may be attributed to differences in uptake from sea water medium opposed to marsh soil. A set of experiments in progress will assess this possibility.

Table 4. Apparent toxaphene content of manufacturing plant effluent (parts per billion).

	1970	1971	1972	1973	1974	1975	1976
January		44	1135(1)	39	17		
February		52	171	45	31		
March		39	184	40	16		
April		124	174	79(2)	11		
May		183	117	31	6.6		
June		187	108	19	6.4		
July		185	86	12			
August	2332	100	102	20			
September	1198	123	66	30			
October	635	141	22	32			
November	248	245	17	21			
December	94	298	28	34			

Notes: (1) Involved change from temporary facilities to permanent pollution abatement facilities.
(2) Involved digging in plant ditch prior to installing culverts at process area.

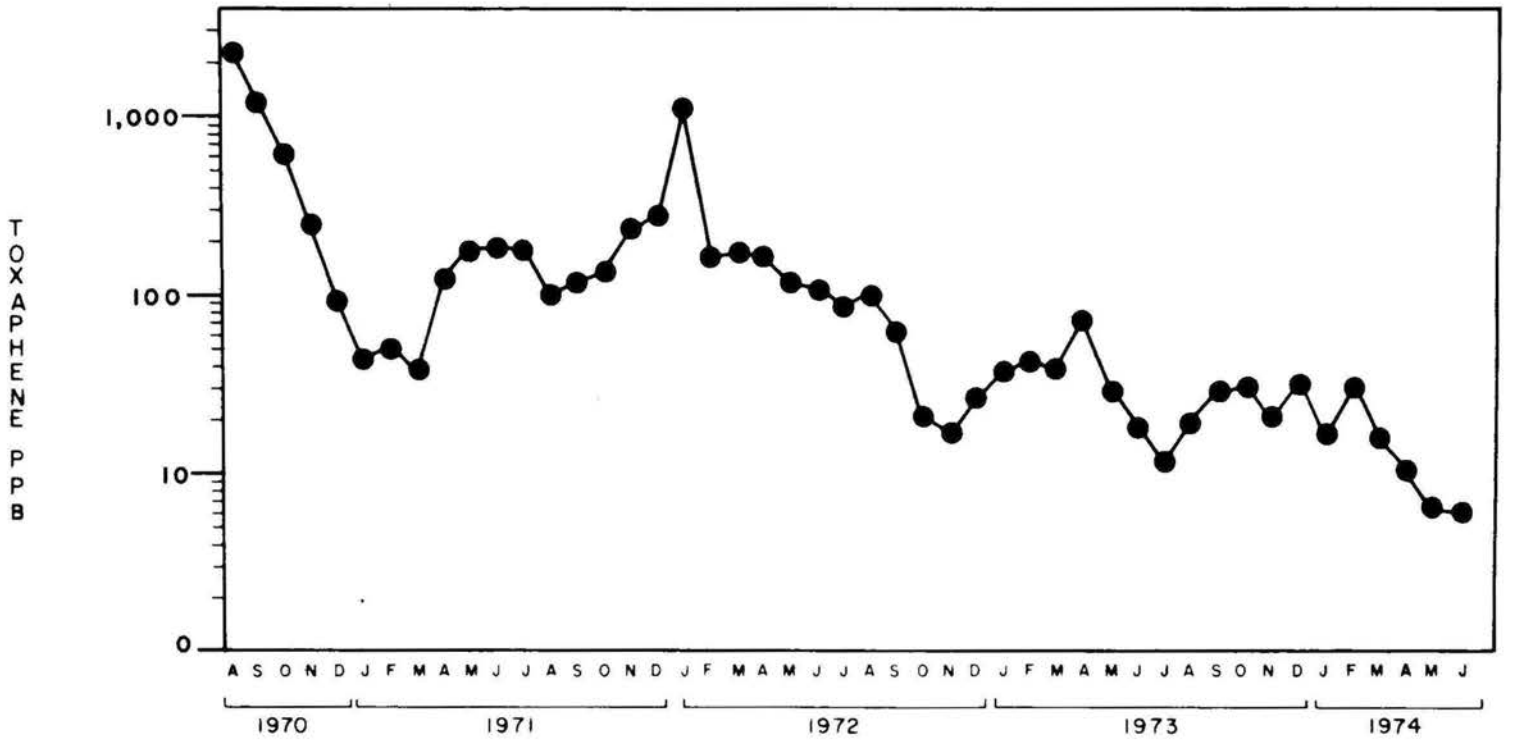

Figure 7. Monthly average of apparent toxaphene concentration of manufacturing plant effluent, 1970-1974. Concentrations expressed in parts per billion (ppb).

Table 5. Uptake of ^{36}Cl labeled Toxaphene by the salt marsh cordgrass, Spartina alterniflora (mean ± one standard deviation).

Days of Incubation	Plant Part	Percent Uptake of Toxaphene	Percent Uptake of ^{36}Cl
26	leaves	0.030 ± 0.0001	0.145 ± 0.0212
26	stems	0.591 ± 0.6081	2.025 ± 1.393
26	roots & rhizomes (combined)	20.145 ± 5.250	22.51 ± 1.639
100	leaves & stems (combined)	0.048 ± 0.0449	0.600 ± 0.3651
100	roots & rhizomes (combined)	1.821 ± 0.727	12.0263 ± 3.658

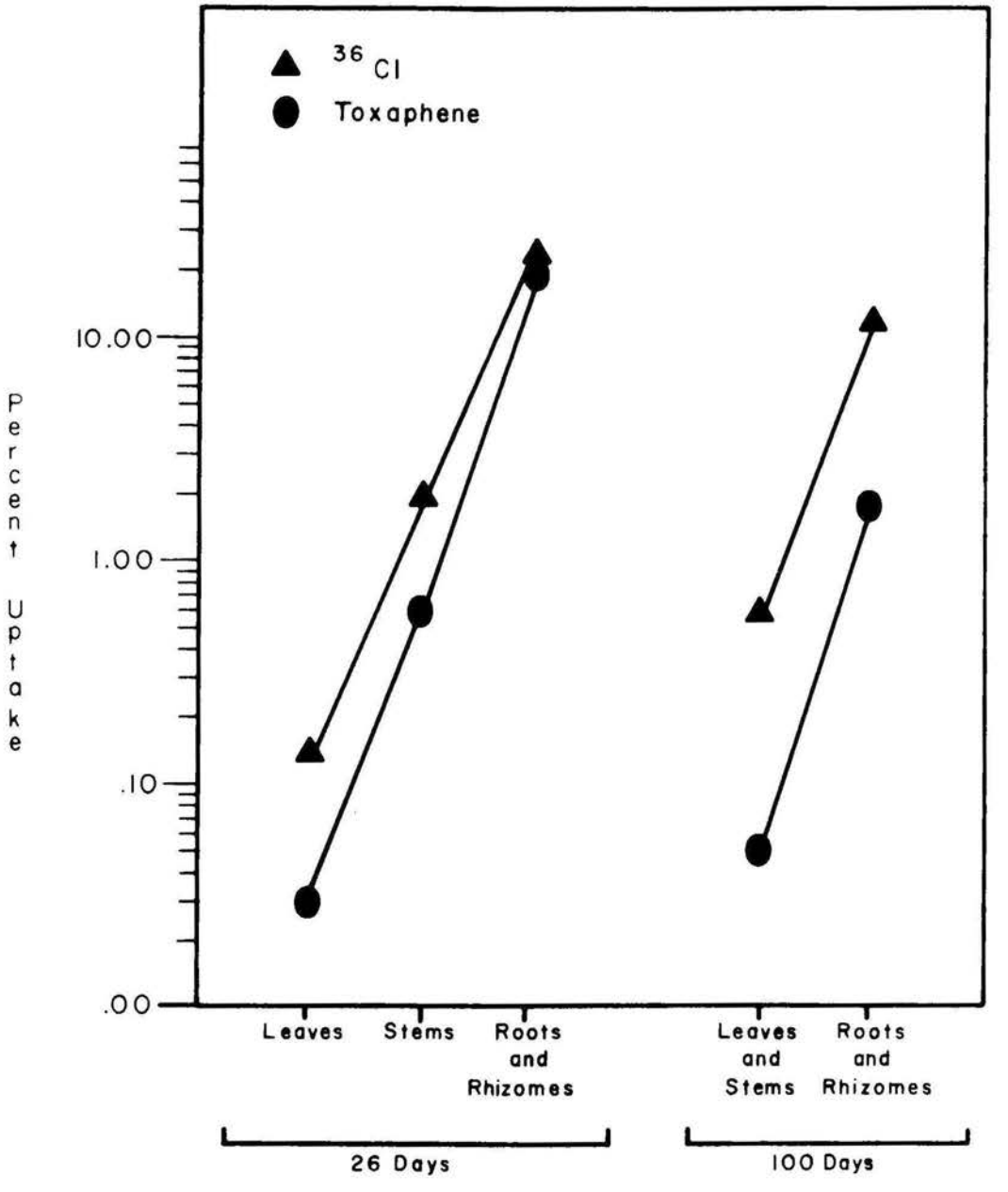

Figure 8. Percent uptake of ^{36}Cl labeled toxaphene by Spartina alterniflora grown in a controlled environment chamber.

Table 6. Average toxaphene concentration (parts per million) and ^{36}Cl concentration (piocuries per mg of plant tissue) in Spartina alterniflora plant parts, after indicated number of days incubation with labeled Toxaphene in sea water (100 ppm toxaphene; 4.316 μc ^{36}Cl). (Mean ± one standard deviation).

Days of Incubation	Plant Part	Toxaphene Concentration ppm	^{36}Cl Concentration pc/mg Plant
26	leaves	6.74 ± 1.17	1.64 ± 0.02
26	stems	47.56 ± 2.80	9.12 ± 3.26
26	roots & rhizomes	61.98 ± 8.45	23.42 ± 7.43
100	leaves & stems	8.78 ± 0.73	5.17 ± 2.14
100	roots & rhizomes	60.56 ± 2.86	19.65 ± 4.35

ENVIRONMENTAL MONITORING

Continued monitoring of toxaphene in selected biota revealed no environmental sample with a concentration greater than 3.47 ppm during 1973-1974. Of the more than 250 samples analyzed, only those listed on Table 7 had significant detectable (0.25 ppm) toxaphene. These concentrations are all considerably lower than those found during 1972-1973 (Reimold, Adams and Durant, 1973).

A summary of four years monitoring the toxaphene content of environmental samples reveals a continual decrease in concentration with the passage of time. The annual mean concentration of toxaphene in the American oyster is shown in Figure 9. In the four years of the study, the oyster never accumulated toxaphene to levels approaching those found in the plant effluent (Figure 7). In the white shrimp (Figure 10), the toxaphene content of the abdomen remained nearly constant while the head and thorax had higher concentrations during 1970-1971 and 1971-1972. The common anchovy (Figure 11), in which toxaphene concentrations decreased from 43.0 ppm during 1970-1971 to 1.8 ppm during 1973-1974, appears to be a better organism to biologically monitor toxaphene than the American oyster. This decrease follows a pattern similar to that in the manufacturing plant effluent (Figure 7).

OTHER RELATED ACTIVITIES

During January 1974, a study was initiated to quantify the dilution that may be associated with the toxaphene manufacturing plant effluent. This was conducted as a separate project by Ms. Sarah Robinson and Ms. Cynthia Vernon, students from DePauw University. The complete description

Table 7. Summary of all significant toxaphene concentrations (part per million-wet weight) of faunal samples analyzed 1973-1974 from the Brunswick, Terry Creek area.

Scientific Name	Common Name	Date of Collection	Collection Quadrat	Toxaphene Concentrations PPM
Anchoviella mitchilli	Common anchovy	24 July 1973	29	3.478
Anchoviella mitchilli	Common anchovy	20 Sept.1973	26/34	3.360
Anchoviella mitchilli	Common anchovy	20 Sept.1973	72	1.789
Anchoviella mitchilli	Common anchovy	20 Sept.1973	60	0.858
Anchoviella mitchilli	Common anchovy	8 Jan. 1974	29	1.555
Anchoviella mitchilli	Common anchovy	5 Mar. 1974	29	2.349
Anchoviella mitchilli	Common anchovy	5 Mar. 1974	26/34	1.478
Anchoviella mitchilli	Common anchovy	5 Mar. 1974	78	3.107
Anchoviella mitchilli	Common anchovy	5 Mar. 1974	60	1.645
Anchoviella mitchilli	Common anchovy	5 Mar. 1974	99	1.065
Anchoviella mitchilli	Common anchovy	30 Apr. 1974	72	0.748
Arius felis	Sea catfish	20 Sept.1973	29	2.166
Bairdiella chysura	Silver perch	24 July 1973	26/34	1.151
Bairdiella chysura	Silver perch	13 Nov. 1973	78	1.119
Bairdiella chysura	Silver perch	24 June 1974	29	0.9122
Bairdiella chysura	Silver perch	24 June 1974	99	0.250
Crassostrea virginica	Eastern oyster	5 Mar. 1974	56	0.554
Eucinostomus gula	Silver jenny	20 Sept.1973	78	1.038
Leiostomus xanthurus	Spot	30 Apr. 1974	60	0.486
Penaeus aztecus	Brown shrimp(head & thorax)	24 June 1974	78	0.250
Penaeus setiferus	White shrimp(head & thorax)	24 July 1973	29	1.772
Penaeus setiferus	White shrimp(head & thorax)	24 July 1973	29	0.511
Penaeus setiferus	White shrimp(head & thorax)	24 July 1973	72	0.250
Penaeus setiferus	White shrimp(head & thorax)	8 June 1974	78	0.879
Stellifer lanceolatus	Star drum	13 Nov. 1973	26/34	0.671
Stellifer lanceolatus	Star drum	13 Nov. 1973	72	0.405
Stellifer lanceolatus	Star drum	8 Jan. 1974	29	0.539
Stellifer lanceolatus	Star drum	30 Apr. 1974	26/34	1.198

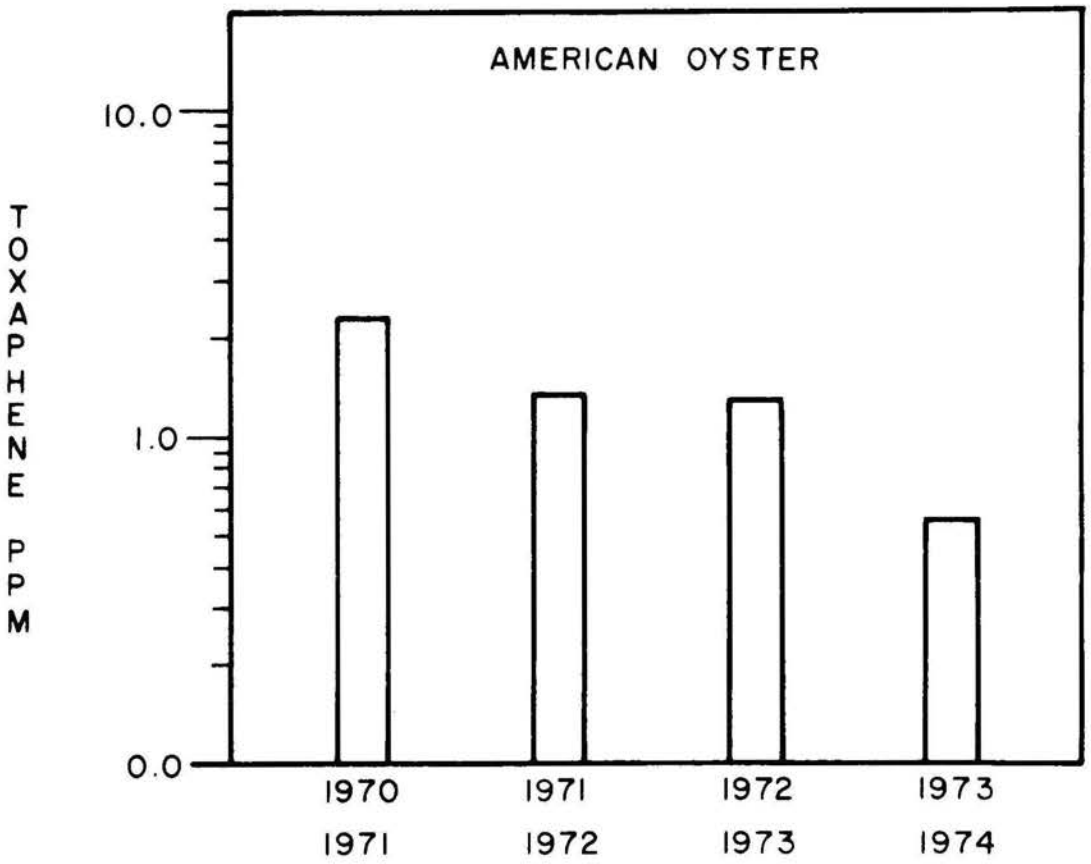

Figure 9. Annual mean toxaphene concentration in the American oyster collected from the Brunswick East Estuary. (Concentration expressed in parts per million, ppm).

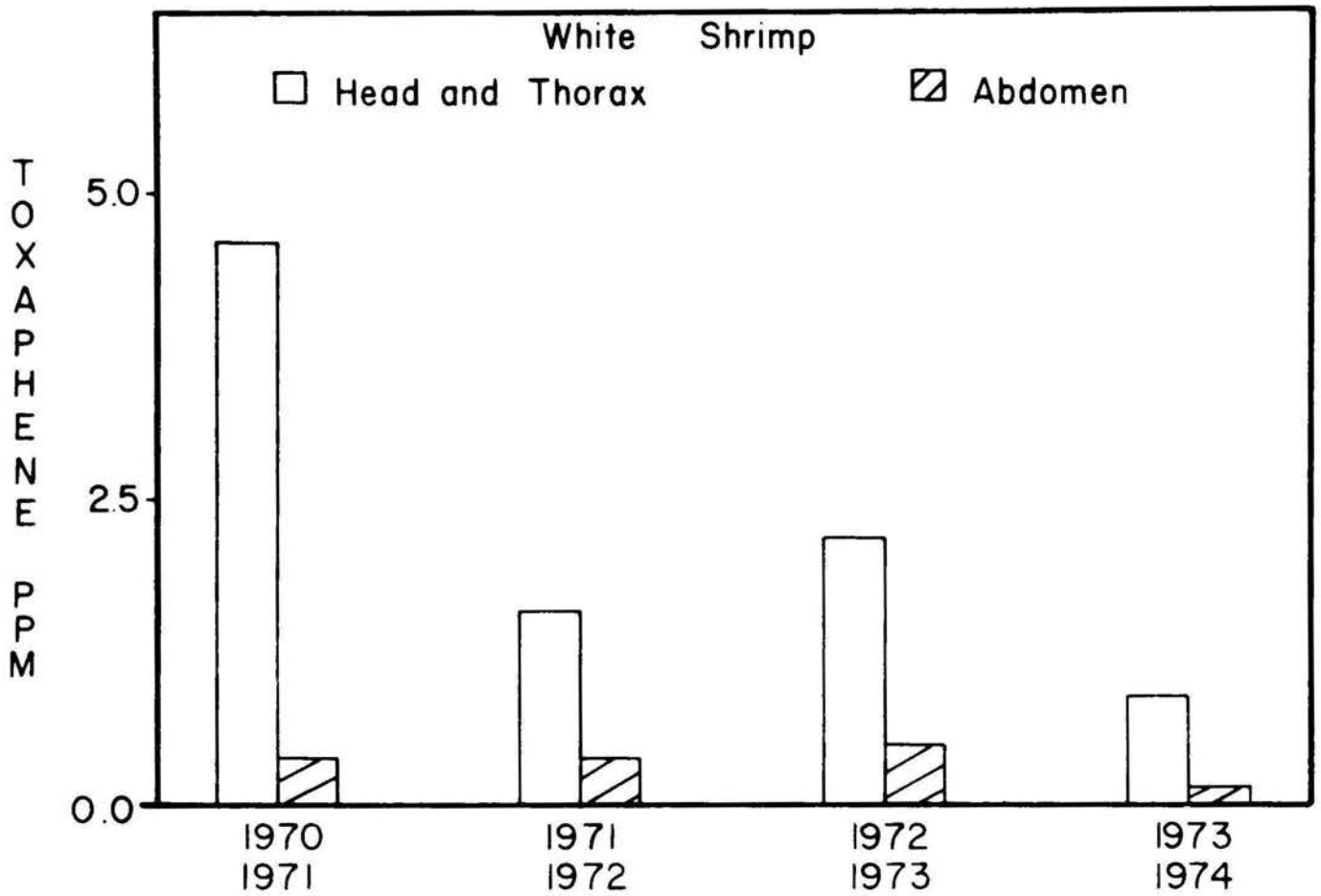

Figure 10. Annual mean toxaphene concentration in white shrimp, collected from the Brunswick East Estuary. (Concentration expressed in parts per million, ppm).

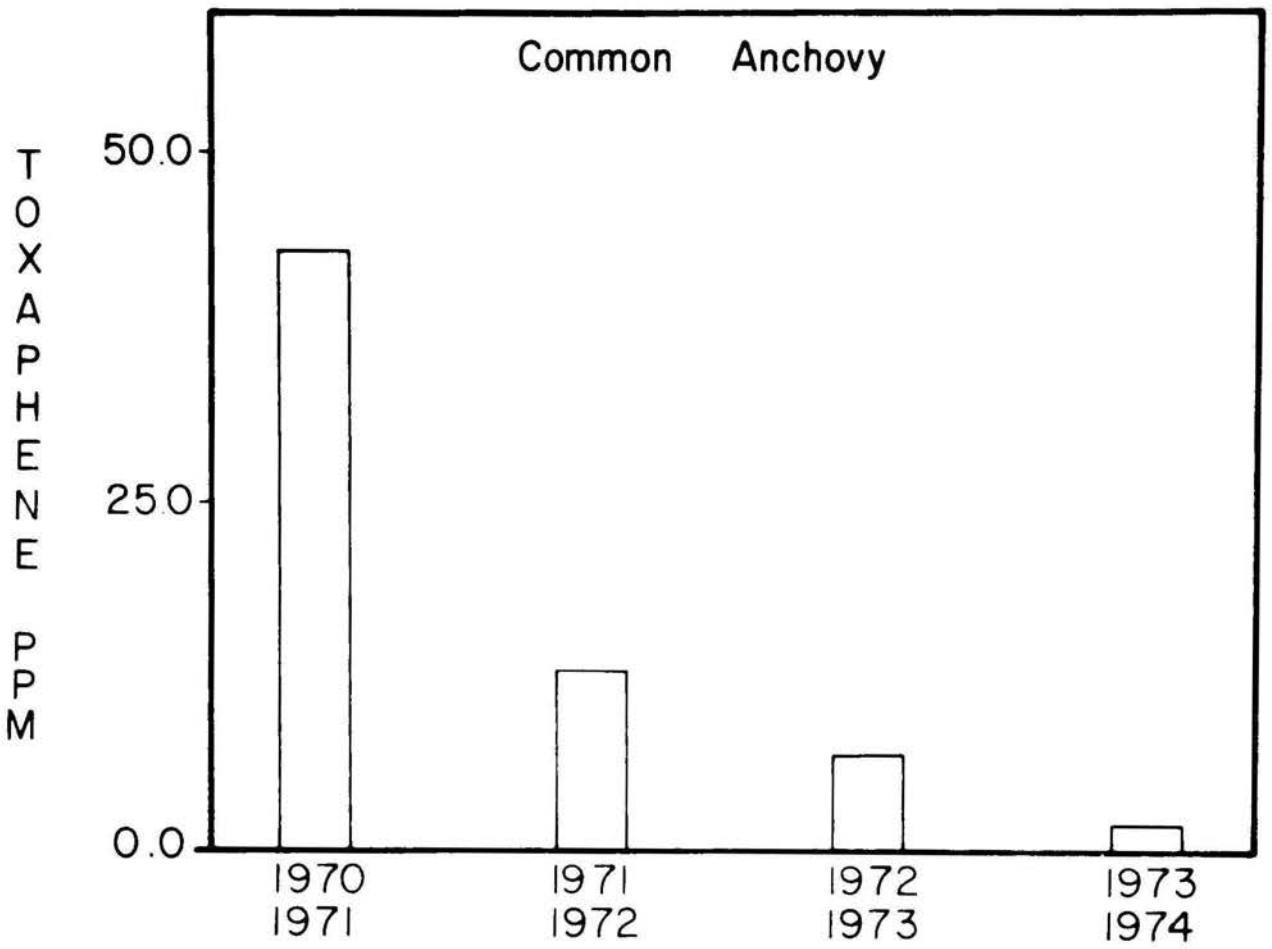

Figure 11. Annual mean toxaphene concentrations in the common anchovy collected from the Brunswick East Estuary. (Concentrations expressed in parts per million, ppm).

of this project (Appendix II) reveals a ten to one dilution of effluent in the Terry Creek Estuary. Based on this work, a more comprehensive dye study is being designed (in conjunction with officials from Hercules, Inc., Brunswick, Ga.) to describe the tidal flushing dynamics and hydrography of the Brunswick East Estuary and Terry Creek.

During 1973-1974, several seminars were presented related to the results of this research. These included presentations at: Department of Zoology, North Carolina State University; Virginia Institute of Marine Science; Biology Department, Armstrong State College; and River Basins Commission, U. S. Department of the Interior. In addition, effort was directed toward providing information to the U. S. Environmental Protection Agency regarding establishment of effluent standards for toxic substances. In this capacity, a written affidavit and live testimony related to the establishment of effluent standards from toxaphene manufacturing plants was provided to EPA.

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APPENDIX I.

Species Diversity Supplemental Information

1973-1974

Appendix I-1

Species diversity and abundance based on number of individuals in the Duplin Estuary for 1973-1974.

H BAR	J	N M Index	Number of Individuals	Number of Species
1.9977	0.5713	0.14398	2658	33

Genus, species	Common Name	Number of Individuals
Anchoviella mitchilli	Common anchovy	274
Arius felis	Sea catfish	19
Astroscopus y-graecum	Southern stargazer	1
Bagre marinus	Gafftopsail catfish	9
Bairdiella chysura	Silver perch	54
Brevoortia tyrannus	Atlantic menhaden	25
Callinectes sapidus	Blue crab	134
Chaetodipterus faber	Spadefish	61
Chilomycterus schoepfi	Striped burrfish	2
Chloroscombrus chrysurus	Bumper	32
Cynoscion regalis	Weakfish	50
Dasyatis americana	Southern stingray	1
Dorosoma cepedianum	Gizzard shad	2
Etropus crossotus	Fringed flounder	3
Eucinostomus gula	Silver jenny	1
Gobiosoma bosci	Naked goby	1
Hypsoblennius hentzi	Feather blenny	2
Ictalurus catus	White catfish	2
Leiostomus xanthurus	Spot	50
Lepisosteus osseus	Longnose gar	1
Loligo brevirostrum	Squid	40
Menticirrhus americanus	Southern kingfish	9
Micropogon undulatus	Croaker	113
Paralichthys dentalus	Summer flounder	4
Penaeus aztecus	Brown shrimp	22
Penaeus duorarum	Pink shrimp	2
Penaeus setiferus	White shrimp	698
Prionotus tribulus	Southern searobin	2
Squilla empusa	Mantis shrimp	1
Stellifer lanceolatus	Star drum	974
Symphurus plagiusa	Tonguefish	64
Trichiurus lepturus	Cutlass fish	3
Trinectes maculatus	Hogchoaker	2

Appendix I-2

Species diversity indices and abundance based on number of individuals in all Brunswick collection sites for 1973-1974.

H BAR	J	N M Index	Number of Individuals	Number of Species
2.4118	0.6784	0.19566	1332	35

Genus, species	Common Name	Number of Individuals
Anchoviella mitchilli	Common anchovy	266
Anquilla rostrata	American eel	2
Arius felis	Sea catfish	9
Bagre marinus	Gafftopsail catfish	1
Bairdiella chysura	Silver perch	160
Brevoortia tyrannus	Atlantic menhaden	1
Callinectes sapidus	Blue crab	109
Centropristis philadelphica	Rock sea bass	1
Chaetodipterus faber	Spadefish	9
Chilomycterus schoepfi	Striped burrfish	3
Chloroscombrus chrysurus	Bumper	1
Cynoscion regalis	Weakfish	54
Dasyatis americana	Southern stingray	1
Dorosoma cepedianum	Gizzard shad	3
Etropus crossotus	Fringed flounder	1
Eucinostomus gula	Silver jenny	6
Fundulus heteroclitus	Mummichog	13
Leiostomus xanthurus	Spot	40
Lepisosteus osseus	Longnose gar	1
Loligo brevirostrum	Squid	53
Menticirrhus americanus	Southern kingfish	1
Micropogon undulatus	Croaker	51
Mugil cephalus	Mullet	1
Opsanus tau	Oyster toadfish	1
Palaemonetes pugio	Grass shrimp	2
Paralichthys dentalus	Summer flounder	8
Penaeus aztecus	Brown shrimp	76
Penaeus duorarum	Pink shrimp	2
Penaeus setiferus	White shrimp	239
Selene vomer	Lookdown	3
Squilla empusa	Mantis shrimp	11
Stellifer lanceolatus	Star drum	187
Symphurus plagiusa	Tonguefish	10
Trichiurus lepturus	Cutlass fish	1
Trinectes maculatus	Hogchoaker	5

Appendix I-3

Species diversity indices and abundance based on number of individuals in all Brunswick collection areas except Terry Creek for 1973-1974.

H BAR	J	N M Index	Number of Individuals	Number of Species
2.3875	0.6953	0.21595	1009	31

Genus, species	Common Name	Number of Individuals
Anchoviella mitchilli	Common anchovy	185
Anquilla rostrata	American eel	2
Arius felis	Sea catfish	3
Bairdiella chysura	Silver perch	115
Brevoortia tyrannus	Atlantic menhaden	1
Callinectes sapidus	Blue crab	70
Chaetodipterus faber	Spadefish	2
Chilomycterus schoepfi	Striped burrfish	3
Chloroscombrus chrysurus	Bumper	1
Cynoscion regalis	Weakfish	43
Dasyatis americana	Southern stingray	1
Dorosoma cepedianum	Gizzard shad	1
Etropus crossotus	Fringed flounder	1
Eucinostomus gula	Sliver jenny	5
Leiostomus xanthurus	Spot	39
Loligo brevirostrum	Squid	48
Menticirrhus americanus	Southern kingfish	1
Micropogon undulatus	Croaker	40
Mugil cephalus	Mullet	1
Opsanus tau	Oyster toadfish	1
Palaemonetes pugio	Grass shrimp	2
Paralichthys dentalus	Summer flounder	7
Penaeus aztecus	Brown shrimp	72
Penaeus duorarum	Pink shrimp	2
Penaeus setiferus	White shrimp	198
Selene vomer	Lookdown	3
Squilla empusa	Mantis shrimp	8
Stellifer lanceolatus	Star drum	139
Symphurus plagiusa	Tonguefish	10
Trichiurus lepturus	Cutlassfish	1
Trinectes maculatus	Hogchoaker	4

Appendix I-4

Species diversity indices and abundance based on number of individuals in Terry Creek for 1973-1974.

H BAR	J	N M Index	Number of Individuals	Number of Species
2.2577	0.7416	0.26490	323	21

Genus, species	Common Name	Number of Individuals
Anchoviella mitchilli	Common anchovy	81
Arius felis	Sea catfish	6
Bagre marinus	Gafftopsail catfish	1
Bairdiella chysura	Silver perch	45
Callinectes sapidus	Blue crab	39
Centropristis philadelphica	Rock sea bass	1
Chaetodipterus faber	Spadefish	7
Cynoscion regalis	Weakfish	11
Dorosoma cepedianum	Gizzard shad	2
Eucinostomus gula	Silver jenny	1
Fundulus heteroclitus	Mummichog	13
Leiostomus xanthurus	Spot	1
Lepisosteus osseus	Longnose gar	1
Loligo brevirostrum	Squid	5
Micropogon undulatus	Croaker	11
Paralichthys dentalus	Summer flounder	1
Penaeus aztecus	Brown Shrimp	4
Penaeus setiferus	White Shrimp	41
Squilla empusa	Mantis Shrimp	3
Stellifer lanceolatus	Star drum	48
Trinectes maculatus	Hogchoaker	1

Appendix I-5

Species diversity indices and abundance based on biomass of trawl collections from the Duplin Estuary for 1973-1974.

H BAR	J	N M Index	Biomass (grams)	Number of Species
2.3765	0.6797	0.22936	23,446	33

Genus, species	Common Name	Biomass (grams)
Anchoviella mitchilli	Common anchovy	448
Arius felis	Sea catfish	676
Astroscopus y-graecum	Southern stargazer	2
Bagre marinus	Gafftopsail catfish	56
Bairdiella chysura	Silver perch	310
Brevoortia tyrannus	Atlantic menhaden	710
Callinectes sapidus	Blue crab	4393
Chaetodipterus faber	Spadefish	275
Chilomycterus schoepfi	Striped burrfish	93
Chloroscombrus chrysurus	Bumper	77
Cynoscion regalis	Weakfish	271
Dasyatis americana	Southern stingray	524
Dorosoma cepedianum	Gizzard shad	84
Etrops crossotus	Fringed flounder	18
Eucinostomus gula	Silver jenny	12
Gobiosoma bosci	Naked goby	1
Hypsoblennius hentzi	Feather blenny	10
Ictalurus catus	White catfish	14
Leiostomus xanthurus	Spot	1041
Lepisosteus osseus	Longnose gar	1004
Loligo brevirostrum	Squid	212
Menticirrhus americanus	Southern kingfish	276
Micropogon undulatus	Croaker	1136
Paralichthys dentalus	Summer flounder	206
Penaeus aztecus	Brown shrimp	214
Penaeus duorarum	Pink shrimp	25
Penaeus setiferus	White shrimp	6920
Prionotus tribulus	Southern searobin	77
Squilla empusa	Mantis shrimp	12
Stellifer lanceolatus	Star drum	2860
Symphurus plagiusa	Tonguefish	1374
Trichiurus lepturus	Cutlassfish	10
Trinectes maculatus	Hogchoaker	103

Appendix I-6

Species diversity indices and abundance based on biomass of trawl collections from all Brunswick collection areas for 1973-1974.

H BAR	J	N M Index	Biomass (grams)	Number of Species
2.6247	0.7382	0.28204	18,354	35

Genus, species	Common Name	Biomass (grams)
Anchoviella mitchilli	Common anchovy	480
Anquilla rostrata	American eel	577
Arius felis	Sea catfish	698
Bagre marinus	Gafftopsail catfish	11
Bairdiella chysura	Silver perch	1621
Brevoortia tyrannus	Atlantic menhaden	151
Callinectes sapidus	Blue crab	4513
Centropristis philadelphica	Rock sea bass	9
Chactodipterus faber	Spadefish	30
Chilomycterus schoepfi	Striped burrfish	32
Chloroscombrus chrysurus	Bumper	1
Cynoscion regalis	Weakfish	621
Dasyatis americana	Southern stingray	557
Dorosoma cepedianum	Gizzard shad	11
Etropus crossotus	Fringed flounder	3
Eucinostomus gula	Silver jenny	46
Fundulus heteroclitus	Mummichog	120
Leiostomus xanthurus	Spot	2436
Lepisosteus osseus	Longnose gar	512
Loligo brevirostrum	Squid	205
Menticirrhus americanus	Southern kingfish	2
Micropogon undulatus	Croaker	753
Mugil cephalus	Mullet	143
Opsanus tau	Oyster toadfish	206
Palaemonetes pugio	Grass shrimp	3
Paralichthys dentalus	Summer flounder	761
Penaeus aztecus	Brown shrimp	892
Penaeus duorarum	Pink shrimp	26
Penaeus setiferus	White shrimp	1771
Selene vomer	Lookdown	19
Squilla empusa	Mantis shrimp	43
Stellifer lanceolatus	Star drum	754
Symphurus plagiusa	Tonguefish	234
Trichiurus lepturus	Cutlassfish	0
Trinectes maculatus	Hogchoaker	112

Appendix I-7

Species diversity indices and abundance based on biomass of trawl collections from all Brunswick collection areas except Terry Creek for 1973-1974.

H BAR	J	N M Index	Biomass (grams)	Number of Species
2.5574	0.7447	0.28992	14,466	31

Genus, species	Common Name	Biomass (grams)
Anchoviella mitchilli	Common anchovy	252
Anquilla rostrata	American eel	577
Arius felis	Sea catfish	290
Bairdiella chysura	Silver perch	1339
Brevoortia tyrannus	Atlantic menhaden	151
Callinectes sapidus	Blue crab	3058
Chaetodipterus faber	Spadefish	3
Chilomycterus schoepfi	Striped burrfish	32
Chloroscombrus chrysurus	Bumper	1
Cynoscion regalis	Weakfish	565
Dasyatis americana	Southern stingray	557
Dorosoma cepedianum	Gizzard shad	4
Etropus crossotus	Fringed flounder	3
Eucinostomus gula	Silver jenny	30
Leiostomus xanthurus	Spot	2431
Loligo brevirostrum	Squid	185
Menticirrhus americanus	Southern kingfish	2
Micropogon undulatus	Croaker	608
Mugil cephalus	Mullet	143
Opsanus tau	Oyster toadfish	206
Palaemonetes pugio	Grass shrimp	3
Paralichthys dentalus	Summer flounder	753
Penaeus aztecus	Brown shrimp	838
Penaeus duorarum	Pink shrimp	26
Penaeus setiferus	White shrimp	1545
Selene vomer	Lookdown	19
Squilla empusa	Mantis shrimp	39
Stellifer lanceolatus	Star drum	518
Symphurus plagiusa	Tonguefish	234
Trichiurus lepturus	Cutlassfish	0
Trinectes maculatus	Hogchoaker	55

Appendix I-8

Species diversity indices and abundance based on biomass of trawl collections from Terry Creek for 1973-1974.

H BAR	J	N M Index	Biomass (grams)	Number of Species
2.1313	0.7001	0.27439	3,888	21

Genus, species	Common Name	Biomass (grams)
Anchoviella mitchilli	Common anchovy	227
Arius felis	Sea catfish	408
Bagre marinus	Gafftopsail catfish	11
Bairdiella chysura	Silver perch	282
Callinectes sapidus	Blue crab	1456
Centropristis philadelphica	Rock sea bass	9
Chaetodipterus faber	Spadefish	27
Cynoscion regalis	Weakfish	56
Dorosoma cepedianum	Gizzard shad	7
Eucinostomus gula	Silver jenny	17
Fundulus heteroclitus	Mummichog	120
Leiostomus xanthurus	Spot	6
Lepisosteus osseus	Longnose gar	512
Loligo brevirostrum	Squid	19
Micropogon undulatus	Croaker	145
Paralichthys dentalus	Summer flounder	8
Penaeus aztecus	Brown shrimp	54
Penaeus setiferus	White shrimp	226
Squilla empusa	Mantis shrimp	5
Stellifer lanceolatus	Star drum	236
Trinectes maculatus	Hogchoaker	57

APPENDIX II.

Flushing Pattern Of

The Brunswick East Salt Marsh Estuary

By

Cynthia Vernon and Sarah Robinson

Edited By Dr. Robert J. Reimold

ABSTRACT

A dye study using fluorescent Rhodamine WT was conducted over a twelve hour tidal cycle in an estuary near Brunswick, Georgia. Water samples were collected at fifteen minute intervals from eight locations. These samples were later analyzed in the laboratory to determine dye concentration. The research was conducted to establish the dilution pattern of effluent from a local chemical plant.

Initially, the dye was concentrated in a narrow column as it flowed out with the receding tide. As the dye gradually moved into larger bodies of water the column began to broaden due to mixing. Samples taken from several stations during this ebb tide did not reveal any fluorescence, indicating that the main thrust of the dye bypassed several of the sample stations, taking a rather direct route to the ocean. However, with the flooding tide the presence of dye was recorded at every station. This indicates that plant effluent, assuming it follows the same general flow as the dye, was carried to St. Simons Sound, diluted considerably, and returned with the flooding tide. It can then be detected over a much wider area than at the time of the first high tide.

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Mr. Roberts, Mr. and Mrs. Roy Smith, Mr. David Gould, Georgia Game & Fish Division, and the entire staff of Hercules, Inc., Brunswick, Georgia, for their assistance in logistic support and permission to use their facilities for collection sites.

INTRODUCTION

This study, conducted during January, 1974, was based on the century-old concept that a tracer can be added to the water and that chemical analysis of water samples, taken downstream from the point of introduction of the tracer, can be used to indicate the amount of dilution that had occurred. At one time, radioactive tracers were used for this procedure. Currently, fluorescent dyes have proven to be a more effective tracer. Fluorescent compounds emit light as the immediate result of the absorption of radiation from some other source. Four fluorescent dyes in use today include Fluorescein, Rhodamine B, Pontacyl Brilliant Pink, and Rhodamine WT, of which the Rhodamine WT is the newest. One known advantage of Rhodamine WT is its low sorption tendencies on soils and suspended sediments. In addition, this dye appears to be more stable than previous fluorescent dyes, is relatively inexpensive, and easy to handle (G. K. Turner Associates 1971).

A fluorometer, used to measure the concentration of the fluorescent dye, can detect concentrations to as low as 0.01 parts per billion. A beam of light is directed through a color filter (to obtain the selected wavelength) onto the fluorescent sample. Another filter is positioned to absorb the original beam of light, allowing only the fluorescent light to be transmitted. This light is then measured directly, its intensity being linearly related to the concentration of fluorescent material (G. K. Turner Associates 1971).

The area directly east of Brunswick, Georgia, used in this study has been described as a salt marsh watershed (Reimold et al 1973), but can be referred to simply as an estuarine marsh. According to Pritchard (1955), an

estuary is a "semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage". Estuarine marshes are usually found behind a barrier island (in this case, St. Simons Island) and contain salt tolerant plants subjected to the diurnal flow of sea water (Thompson et al 1973). Marshes are also "characterized by an intricate drainage pattern of tidal creeks" (Steers 1958), which are constantly changing due to 1) the formation of dams by spreading vegetation, 2) undercutting from erosion, or 3) the creation of a secondary marsh. The Terry Creek area drainage channels have been somewhat stabilized in location by the Spartina alterniflora (salt marsh cord grass) root development on the mud flats (Ragotzkie 1958). Their characteristic drainage and dilution patterns can be determined by the use of tracer dyes in the water.

This paper deals with the results from a dye study performed on Terry Creek and the surrounding estuary (Figure 1) to determine the diffusion and dilution patterns of effluent from a local chemical plant. According to K. F. Bowden (1958), one of the major areas of estuarine investigation should involve the effects of circulation and mixing processes on the movement and dispersion of foreign substances introduced to the estuary in various ways. This study provides information regarding the dilution pattern in a specific body of water which can be used to estimate the flow and concentration of the chemical plant effluent as well as other foreign substances after their addition to this water.

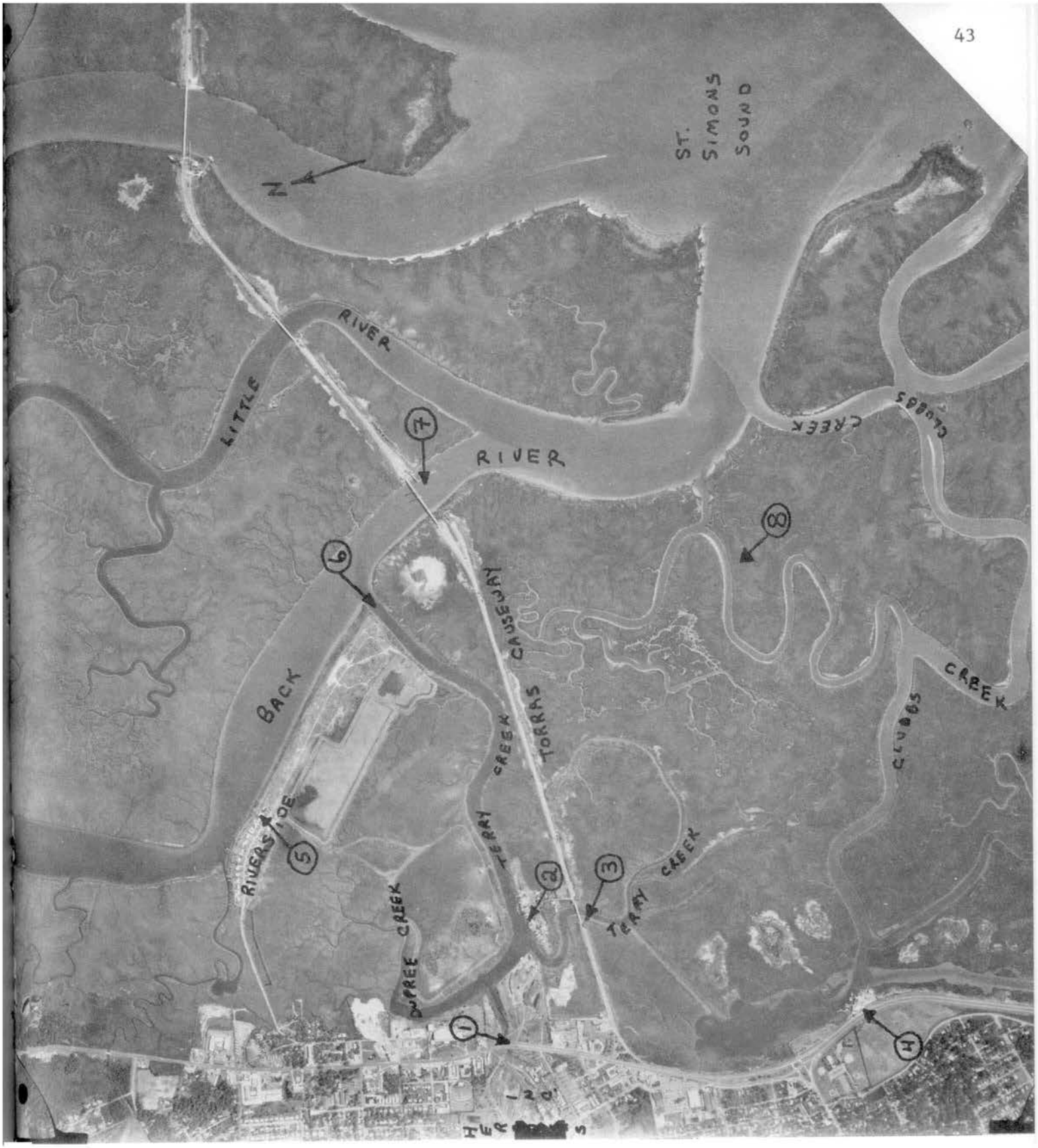


Figure 1. Geographic location of collection stations east of Brunswick, Ga. Scale 1:24000

METHODS

Before samples from Terry Creek could be analyzed, a calibration of the fluorometer was necessary (Carpenter 1960). Five known concentrations of Rhodamine WT dye, 1.25, 2.5, 5, 10, and 20 parts per billion, were analyzed using a Turner Model 111 Fluorometer with primary filter #110-832 (0.546 μ) and secondary filter #110-833 (0.590 μ). A linear regression was computed with the recorded values and the resulting equation,

$$\hat{y} = 1.86 + .25x$$

was then used to determine the dye concentrations from the Terry Creek study. By substituting the fluorescent unit found by the fluorometer for x, the average dye concentration in parts per billion was the resultant $\hat{y}$ value.

When determining the amount of dye required for a project there are two factors to consider: the volume of water involved, and the discharge and turbulence for the particular stream (G. K. Turner Associates 1971). By combining known facts with reasonable speculation the proper amount to add can be derived. For this study, enough Rhodamine WT dye was applied to attain a theoretical concentration in Terry Creek of at least 10 parts per billion. The dye, obtained from E. I. DuPont Company, Organic Chemicals Department, Dyes and Chemicals Division, Doraville, Georgia, (code #314600) in a liquid form, was at a concentration of 20 parts per hundred.

Knowing the flow of effluent from the chemical plant effluent ditch (the first collection site) to be 7.57×10^7 liters per day and assuming this to be diluted by Terry Creek to 7.57×10^8 liters per day, the hourly flow can be calculated as approximately 3×10^6 million liters, if the flow rate is linear. The dye injection was adjusted to extend over a two and a half hour period. To obtain the 10 parts per billion desired concentration,

in theory about one liter of dye would be required. To insure adequate concentration approximately 19 liters of dye were added.

The Rhodamine WT dye was added from 1530 hours (high slack water) to 1755 hours. A continuous flow of dye was obtained by siphoning it from a barrel on a catwalk directly over the effluent ditch. During the twelve hour period a complete tidal cycle (both ebb and flood tides) was observed to provide information concerning the amount and location of dye that may be carried back upstream by incoming water, after its initial dispersion in the ebbing tide.

From 1530 hours, 15 January 1974, until 0430 hours, 16 January, water samples were taken every fifteen minutes and placed in plastic sample bottles for transport to the laboratory. Eight different sites (Figure 1) in the salt marsh watershed east of Brunswick, Georgia, were sampled: 1) the effluent ditch from a chemical plant (dye was also introduced at this point), 2) Roberts' Dock, 3) Terry Creek bridge, 4) the dock at the Georgia Department of Natural Resources, Game and Fish Division, 5) a private dock at Riverside, a housing development, 6) the junction of Terry Creek and Back River, 7) the toll bridge on the Torras Causeway over Back River, and 8) a site along Clubbs Creek. These eight locations were chosen in order to cover all possible avenues along which the ebbing tide might carry the dye. We assumed the major outward flow would be along the branch of Terry Creek towards station #4, the Game and Fish dock, or up Back River to Riverside, station #5. Assuming the flooding tide will return some dye with it, dye could appear at station #8 along Clubbs Creek, an unlikely spot for the dye to reach with the ebbing tide. The tide could also carry dye at some of the stations further west, reversing the previous flow.

RESULTS

The results of the fluorometer analyses show that a definite dispersion and dilution pattern can be traced in the area studied and that previously conceived ideas regarding the tidal flow were strengthened in some cases and altered in others. Each station used for sampling revealed a different individual pattern but when viewed on the whole, most dye concentrations fit a generalized pattern directly following the ebb and flood of the tides.

Since all of the Rhodamine WT dye was added at station #1, readings during the first 2½ hours were the highest at this location (Figure 2). The initial dye concentration, taken directly from the barrel used for mixing, was recorded at 2.1×10^6 ppb. This concentration was immediately diluted by the water of the effluent ditch resulting in readings that started at 6251.86 ppb, reduced to less than 1000 ppb and increased again to 2851.86 ppb before the dye addition was completed. Concentrations quickly fell to less than 5 ppb after 1800 hours, generally decreasing until 2030 hours when a slight but steady increase in fluorescence was recorded. With the exception of minor upward fluctuations at 2145, 2215, and 2415 hours, the concentration remained under 3 ppb until 0245 hours, when an overall increase was observed in the readings. The final reading taken at high water (0430 hours) was 10.61 ppb.

Samples taken from station #2 (Figure 3) began with a concentration of 1.92 ppb which increased to 36.86 ppb at 1615 hours, approximately 45 minutes after the introduction of the dye upstream. The main flow of dye seemed to be toward the northern side of Terry Creek, since dye was noticed on the opposite side of the creek at 1600 hours. Fluorescence increased gradually to 58.74 ppb at 1845 hours and then decreased again when no further dye was

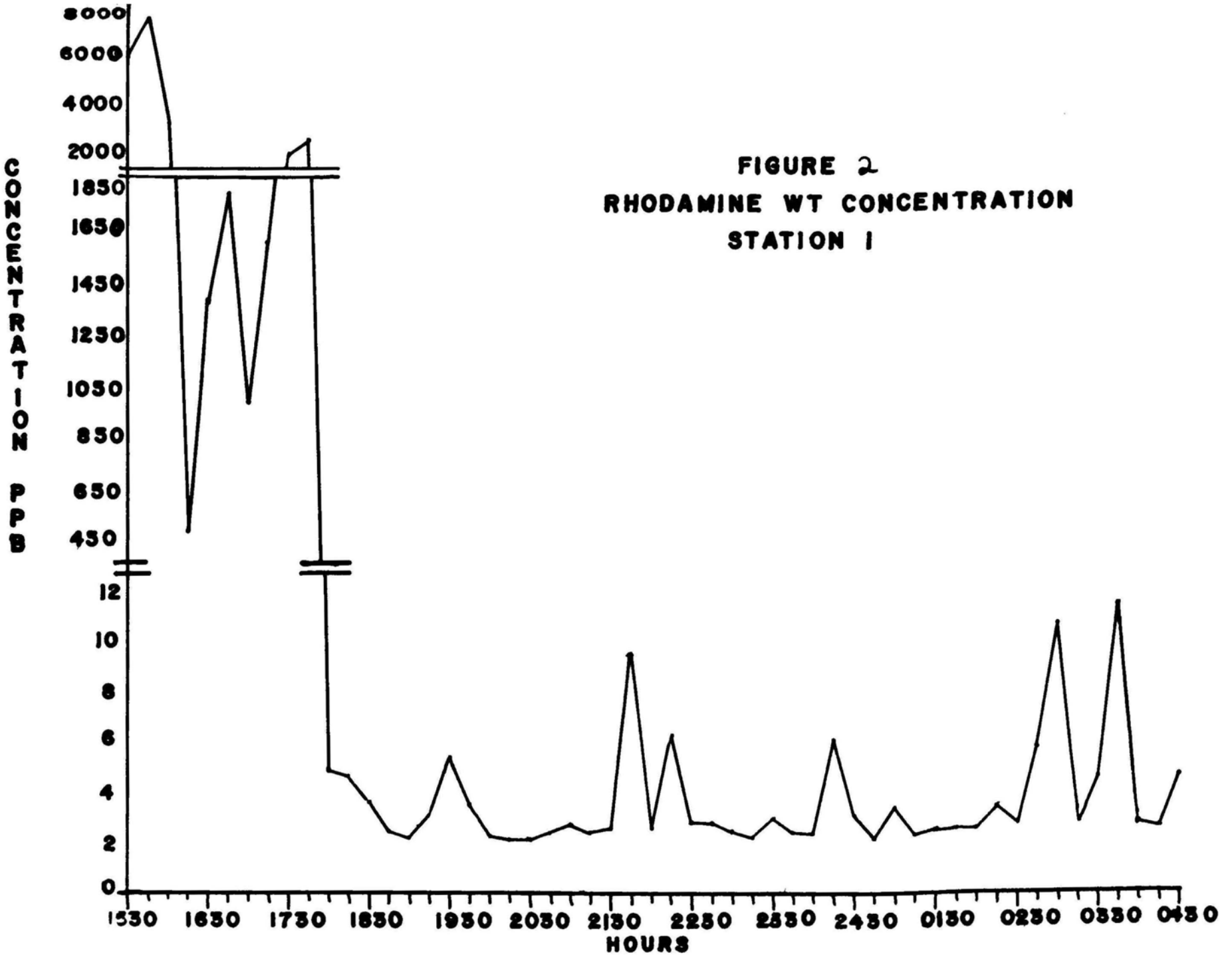


FIGURE 2
RHODAMINE WT CONCENTRATION
STATION 1

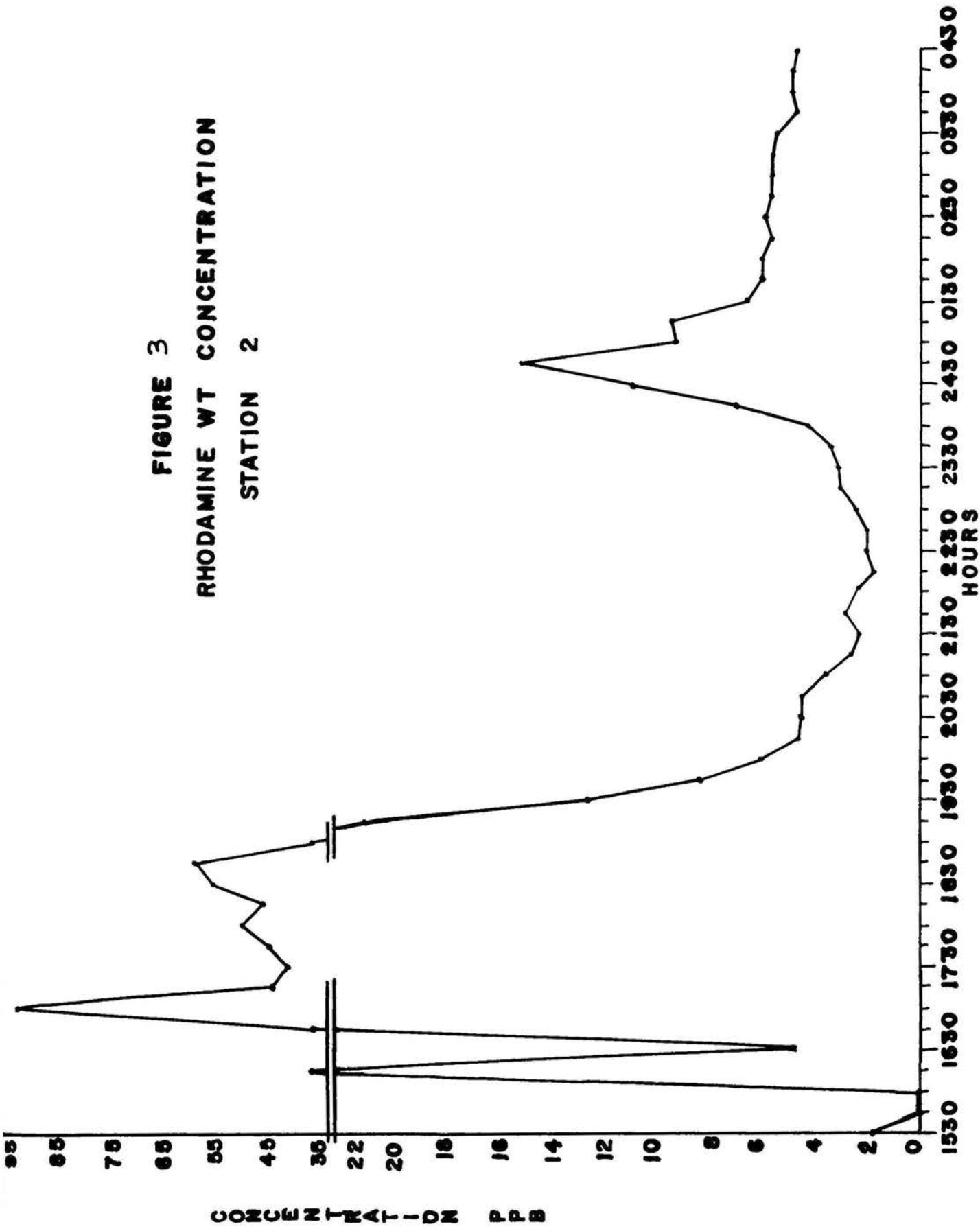


FIGURE 3
RHODAMINE WT CONCENTRATION
STATION 2
CONCENTRATION PPB
95
85
75
65
55
45
35
22
20
18
16
14
12
10
8
6
4
2
0
1530
1630
1730
1830
2030
2130
2230
2330
2430
0130
0230
0330
0430
HOURS

was added at station #1. Concentrations dropped to 12.86 ppb at 1930 hours, 4.74 ppb an hour later and finally stopped at 2.05 ppb at 2245 hours. An increase between 2300 and 2445 hours was noticed with fluorescent readings peaking again at 15.36 ppb. Concentrations gradually declined to 4.74 ppb on the last reading.

No fluorescence was found in station #3 (Figure 4) samples until 1645 hours when a reading of 1.99 ppb was recorded. The values remained low (not exceeding 2.11) until 2045 hours when values rose to 4.36 ppb. Concentrations decreased again until jumping to 14.74 ppb at 2445 hours. After this reading the values decreased gradually with the incoming tide.

Station #4 (Figure 5) was characterized by extremely low fluorescent readings, rarely registering a value at all and only exceeding 2 ppb in four samples. Five values averaging 2 ppb were recorded from 1845 to 1945 hours and readings fluctuated between 0 and 1.92 ppb until 0400 hours. The two highest readings, taken from the last two samples, showed an increase from 2.36 to 2.61 ppb at high slack water.

In samples taken from station #5 (Figure 6), fairly high background fluorescent readings were observed, ranging from 2.11 ppb in the first sample to 1.92 ppb. Higher concentrations were noted beginning at 0100 hours with a reading of 2.86 ppb but values again gradually decreased as the tide rose, ending with a slight increase at 0430 hours.

Dye concentrations at station #6 (Figure 7) would be expected to show two major peaks as the dye flowed out and back in with the tide. Instead, an unusual pattern was obtained. Flourescent readings showing dye from Terry Creek were first noticed at 1730 hours, two hours after the dye had been added. Concentrations increased to 36.86 ppb at 1930 hours, decreased

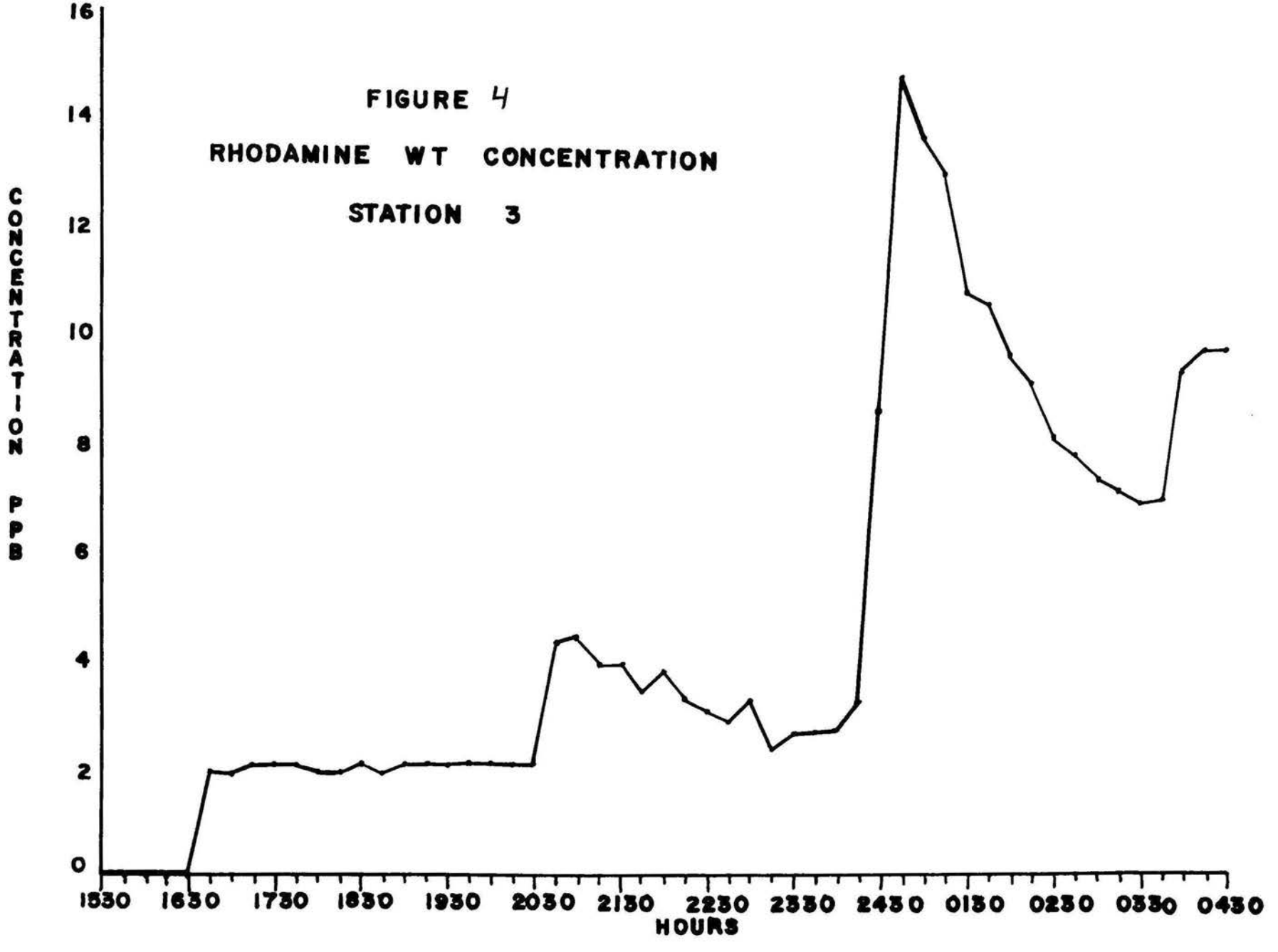


FIGURE 4
RHODAMINE WT CONCENTRATION
STATION 3
CONCENTRATION PPB
0
2
4
6
8
10
12
14
16
1530
1630
1730
1830
1930
2030
2130
2230
2330
2430
0130
0230
0330
0430
HOURS

FIGURE 5

RHODAMINE WT CONCENTRATION

STATION 4

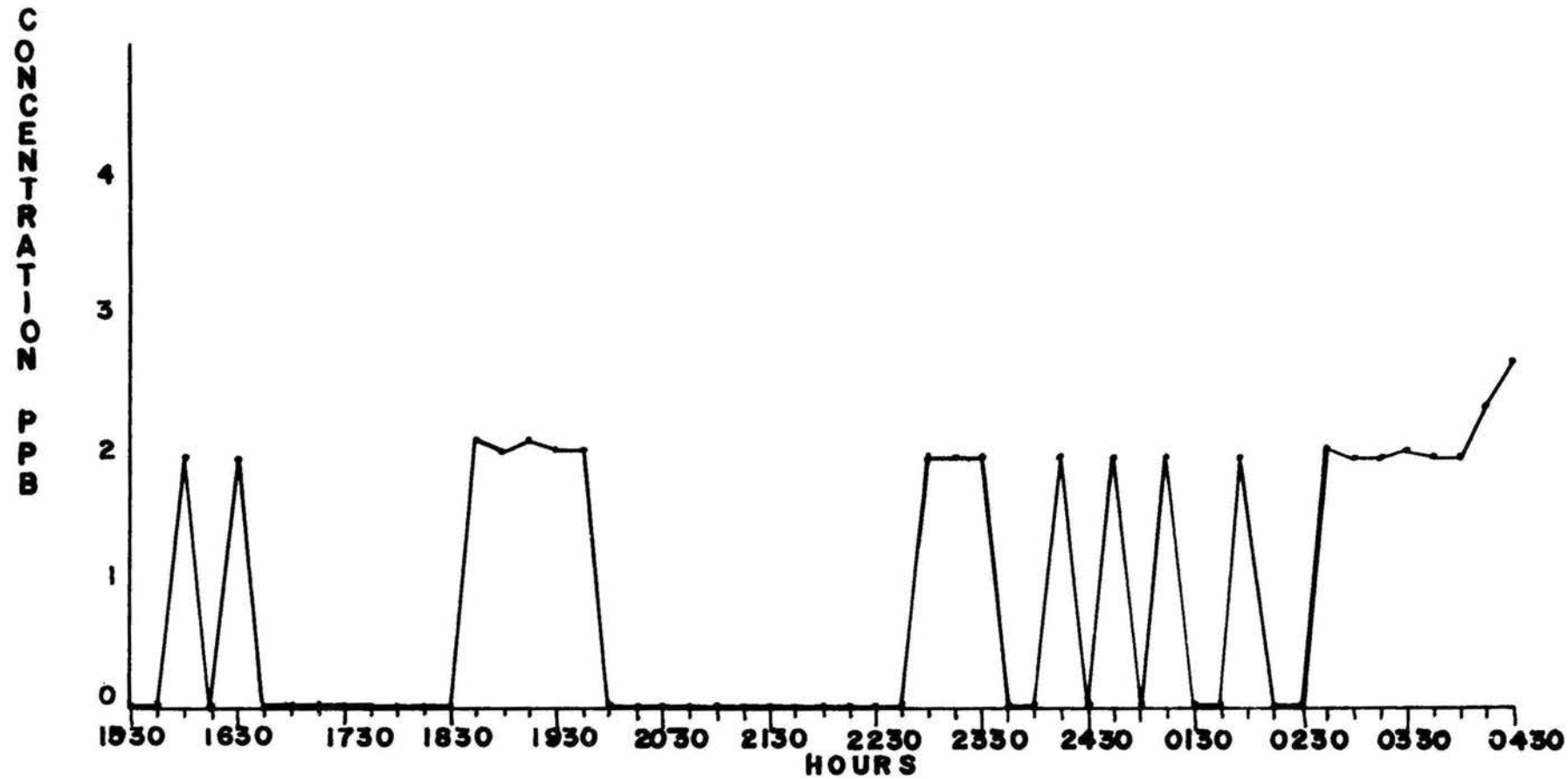


FIGURE 6

RHODAMINE WT CONCENTRATION

STATION 5

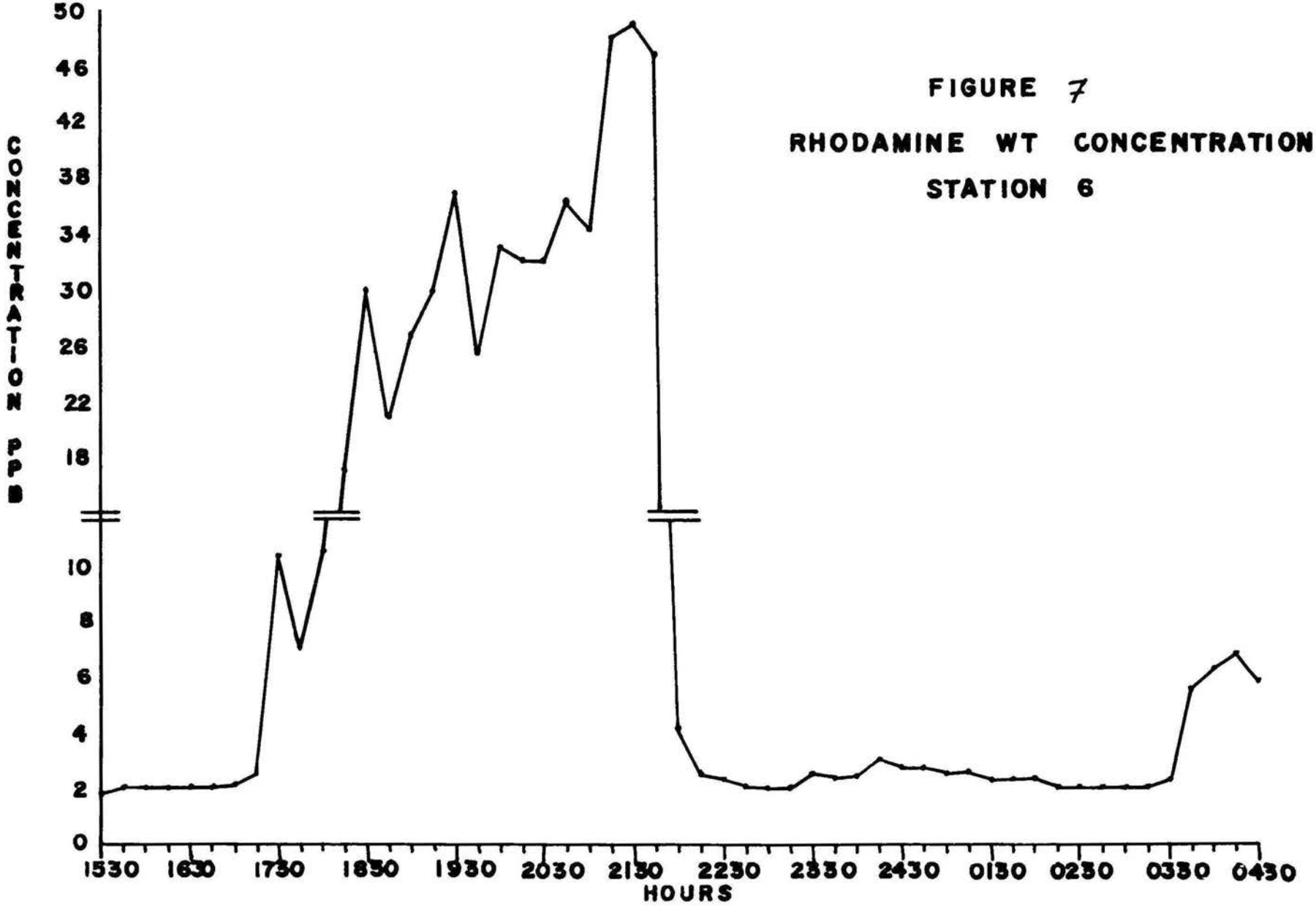


FIGURE 7

RHODAMINE WT CONCENTRATION

STATION 6

somewhat the following hour, and rose again to a high of 46.86 ppb at 2145 hours. An immediate decrease to 4.11 ppb was recorded in the next sample, with concentrations remaining fairly low until 2330 hours. Following this was a slight rise in fluorescence to 3.11 ppb, though subsequent values fell steadily until 0315 hours. The last five samples taken showed higher values, averaging about 6 ppb.

Lower than expected fluorescent readings were obtained at station #7 (Figure 8) along Back River. Low dye concentrations (1.92 to 2.05 ppb) were observed between 1845 and 2000 hours and again between 2100 and 2245 hours. Values increased steadily to 2.86 ppb at 2345 hours but returned quickly to concentrations averaging 1.99 ppb, maintaining this value until 0415 hours. The last sample showed the highest concentration for that station, 3.74 ppb.

No significant readings were obtained for station #8 until 2430 hours (Figure 9) when the dye concentration became 2.55 ppb. An increase to 3.05 ppb at 0100 hours was followed by a steady decrease in values, and a return to the basic background figures after 0230 hours.

DISCUSSION

Fluorescent Rhodamine WT dye was introduced into Terry Creek at 1530 hours on January 15, 1974. In general, the dye was confined to a rather narrow column as it flowed along Terry Creek with the ebbing tide. The researchers stationed at site #6 observed that upon entering Back River this column broadened somewhat; not enough, however, to span the width of the river. By the time the dye had been carried the length of Back River to St. Simons Sound it had taken on a much wider shape, perhaps due to the dilution and mixing that had occurred in the larger body of water. The dye

FIGURE 8

RHODAMINE WT CONCENTRATION

STATION 7

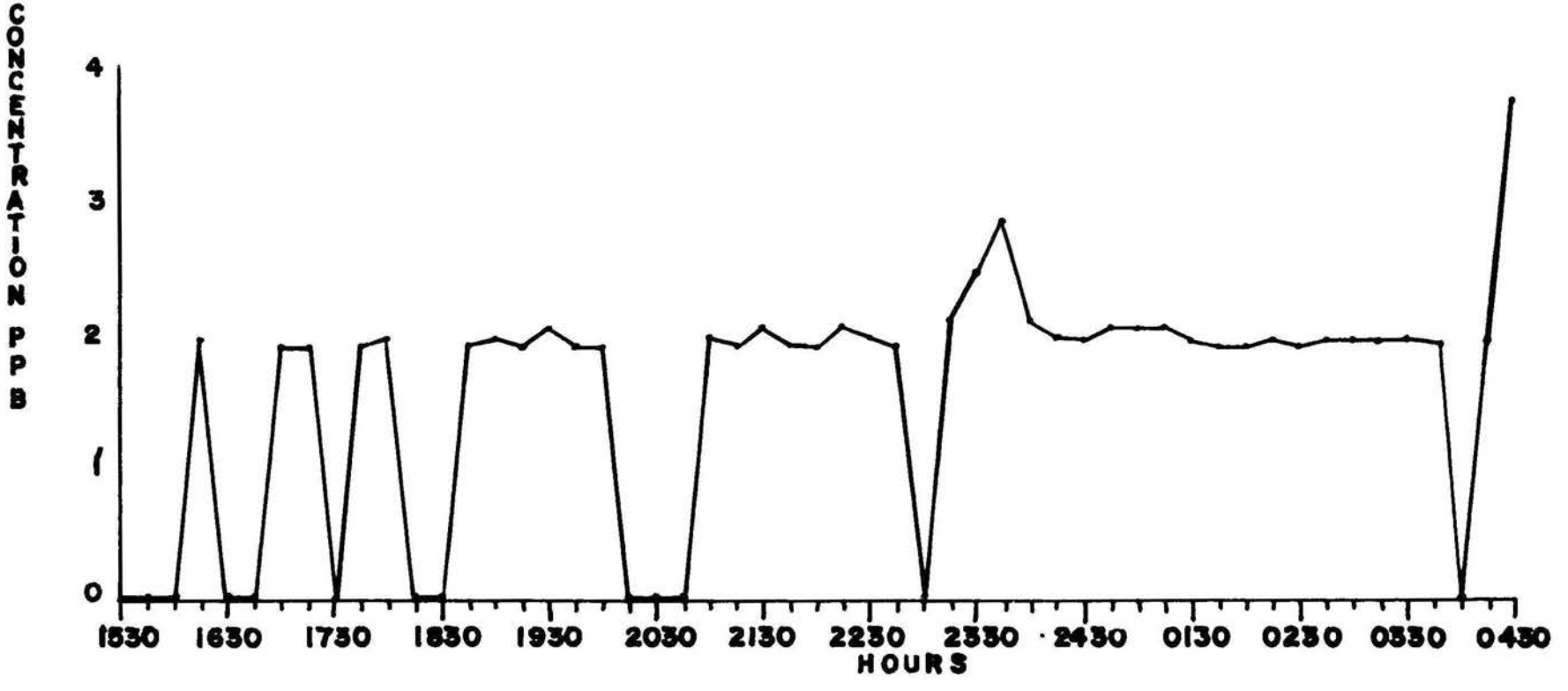
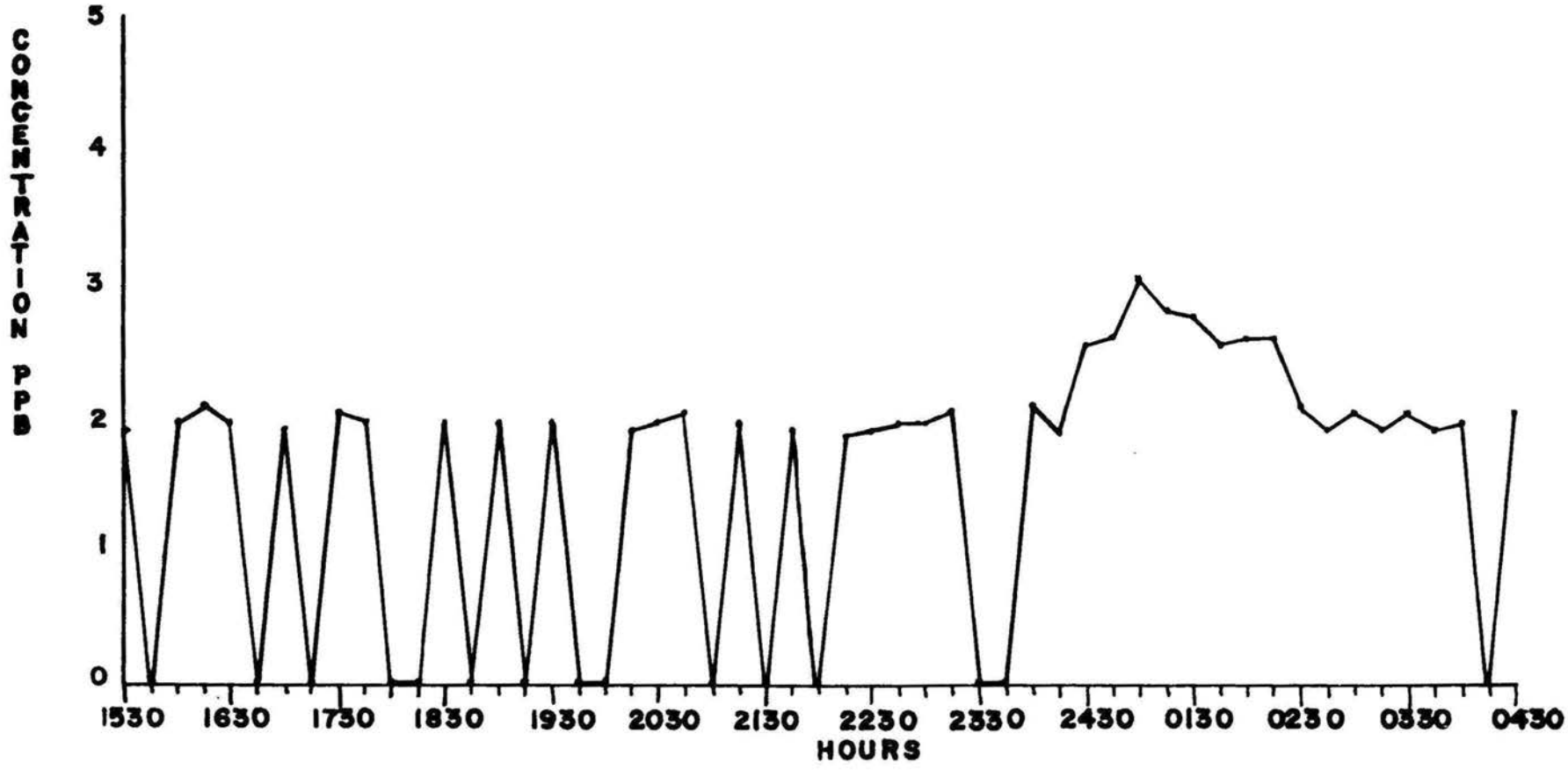


FIGURE 9

RHODAMINE WT CONCENTRATION

STATION 8



served as an indicator of the circulation pattern of this particular portion of the estuary, in addition to providing a means to determine the dispersion pattern of effluent added to the water. Because a relatively small amount of dye was detected at stations #4, #5, #7, and #8 during the period in which the tide was receding, the main thrust of the dye bypasses these areas, taking a more direct route to the ocean by flowing along Terry Creek towards Back River and into St. Simons Sound. Researchers at station #3 observed that the water flowed north into the main channel of Terry Creek during the ebb tide. Because this flow was opposite to the direction in which the dye was traveling, a lower dye concentration was recorded here than at stations #2 and #6. This factor would also limit the quantity of dye at #4 and #8.

Although some of this water may flow south towards Clubbs Creek (past station #4), very little would reach as far as station #8 by following this path; some probably entered the man-made channel south of the Game and Fish dock, parallel to U.S. 17. A factor to consider with regard to the negligible results at #4 is the geography of the particular location and the volume of water involved. The channel leading to station #4 from #3 appears from the photograph (Figure 1) to be very narrow, limiting the volume of water and its flow rate. The channel broadens at this point; this larger body of water would tend to slow down the transfer of dye to the dock at the extreme end, as well as dilute it even further. The dock at Riverside (station #5) does not receive dye during this particular period of the tidal cycle because water from Terry Creek should flow south along Back River towards the ocean, not north away from it. As site #7 is directly in the path of the dye pouring out with the ebbing, it is reasonable to expect dye at this location. Extremely small concentrations were detected by fluorometric analysis however.

The main reason for these puzzling results is that the dye was still flowing in a rather narrow column as it passed this particular station and the researchers, positioned on the eastern bank, were not close enough to the major concentration of the dye near the opposite shore to obtain samples with large concentration.

That this situation should occur at station #7 raises a question about the significance of data from position #6. As was noted earlier, there was a considerable amount of dye detected there. This is directly related to the fact that the researchers taking samples at this spot had anchored their boat immediately inside the mouth of Terry Creek. They were therefore at the optimum collection point -- in the center of the flow, and in water where the dye had not yet been diluted to a great extent. The actual position of the boat in the creek at different times throughout the study appears to have contributed to the variation in concentrations detected at station #6, and to the values taken at stations #6 and #7. The boat was initially anchored directly in the center of Terry Creek where researchers were able to collect samples containing high concentrations of dye. Later (2200 hours), southeasterly wind pushed the boat against the northern bank of Terry Creek, limiting the possibility of picking up any very large concentrations. Another slight wind change, this time accompanied by a shift in the current, caused the boat to be pulled away from the bank, but further into Back River, and still not in the original location. Therefore, although the readings from 1715 to 2145 hours were quite high, values for samples collected from 2215 to 0430 hours were closer to anticipated figures.

Dye was detected at nearly every station as water from the flooding tide reached the various locations at different times. Water from St. Simons

Sound returned upstream through Back River, some of it branching into Clubbs Creek past station #8 and on to station #4, and some of it flowing into Little River. As expected, part of the flood tide turned into Terry Creek, evidenced by the higher fluorometric readings at stations #1, #2, #3, and #6, while some of the dyed water was traced to station #5.

By this time the dye had become considerably diluted, having spread to a greater area in St. Simons Sound by the tide. Due to this large dilution factor, the values recorded for stations #1, #2, and #6 were lower than the readings from samples collected during the first few hours of the study at these sites.

A theoretical graph for stations #1, #2, #3, #6, and #7 would show the presence of the maximum amount of dye towards the beginning of the experiment, as the ebbing tide carried the dye past each location. Although diluted considerably, a higher dye concentration would also be expected as the tide again passed each station in its return. Attempts have been made to explain discrepancies in the data from several stations.

The fact that the data from site #7 was inconsistent with site #6 was largely due to the inability of the researchers to obtain a favorable position directly in the path of the dye flow. Examination of the photograph indicates that dye-stained water leaving Terry Creek is pushed against the western bank of Back River by the water flowing from the northern section of Back River. This coincides with our earlier speculations that the researchers, positioned on the eastern bank of Back River, were unable to collect samples that contained high concentrations. The findings from samples taken at site #3 indicate the constant presence of dye; the fluorescent readings never returned or came close to the original reading of zero. Perhaps some of the

dye was trapped here because of the geography of the location and was never diluted to a great extent.

Samples taken at Roberts' Dock (station #2) invariably showed higher concentrations (up to five times) than either station #3 or #6 when diluted dye was brought in by the flood tide (approximately 2400 through 0100 hours). If a normal dilution and dispersion pattern had been followed, samples from station #6 at the mouth of Terry Creek would have had higher dye concentrations than those farther upstream, where the dye would be diluted even more. This "normal" pattern can be seen in comparing values for station #6 and station #1 during the same time period. It is conceivable that dye converged on site #2 from two directions -- some as it was carried upstream in Terry Creek, and some from the total at station #3. In contrast, site #6 only received dye that had been diluted many times as it flowed from Back River into Terry Creek.

Upon analysis, many locations showed evidence of fluorescent particles prior to the introduction of the Rhodamine WT to the system. Obviously, no dye could have reached these areas yet, therefore the values have been attributed to background material -- detritus, suspended sediments, plankton, and phytoplankton. The background value, a figure which is the highest reading that can be attributed primarily to background material, varies from station to station. For example, samples from station #4 at the Game and Fish dock repeatedly failed to register any fluorescence; presumably detectable concentrations appeared only when Rhodamine WT was present in the sample. On the contrary, the dock at Riverside (station #5) had a much larger background value since the fluorescent value of samples taken in the ebbing tide had a mean of approximately 2.11 ppb. Two other sites had a background value of 2.11 ppb

(stations #1 and #8). Station #3 was the only other station with a background value of zero. Roberts' Dock (#2) registered a background of 1.92 ppb and 2.05 ppb was the figure arrived at for locations #6 and #7.

Besides the variance in background values determined from station to station, there was a great amount of background fluctuation within each individual location. These fluctuations are graphically illustrated at station #8 between 1530 and 2200 hours, a time period before dye could possibly have been detected. Values jump repeatedly between 0 and 2 ppb, evidence that new water is constantly flowing past a particular spot, bringing a variety of materials that may show up as fluorescence when tested. Several other stations (#4, #7) exhibit this background vacillation to a lesser degree.

To provide better means for analyzing the dilution pattern of a fluorescent tracer in the estuarine environment several alternatives have been considered.

For example, to arrive at a more accurate background value, samples could be collected at each location at regular intervals (hourly) prior to the actual field study. In addition, as was noted earlier, concentrations varied with the position researchers took in the stream. Following dye studies should employ more researchers if necessary in order to collect samples from different locations in the general area of each station -- along the bank, in the center of the flow, and even at different depths.

Perhaps better mixing conditions for the Rhodamine WT could be arranged in the future. Though not a major problem, the dye, as it was introduced, did not correspond to the manner by which the chemical plant effluent was added to Terry Creek. The effluent passed through a narrow ditch spanned

by a dam-like arrangement which provided considerable turbulence. Dye was siphoned into the stream at a point about 200 yards downstream from the actual effluent entrance through a tube submerged only six to eight inches into the water.

Since many stations showed evidence of an increased dye concentration at 0430 hours, it might have been worthwhile to continue the study for a greater length of time. Readings could also have been taken for a few days after the experiments, perhaps only during high and low tide. Though the 15 minute collection times were adequate for this particular 12 hour experiment, longer time intervals would be sufficient if the total time was extended. Lengthening the study would provide more information regarding the length of time the effluent stays in the vicinity. Does the amount of effluent added over 2.5 hours (the amount of time it took for the dye to be emptied into the stream) ultimately become entirely dissipated or does it persist in the watershed for several days?

Additional stations would aid in forming a clearer picture of the limits of the dye's flow. If the same experiment is to be repeated, site #2 could be moved east to a point midway between #1 and #6. Three other sites might be included: the bridge over Little River, St. Simons Sound, and along Clubbs Creek. Aerial photographs would also be helpful in determining the overall dispersion pattern. None were taken on January 15 due to unfavorable flying conditions.

CONCLUSIONS

The results of this study provide a basis for several conclusions regarding the circulation and dilution patterns evident in the Terry Creek area. The ebbing water follows a direct route from the Hercules ditch into Terry Creek and flows eastward, joined shortly by water moving north from the small southern branch of Terry Creek. This relatively small mass of water empties into Back River with a good deal of force, sending some Terry Creek water to the eastern bank, while the majority is pushed along Back River's western bank by the water mass flowing south from the northern section of Back River. As Back River joins Little River which flows from the northeast, the water mass increases in size and moves southeastward where Clubbs Creek adds its water before reaching St. Simon's Sound. Water draining through Clubbs Creek comes primarily from the area surrounding the Game and Fish dock and the estuary immediately south of the Torras Causeway.

Significant dye concentrations were obtained at study sites during the flooding tide indicating that water containing dye was both carried out and returned to the estuary with the tides. The circulation pattern for this stage is much harder to ascertain because of the wider variety of river branches open to incoming water. From St. Simon's Sound water flows north along Back River. A fraction of this flows into Clubbs Creek, eventually reaching the Game and Fish dock where it either remains or drains south into the ditch parallel to U.S. 17. The great majority of the water, however, continues up Back River, part of this branching into Little River. A portion of the water in Back River turns into Terry Creek, some of it flowing down the small southern tributary of Terry Creek, past station #3 and possibly reaching #4. The remaining water in Back River continues in a northwesterly

direction, passing the Riverside station. No stations were located farther upstream on either Back River or Little River, so no data is available on the extent of fluorescent water in the northern areas of the estuary.

New water is continually infiltrating the estuary so it is not possible to conclude that the entire original body of dye-stained water is present after having receded and returned again. Some of the original water mass undoubtedly returns on the flood tide, but much of it has been replaced by new water that redilutes the dye as it is carried back into the estuary. Regardless of whether it is the original or new water that transports the dye, the Rhodamine WT has been considerably diluted during the tidal cycle. When first introduced to Terry Creek (station #1), the dye and effluent mixed had a concentration of over 8000 ppb. By the time it had reached the mouth of Terry Creek it had been diluted to approximately 50 ppb or a dilution factor of 160 times. Upon its return with the flood tide the additional dilution factor was 10 times. The total dilution at one site in Terry Creek was about 1600 times over the one tidal cycle studied. Since very low values were obtained for the dye concentration at stations #4, #5, #7, and #8 (for various reasons that have been described earlier), the main concentration of dye is located in Terry Creek during both the flooding and ebbing tide.

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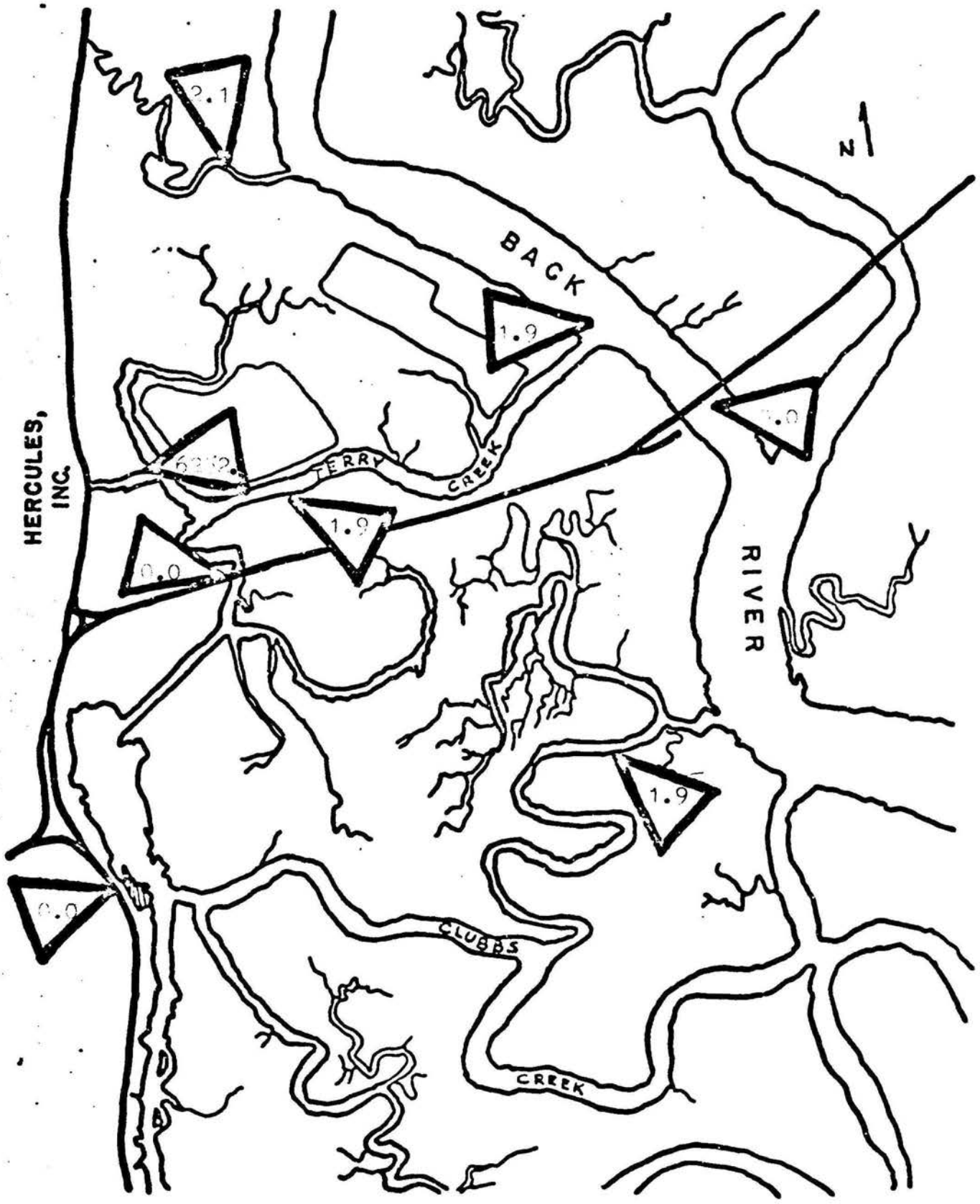
APPENDIX I

Hourly Comparison of Rhodamine WT Concentration (ppb) at Each Station



BRUNSWICK EAST, GEORGIA

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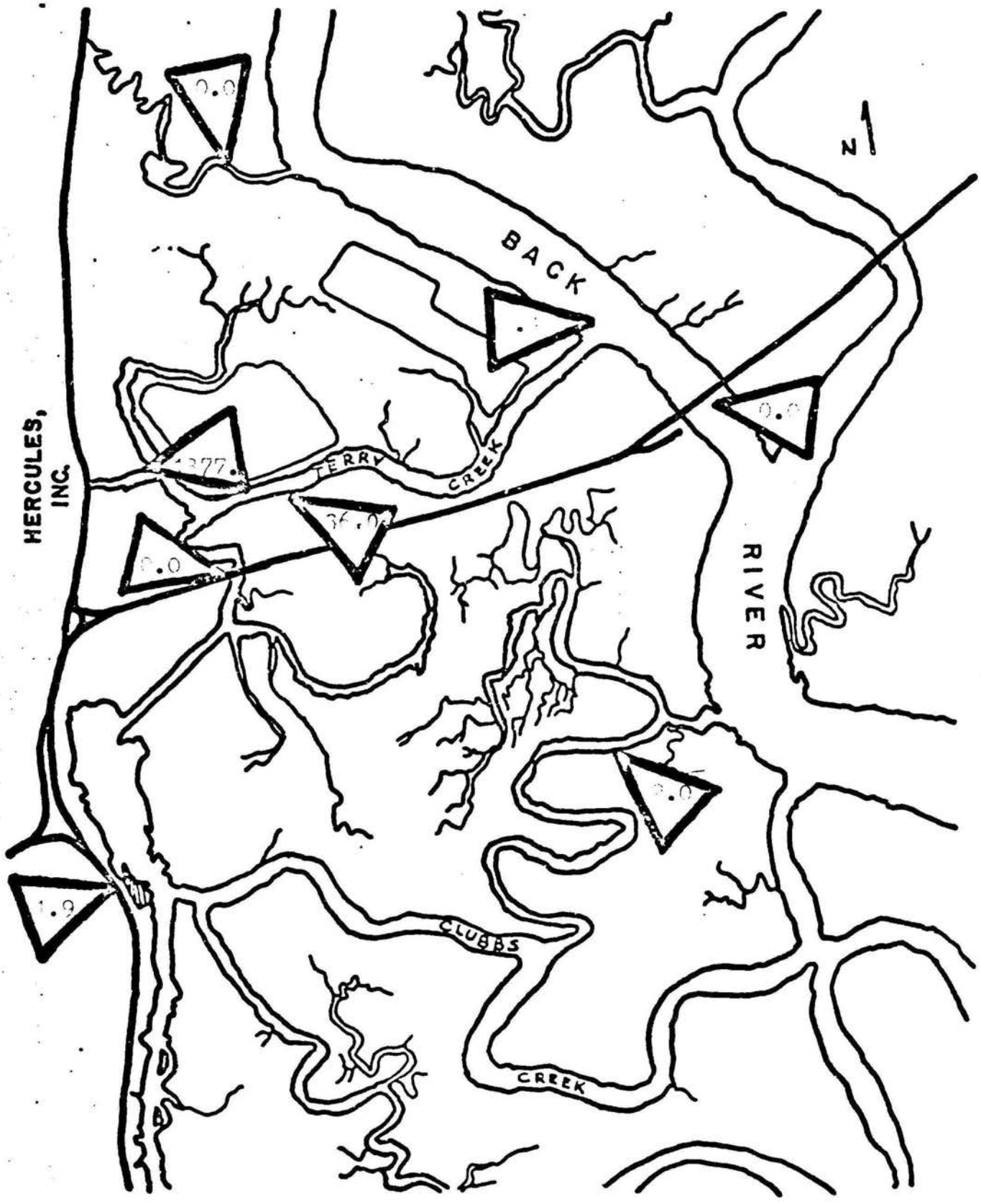
RHODAMINE WT CONCENTRATION, ppb,

15-16 JANUARY, 1974 1530 HRS.



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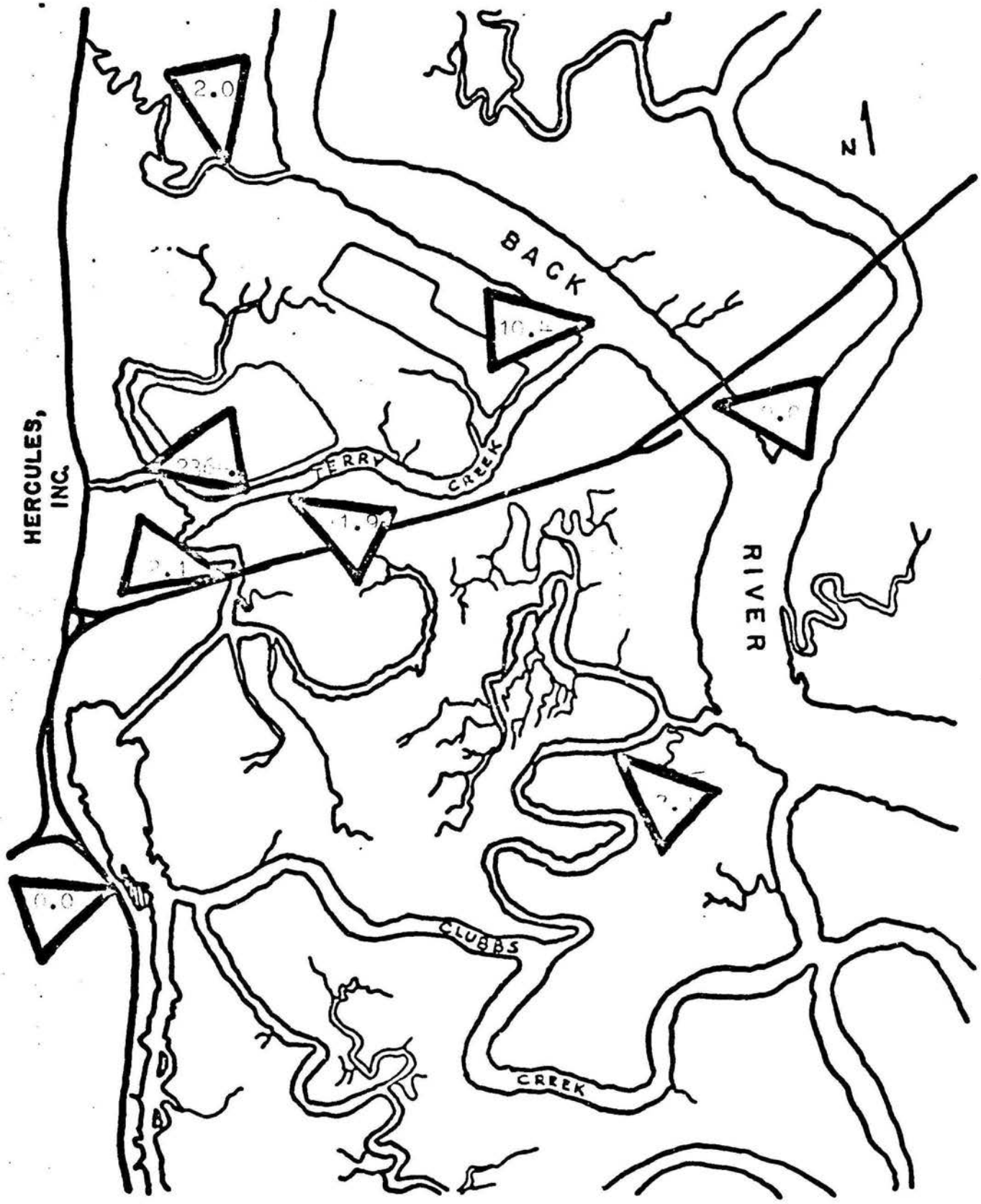

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SCALE 1:24000

RHODAMINE WT CONCENTRATION, ppb,

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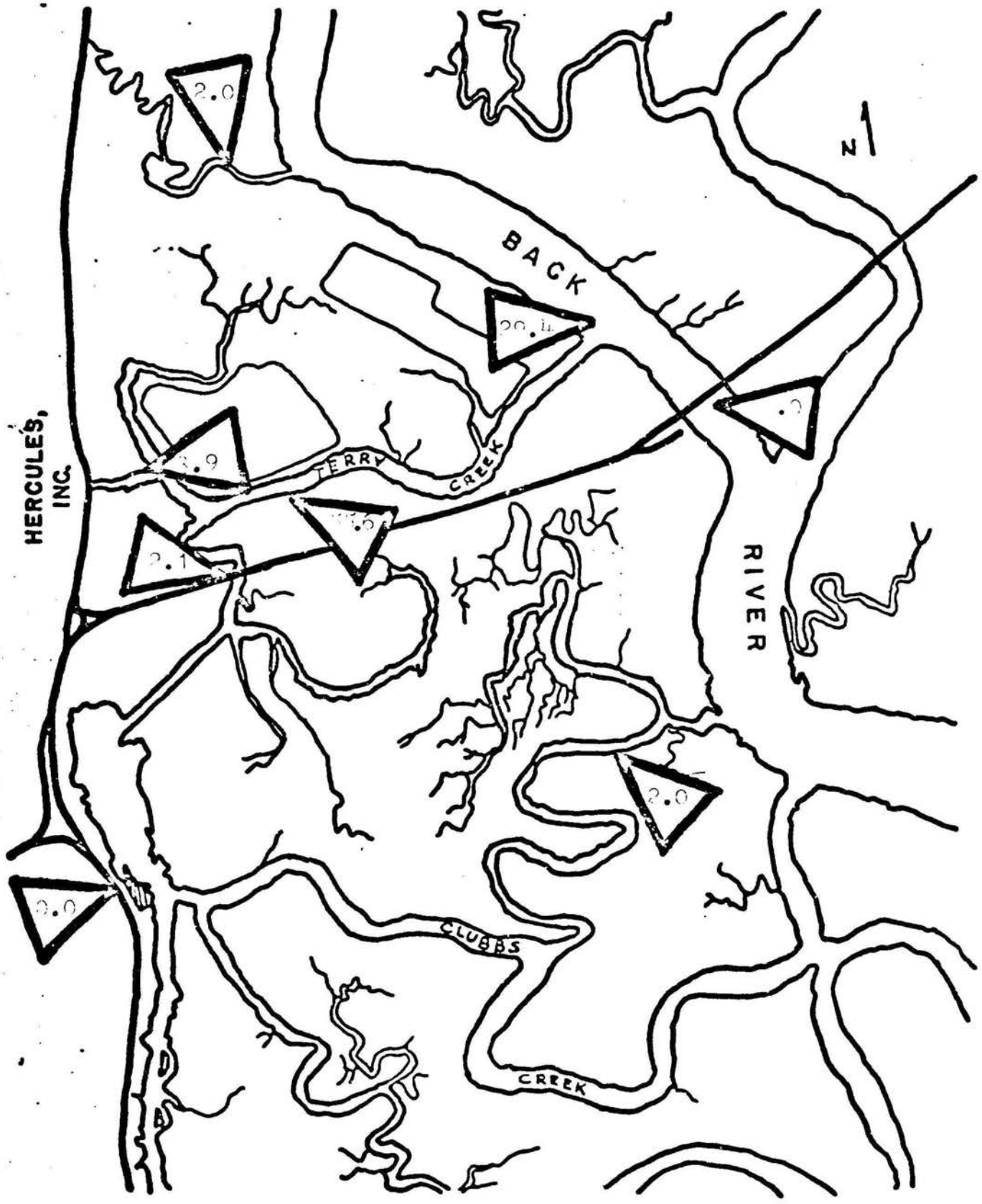

BRUNSWICK EAST, GEORGIA

SCALE 1:24000

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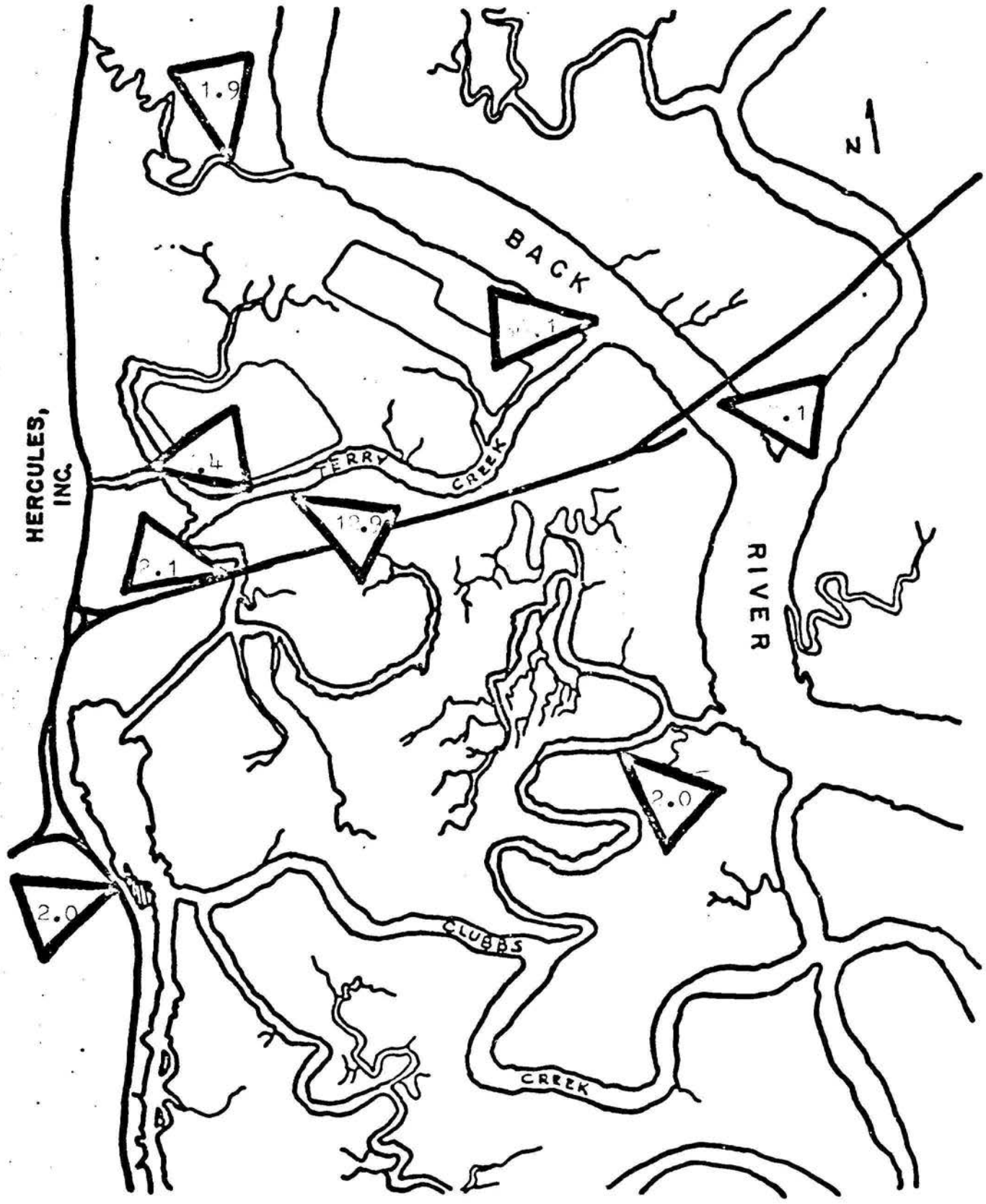

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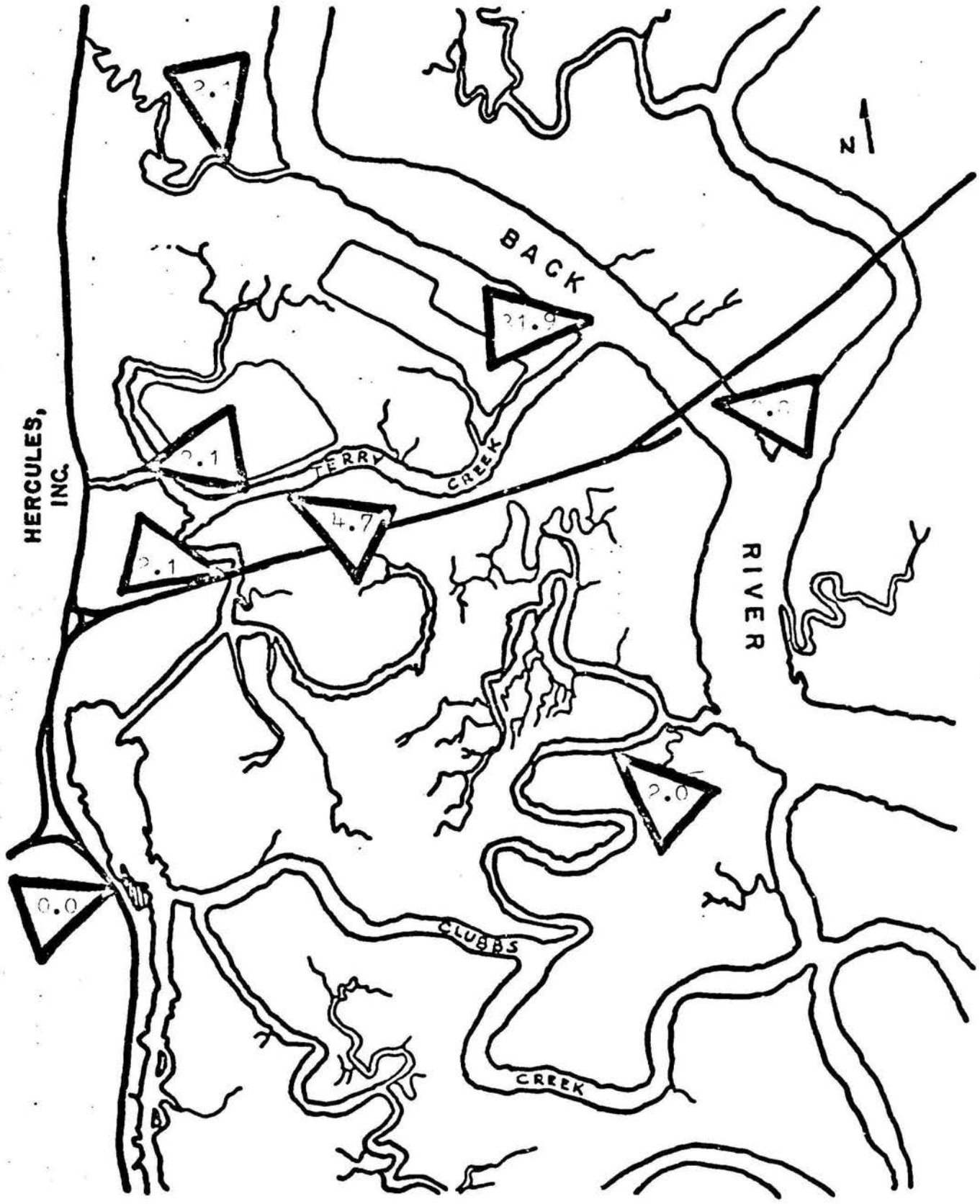

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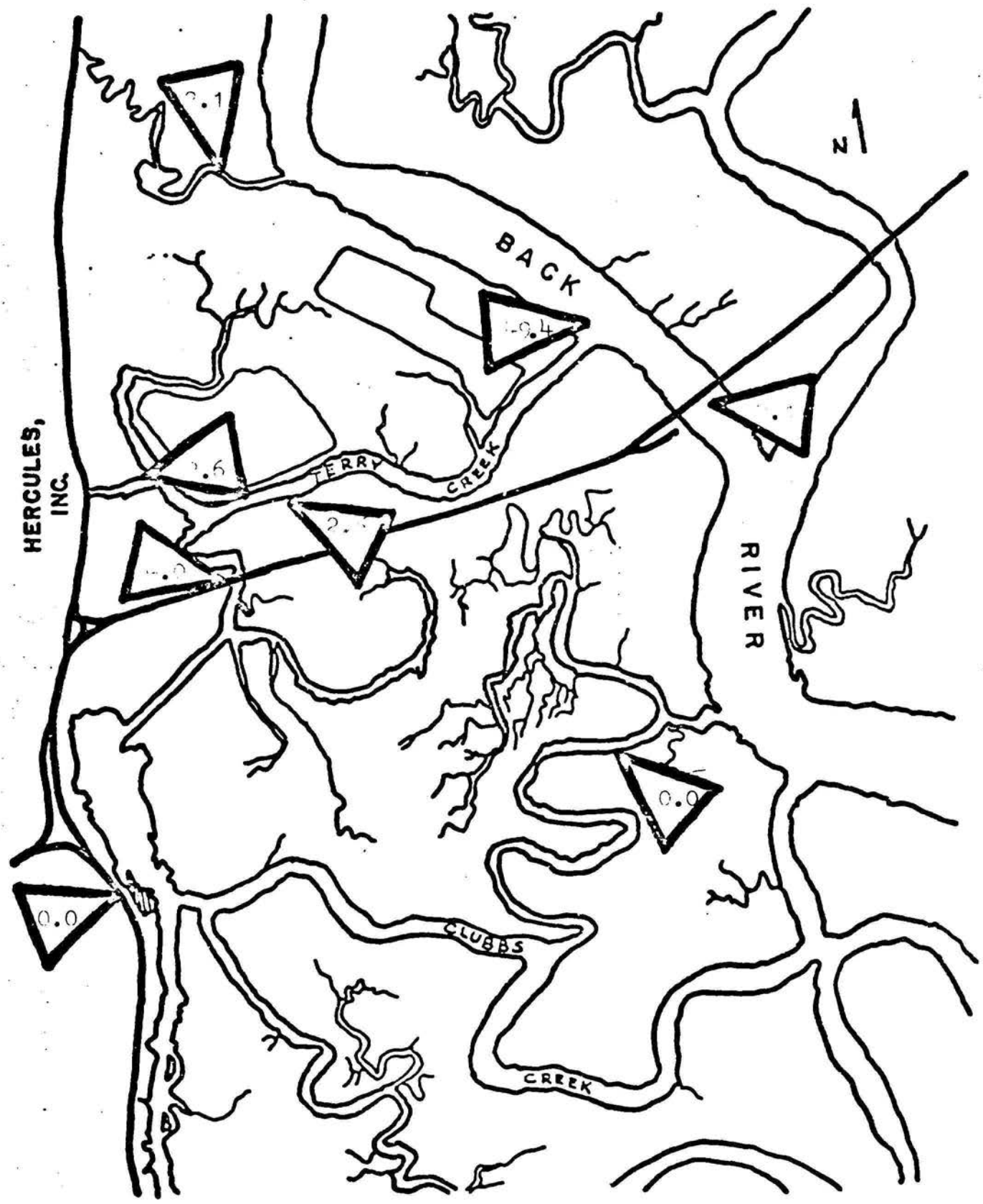

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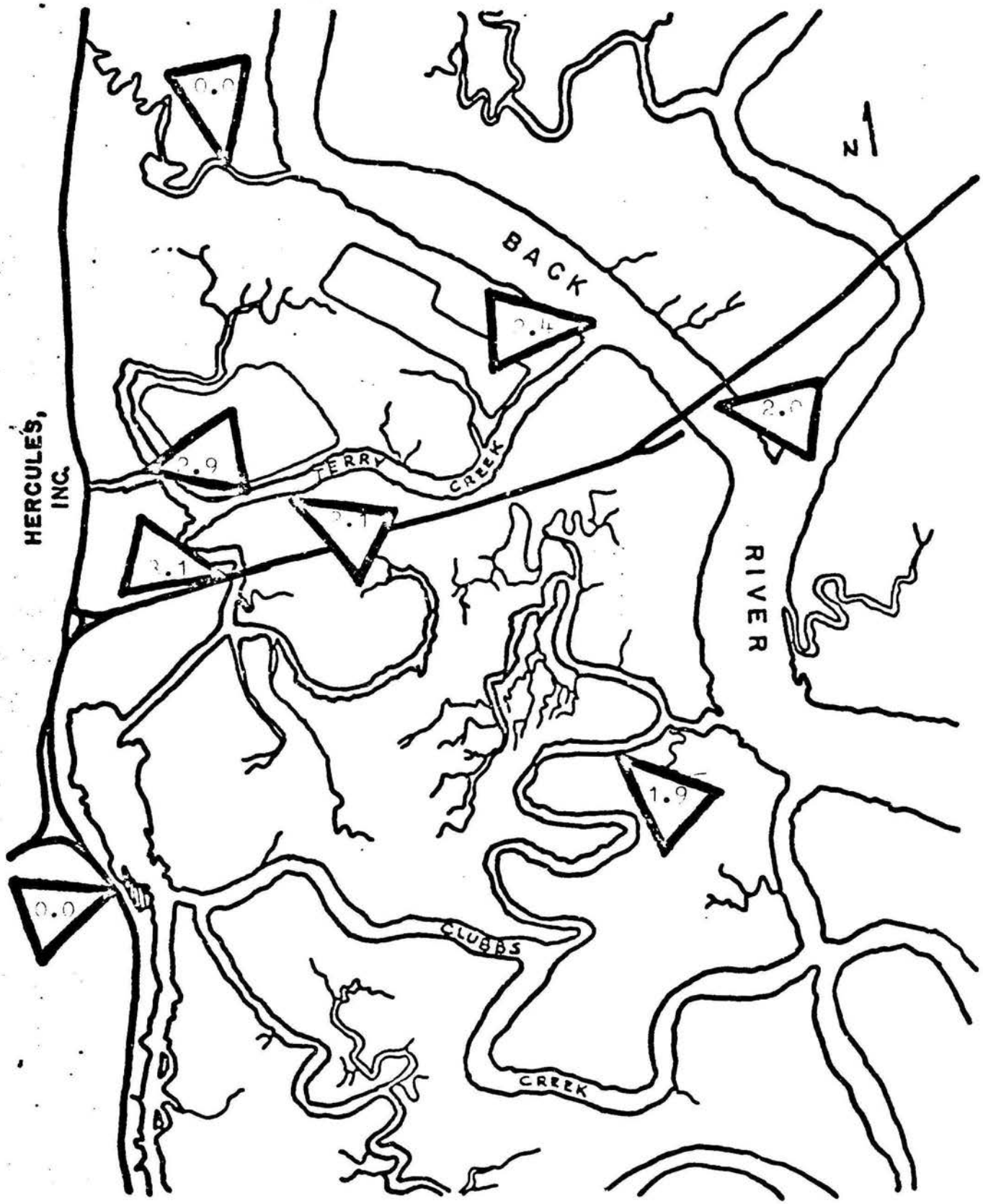

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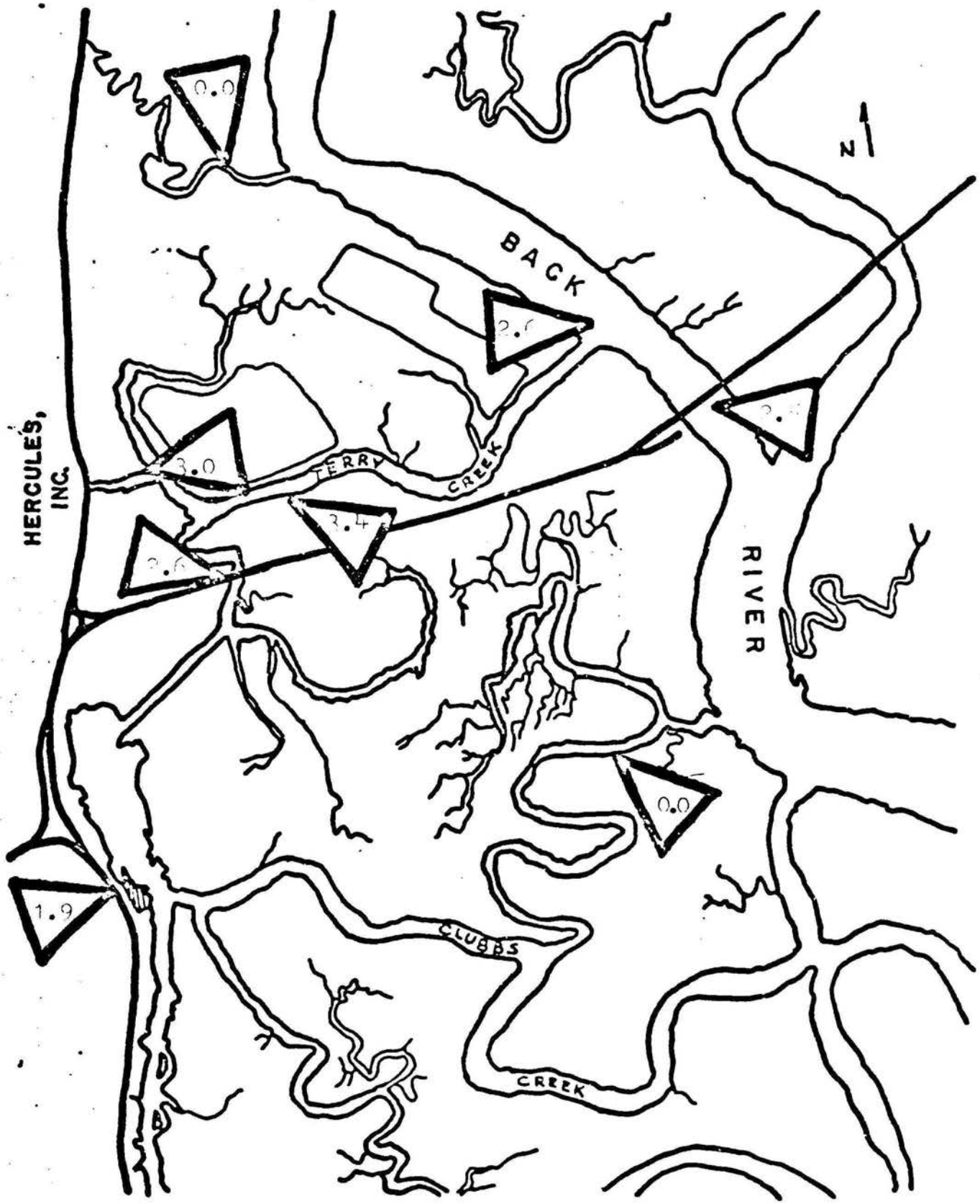

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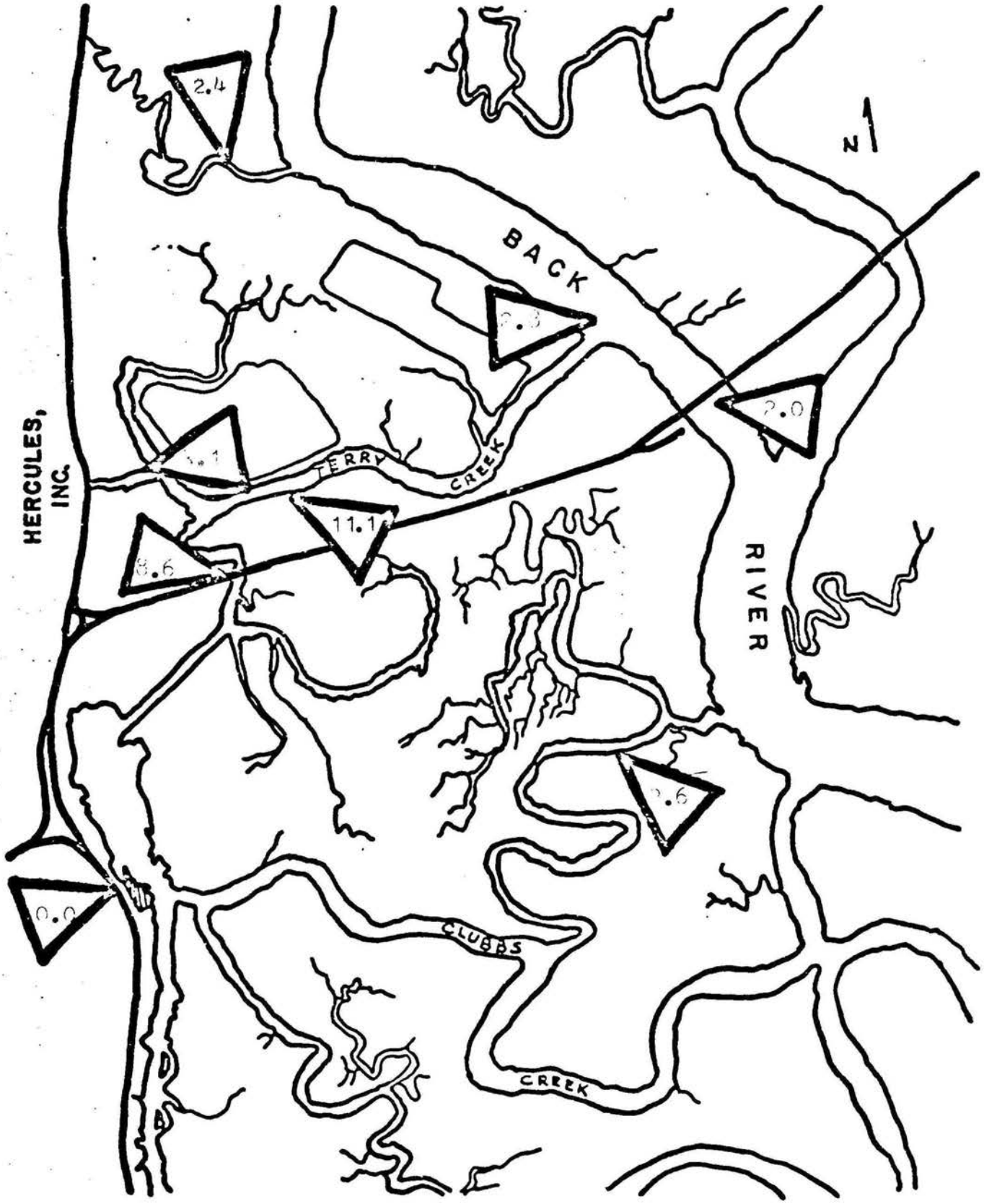

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SCALE 1:24000

RHODAMINE WT CONCENTRATION, ppb,

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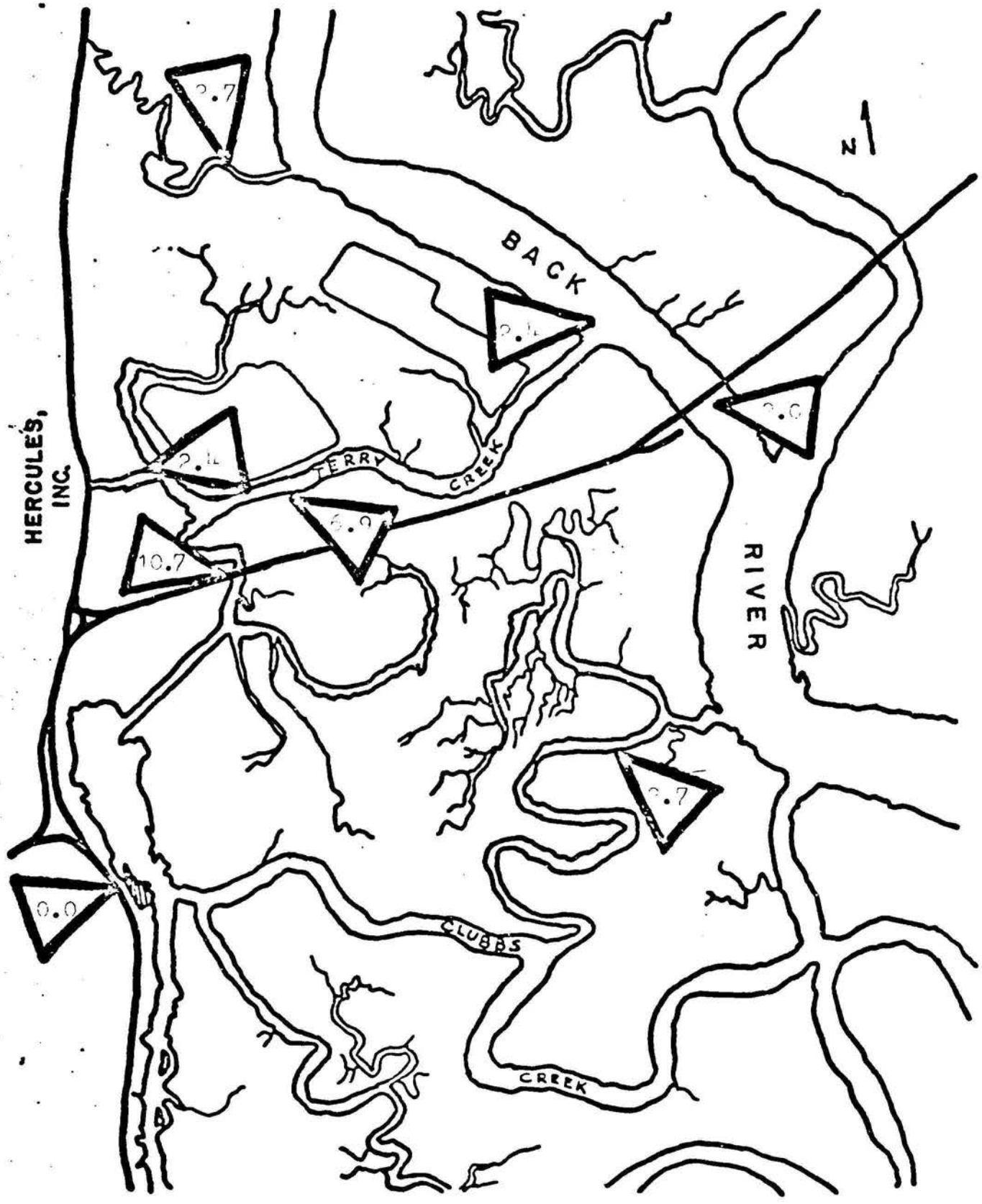

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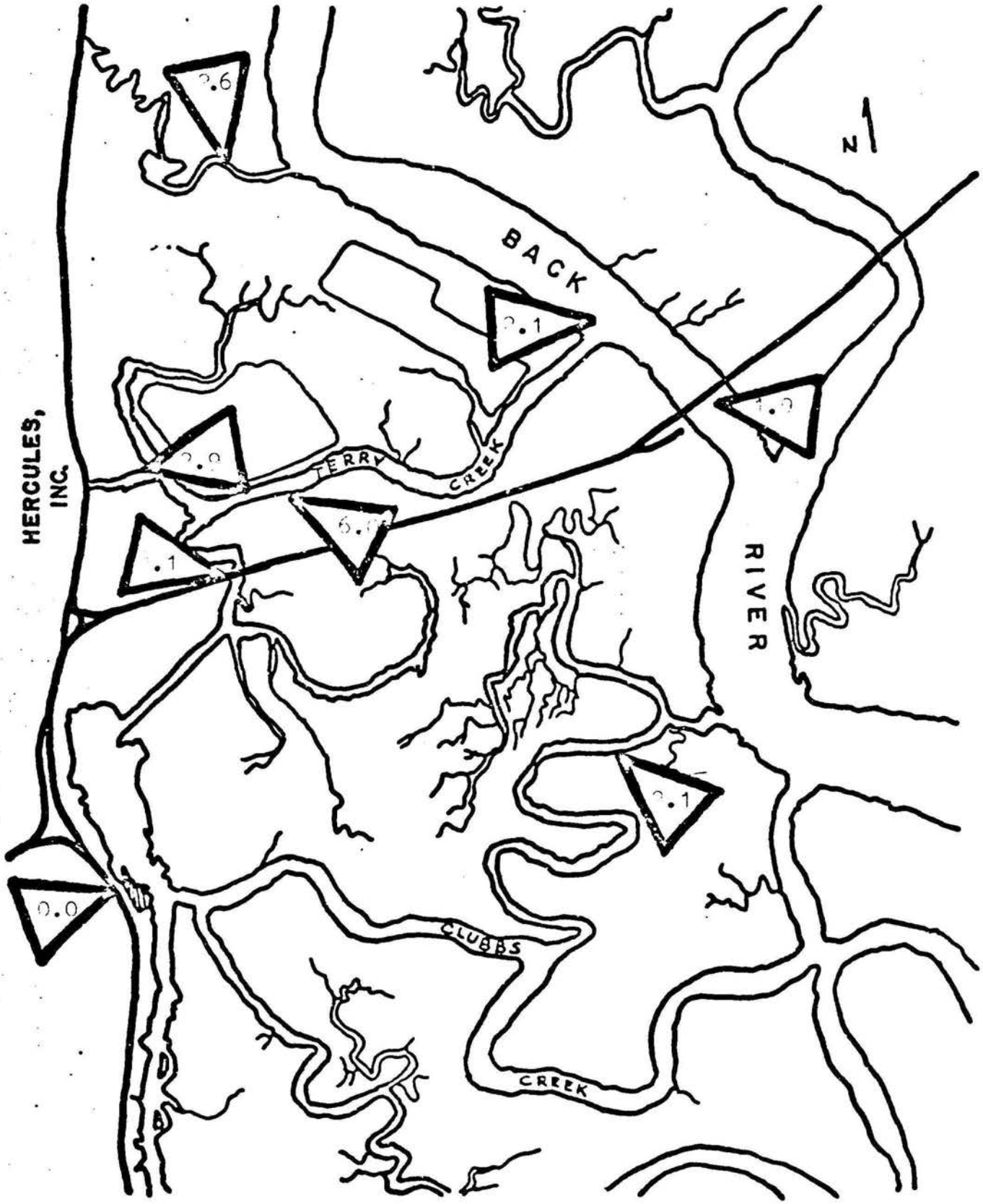
SCALE 1:24000

RHODAMINE WT CONCENTRATION, ppb,

15-16 JANUARY, 1974 0130 HRS.



BRUNSWICK EAST, GEORGIA

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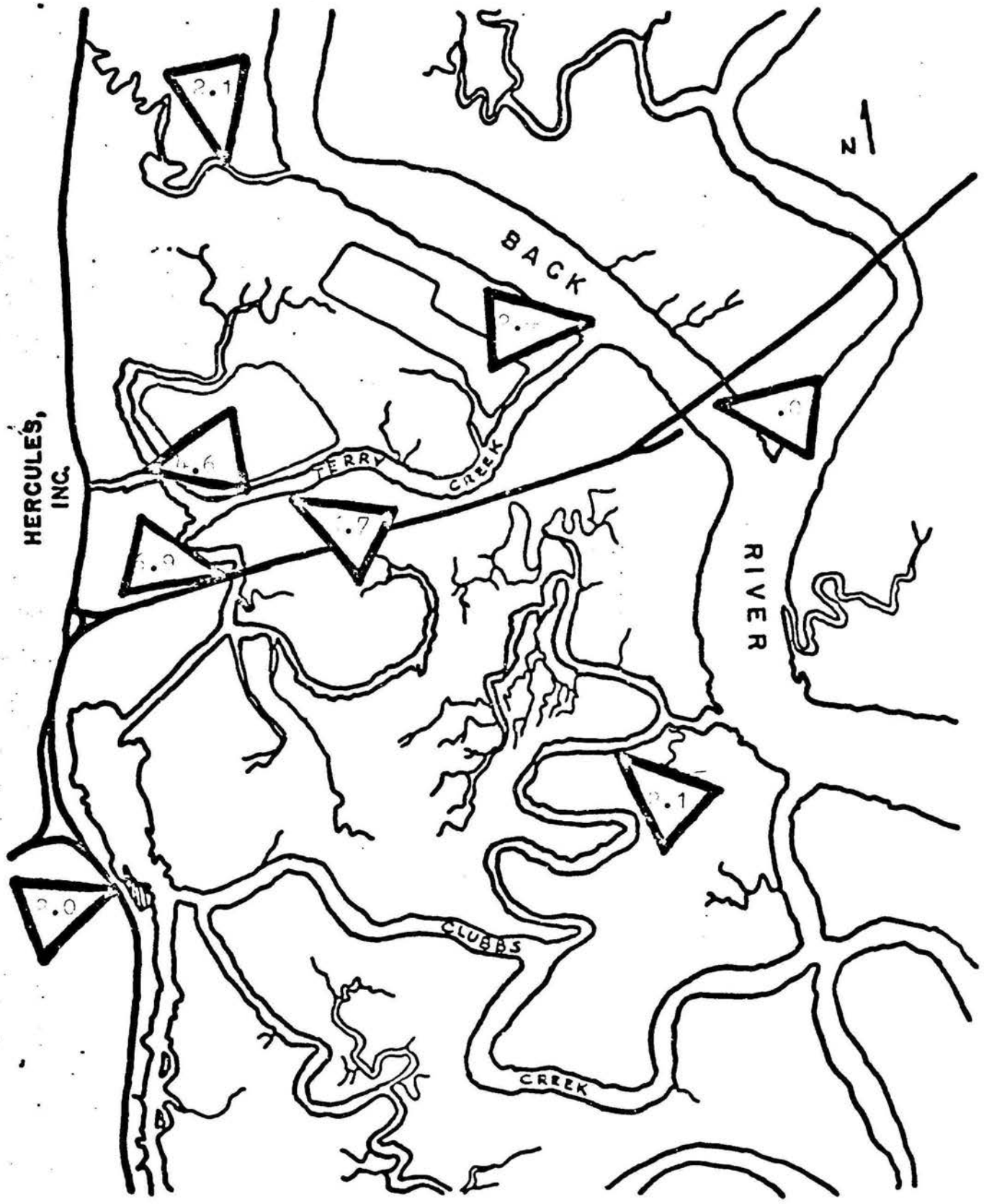
RHODAMINE WT CONCENTRATION, ppb,

15-16 JANUARY 1974 0230 HRS



BRUNSWICK EAST, GEORGIA

SCALE 1:24000

RHODAMINE WT CONCENTRATION, ppb,

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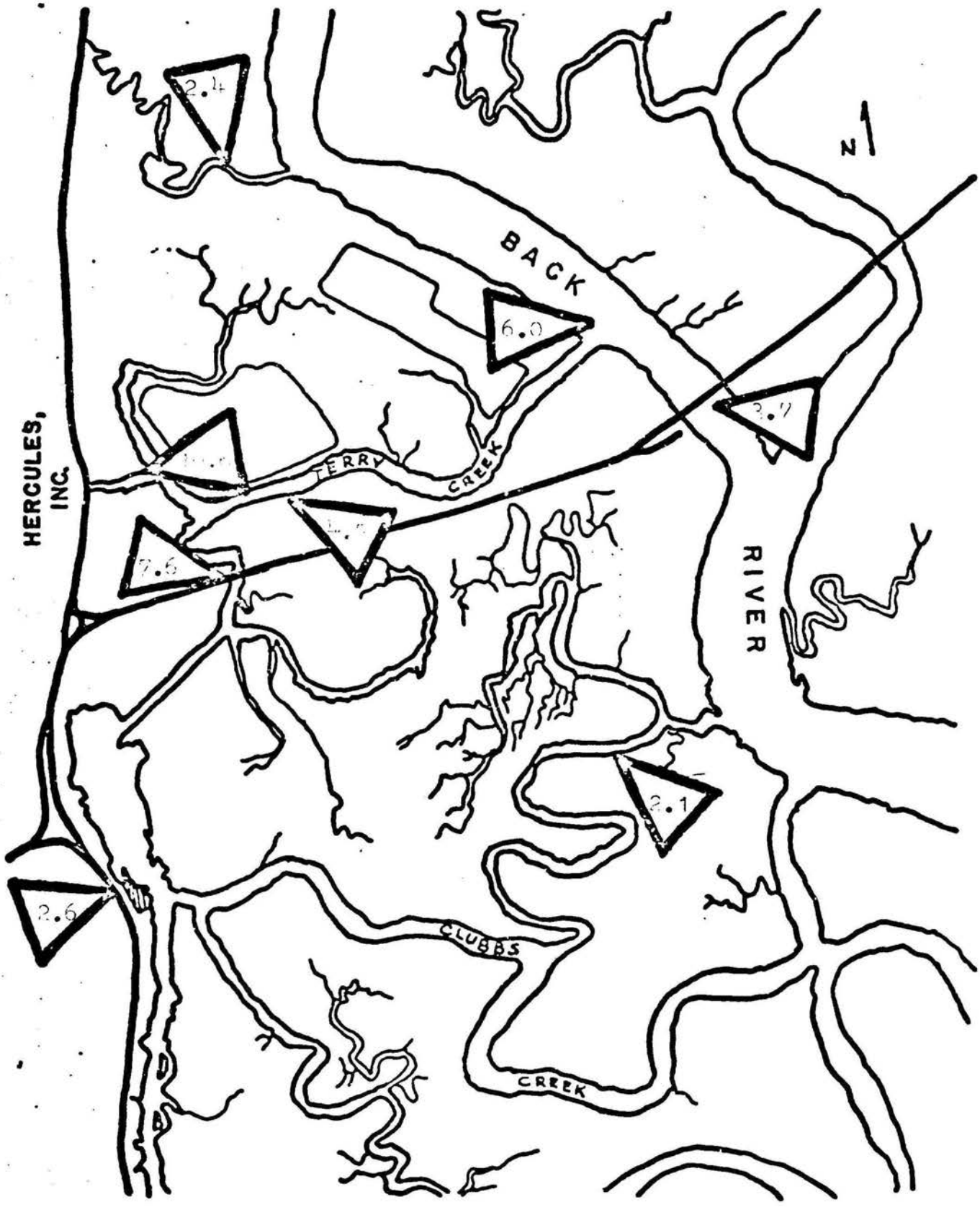

BRUNSWICK EAST, GEORGIA

SCALE 1:24000

RHODAMINE WT CONCENTRATION, ppb,

15-16 JANUARY, 1974 0430 HRS.