AN INVESTIGATION OF THE PHYSIO-CHEMICAL CHARACTERISTICS OF A RIVER ESTUARY

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INTRODUCTION

It has become increasingly more apparent that the distribution and population of organisms increases or decreases depending upon the ecological balance established between the organisms and their environment. The purpose of this study was to determine quantitatively and qualitatively the distribution of plankton in the Patapsco River and its tributaries. To achieve this end, the physical and chemical factors of the area under investigation were studied and correlated with the biological findings. The physical and chemical factors considered were: temperature, pH, chlorinity, oxygen, carbon dioxide, silica, phosphates, soluble iron, insoluble iron, ferrous salts, total iron, nitrates and nitrites.

The area studied can be described as that part of the Patapsco River extending from Seven Foot Knoll Lighthouse up to the North West Harbor and Middle Branch. Stations were set up at points along the river and its tributaries. The stations, were arbitrarily divided into two categories; namely, shore stations, which bear Arabic numbers and off shore stations which bear Roman numbers (see Plate I). The shore stations and locations are given in Table I.

It will be noted that the samples collected from the shore were taken only from the surface, while those collected from the off shore stations were taken from the surface and at fifteen feet; except at those stations where the depth was less than fifteen feet, in which case the samples were taken from the bottom. The depth of the Patapsco River ranges from 1 to 38 feet. The greater depths are found in the channel areas. However, in no case was a station placed directly in a main channel, since the passage of craft might create conditions which were atypical. The floor of the river is varied ranging from a hard rock bottom to a mud soft bottom (Table 2).

TABLE I. Description of Stations and Locations

Station Number	Location
Station 1	Chester and Aliceanne Streets, pier D.E. Foote Company, canners
Station 2	Boston and South Linwood Streets, pier
Station 3	Canton Pier, Pennsylvania Railroad
Station 4	Colgate Creek, off bridge
Station 5	Sollers Point, off mud flat
Station 6	Humphreys Creek, off highway bridge
Station 7	Sparrows Point Shipyard, pier 1
Station 8	Fort Howard Veterans Hospital, pier south of lighthouse
Station 9	Smith Cove, pier
Station 10	Hanover Street Bridge, mouth of upper branch of Patapsco River
Station 11	Maryland Drydock, Pier 5
Station 12	Wagners Point, pier, Eastern Box Factory
Station 13	Leading Point, pier, U.S. Quarantine Station
Station 14	Hawkins Point, pier, U.S. Reservation
Station I	50 feet west of #1 spar bouy at Fort McHenry
Station II	200 feet south west of flash bouy #17M, Fort McHenry Channel
Station III	50 feet east of white spar bouy at south east corner of #3 anchorage
Station IV	300 feet east of beacon-channel leading to Gas and Electric Company, Sollers Point
Station V	100 feet south west of #3 spar bouy at Bear Creek

TABLE I Continued Description of Stations and Locations

Station Number	Location
Station VA	600 feet south of state highway draw bridge, Bear Creek
Station VB	1000 feet above the mouth of Peach Orchard Cove abeam City Dock
Station VC	1500 feet due north of mud flat at Watersedge Park up Bull Neck Creek, mid stream
Station VD	1000 feet south east on Grays Creek, abeam building on left side of creek, mid stream
Station VE	1000 feet due east of railroad draw bridge, Bear Creek
Station VF	Bear Creek, mid stream, abeam mouth of Chink Creek, off south east course from Chink Creek
Station VG	200 feet south of highway draw bridge, mid stream of Bear Creek
Station VI	200 feet east of #4M Flashing Bell bouy south of Fort Carroll
Station VII	400 feet north of CB Flash bouy, Brewton Channel
Station VIII	½ mile south west of Millers Island Range Lighthouse
Station IX	1000 feet north west of Seven Foot Knoll Lighthouse
Station X	1000 feet west of #7 Can Bouy, Bodkin Creek
Station XI	300 feet south west of #2 Flash bouy, Rock Creek
Station XII	100 feet north west of #3 Can bouy, Stony Creek
Station XIII	200 feet north west of #6 Flashing Bell bouy

TABLE I. Continued Description of Stations and Locations

Station Number	Location
Station XIIIA	100 feet east of #11 Can Bouy, Curtis Creek
Station XIIIB	100 feet east of #15 Flash Bouy, Curtis Creek
Station XIIIC	200 feet south of Railroad Bridge, Curtis Creek
Station XIIID	500 feet east of Thomas Point, Curtis Creek
Station XIIIE	1½ miles of Furnis Creek, mid stream
Station XIIIF	1½ miles up Marley Creek, 100 feet east of sunken barge
Station XIV	100 feet south of #17 Flash Bouy, Fort Covington
Station XV	1000 feet east, south east off Ferry Bar Beacon

TABLE 2. Depth and Bottom Composition at Stations

Station Number	Depth	Bottom Composition
Station I	20 feet	Hard
Station II	22 feet	Hard
Station III	22 feet	Hard
Station IV	16 feet	Hard
Station V	15 feet	Sticky
Station VA	16 feet	Soft
Station VB	11 feet	Soft
Station VC	14 feet	Soft
Station VD	12 feet	Soft
Station VE	15 feet	Soft
Station VF	14 feet	Soft
Station VG	12 feet	Soft
Station VI	19 feet	Sticky
Station VII	19 feet	Sticky
Station VIII	17 feet	Hard
Station IX	6 feet	Hard
Station X	13 feet	Hard
Station XI	12 feet	Sticky
Station XII	15 feet	Sticky
Station XIII	18 feet	Clay
Station XIIIA	25 feet	Sticky
Station XIIIB	17 feet	Sticky
Station XIIIC	21 feet	Soft
Station XIIID	12 feet	Soft
Station XIIIE	12 feet	Soft
Station XIIIF	12 feet	Soft
Station XIV	15 feet	Sticky
Station XV	11 feet	Sticky

CHAPTER I

REVIEW OF LITERATURE

Temperature. In any study of this nature, the role played by temperature is of paramount importance. It has become an established fact that temperature acts as a conditioning factor relative to the seasonal as well as vertical distribution of plankton. Further, it is reported to influence such activities as body growth, reproduction, migration of some fish, etc.[1] Because of these, temperature is always included in a paper such as this. So much data is reported on this factor that it would be impractical to review all of the literature. A few pertinent investigations follow:

The temperature at the mouth of the Chesapeake Bay was reported by Cowles to range from 4.0°C. to 27°0 C., while the range near Baltimore was between 0.0°C. to 25.0°C.[2] The maximum temperature of the surface waters of the Baltimore area appeared in August with a high of 24.8°C., and a minimum of .3°C., recorded in January. The highest temperature recorded from the bottom waters of the Baltimore region was 24.4°C. and .9°C. occurring in August and January respectively.

The seasonal trend of the estuarine waters of the Chesapeake Bay was characterized by Newcombe by a rise in temperature from March to

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[1] R.E. Coker, "Influence of Temperature on Forms of the Freshwater Copepod, Cyclops vernales, Fisher", Internationale Revue der gesamten Hydrobiologie und Hydrographie. 30:411-427, 1934

[2] R.P. Coweles, "A Biological Study of the Offshore Waters of Chesapeake Bay" U.S.D.I. Bureau of Fisheries Bull. 1091:278-381, 1930.

August.[1] The maximum temperature being reached in the latter month. The ascent in temperature during June and July appeared to be less sharp than in the preceding months. The descent of temperature is gradual in September and much more decided in the last two months of autumn. The surface water temperature is lower than the bottom water from the latter part of September to the second week of April. Newcombe found that an appreciable variation in temperature could occur within a short period of time, this being a result of water movements. The greatest difference between top and bottom temperatures appear in the summer, with a normal difference of 3.0°C. In their investigation of the distribution of the phosphates in the Chesapeake Bay, Newcombe and Lang noted that the seasonal temperature changes were accompanied by corresponding changes in chlorinity and dissolved oxygen concentrations.[2]

In the lower Patapsco River area Olson, Brust and Tressler found that thermal stratification of the water was not present to any appreciable degree; since the region investigated was neither saline nor deep.[3] The difference between surface water and bottom water did not rise above 2.0 C. in summer and 4.0 C. in winter. The investigators reported that the pollution factor of the region was affected by the elevated

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[1] C.L. Newcombe, W.A. Horne, and B.B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in Chesapeake Bay", Journal Mar. Res., 2:87-116, 1939.

[2] C.L. Newcombe and A.G. Lang, "The Distribution of Phosphates in The Chesapeake Bay", Proc. Am. Philosophical Soc., 81:393-420, 1939.

[3] 3R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biological Laboratory Publication #43:1-40, November, 1941.

summer temperatures, e.g., influence of decomposition rate of river effluents, respiratory and growth rates of plankton and dissolved oxygen index.

The air temperature remained higher than the surface water temperature of the Patuxent River from the latter part of January until the latter part of June.[1] Otherwise, the air temperatures were lower than the surface water. Nash further reported a simultaneous decline in the temperature of the surface and bottom waters occurred in early August. An overturn made its appearance from September to December, completely concluding in March. Upstream seasonal temperature changes began sooner.

Hydrogen-Ion Concentration. Hydrogen-ion data has been an important part of many ecological studies. Investigations of this nature have been comprised of limited readings on a particular body of water or more comprehensive studies consisting of many determinations over a long period of time. Comprehensive studies enable one to obtain a whole picture such as variations resulting from seasonal changes. pH variations are the result of two principal factors: biological and pollution. The value of the knowledge of the hydrogen-ion concentration is twofold, e.g., functioning as an index to environmental conditions and acting as a conditioning factor in the periodicity of phytoplankton.

Changes resulting from the biological factor are brought about by phytoplanktonic extraction of carbon dioxide from bicarbonates dissolved in the water in the photosynthetic process. The removal of carbon dioxide from the water yields an environment with a higher pH.

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[1] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biological Laboratory Publication #64:147-174, Dec., 1947.

Processes which tend to add carbon dioxide to the water such as respiration, decomposition, and the dissolving of atmospheric carbon dioxide in water; lower the pH value of the water.

Normally, the pH range of natural bodies of water is wide, ranging from a pH of 4.0 to 10.0. A pH lower than 4.0 has been reported in bog lakes or lakes from which the water is derived from volcanic sources.[1] Readings above pH 10.0 are recorded resulting from waters stemming from volcanic rock containing sodium carbonate.[2]

In certain brown lakes and other lakes of northeastern Wisconsin, Juday and Birge found that the hydrogen-ion concentration range was approximately the same; between 4.9 and 9.1.[3] These same investigators and Meloche noted an acid reaction of the surface waters of 93 per cent of the seepage lakes ranging from pH 4.4 to pH 9.4.[4] The variation between surface and bottom was from 0.0 to 2.6. The hydrogen-ion

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[1] M.E. Jewel and H.W. Brown, "Studies on Northern Michigan Bog Lakes", Ecology, 10:427-475, 1929.

[2] P.M. Jenken, "Reports on the Percy Sladen Expedition to the Soin Rift Valley Lakes in Kenya in 1929. I Introductory Account of the Biological Survey of Five Fresh Water Alkaline Lakes", Ann.Mag. Nat. Hist., 9:533-553, 1932.

[3] C. Juday and E.A., Birge, "Dissolved Oxygen & Oxygen Consumed in the Lake Waters of Northeastern Wisconsin", Transactions of the Wisconsin Academy of Sciences, Arts and Letters, XXVII:415-486, 1932.

[4] C. Juday, E.A.Birge and V.W. Meloche, "The Carbon Dioxide and Hydrogen-ion Content of Lake Waters of Northeastern Wisconsin", Trans. of the Wisconsin Academy of Sciences, Arts and Letters, 29:1-82, 1935.

concentrations paralleled the bound carbon dioxide, free carbon dioxide and calcium concentrations. A pH range from 4.6 to 8.4 was recorded for Helmet and Oconomowoc Lakes respectively.[1]

Waskesiu Lake demonstrates little variation in hydrogen-ion concentration.[2] Rawson recorded the pH of the surface water as approximately 8.2. He found that the pH of the bottom waters increases in September with the advent of the autumnal circulation and remained more or less constant at 8.1.

Investigations of estuarine waters of the Chesapeake Bay near Solomons Island demonstrated that the hydrogen-ion concentration is in direct agreement with the increasing chlorinity factor found in the more saline waters of downstream.[3] This same accord is found in the vertical increase in salinity. The work of Nash conducted on the estuary of the Patuxent River confirms the pH characteristics of the area investigated by Brust.[4] Nash found the pH of the surface water is always more alkaline than the bottom water. The minimum range of the

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[1] C. Juday, E.A. Birge and V.W. Meloche, "Chemical Analysis of the Bottom Deposits of Wisconsin Lakes II. Second Report", Transactions of the Wisconsin Academy of Sciences, Arts and Letters, 33:94-114, 1946.

[2] D.S. Rawson, "Physical and Chemical Studies in Lakes of Prince Albert Park, Saskatchewan", Jour. of the Biol. Board of Canada, II, #3:227-283, 1936.

[3] H.F. Brust and C.L. Newcombe, "Observations on the Alkalinity of Estuarine Waters of the Chesapeake Bay Near Solomons Island, Maryland." Jour. Mar. Res. III, #2, 1940.

[4] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab., Pub. #64:147-174, Dec. 1947.

bottom water (pH 7.5) correlates with the period during which the dissolved oxygen factor is lowest, that being from June to August inclusive.

The pH values of Western Lake Erie were reported by Chandler to range from pH 7.5 to pH 8.4.[1] The maximum pH was reached from July to October, the minimum from November to April, Although temporary thermoclines were present, a conspicuous variation in pH was not observed vertically.

In Buckeye Lake, the highest pH value was recorded in August (pH 8.9) the lowest reading was obtained in July (pH 7.3).[2] The hydrogen-ion concentration was roughly in inverse proportion to the free carbon dioxide.

Much research has been conducted relative to the effect of the hydrogen-ion concentration upon plant and animal aquatic forms. Daily investigating Lake Michigan in the vicinity of Evanston, Illinois, found that the pH range varied from pH 7.4 to pH 8.4 through the entire annual cycle.[3] He is of the opinion that hydrogen-ion concentration produces a negligible effect on phytoplankton seasonal periodicity.

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[1] D. Chandler, "Limnological Studies of Western Lake Erie", Ohio Journal of Science, XL, #6:291-336, 1939.

[2] W. Tressler, L. Tiffany and W. Spencer, "Limnological Studies of Buckeye Lake, Ohio", Ohio Jour. Sci. XI#5:261-290, 1940

[3] W.A. Daily, "A Quantitative Study of the Phytoplankton of Lake Michigan collected in the Vicinity of Evanston, Illinois", Butler University Botanical Studies. 4(6), 1938.

The effect of hydrogen-ion concentration on the population of any specie, excluding ciliates in saprobiotic habitats, is questioned by Hutchinson.[1]

Hiestand and Hale concluded that the rate of oxygen consumption of gastropod molluscs is in direct proportion to the hydrogen-ion concentration.[2] Hyman, likewise found that this relationship also exists in Planaria,[3] while Hall maintains that increasing the pH tends to check the oxygen consumption of puffer fish.[4]

pH values as low as 2.8 were found in the polluted areas of the Curtis Creek.[5] These acid readings were a result of direct waste acid disposal. Values less than 4.5 impaired activity and growth of planktonic forms. Olsen concludes that diatoms and protozoa were particularly sensitive to low hydrogen ion concentrations over a short time, while algae were not quite as sensitive.

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[1] G.E.Hutchinson, "Ecological Aspects of Succession in Natural Populations", American Naturalist, LXXV:406-418, 1941.

[2] W.A. Hiestand and D.M. Hale, "Respiration Studies with Freshwater Molluscs: II Oxygen Consumption in Relation to Hydrogen-ion Concentration", Proc. Indiana Acad. Sci., 47:293-298, 1938.

[3] L.H. Hyman, "On the Action of Certain Substances on Oxygen Consumption:VI. The Action of Acids", Biol. Bull. 49:288-322, 1925.

[4] F.G. Hall, "The Influence of Varying Oxygen Tension Upon the Rate of Oxygen Consumption in Marine Fishes", Am. Jour. Physiol. 93:417-421, 1930.

[5] R.A. Olsen, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biological Laboratory Publication #43:1-40, November, 1941.

Littleford is of the opinion that the toxicity of copperas to the Four-Spined Stickleback, <u>Apeltes</u> <u>quadracua</u>, is a result of a lowering of the pH of the solution.[1] The decrease in toxicity noted to occur with a lowering of the temperature of the concentration can be correlated with a corresponding lack of decrease in the pH of the solution. The difference existing in the pH of the solutions at low and at high temperatures results from differences existing in the speed of the chemical reactions that take place when copperas is added to water. Copperas dilutions having a pH less than 5.00 are toxic to the stickleback to a greater or less degree over very short periods of time. Concentrations between 5.00 and 5.70 have the per cent survival increased to sixty per cent. In those cases where the pH is 6.00 or over, one hundred per cent survival was obtained.

In concentrations greater than 2,000 parts per million, it was observed that death was hastened by the formation of a thick, slimy scum on the gills of fish. This condition has been observed by many workers and is adequately discussed by Ellis;[2] therefore, no extended discussion is needed.

The lethal action of pollutants has been considered by Ellis to be of two general types: (1) external action by a combination of chemical

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[1] R.A., Littleford, "Survival of Four-Spined Stickleback, <u>Apeltes quadracus</u>, in Copperas Dilutions", Unpublished, 1-8.

[2] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fisheries. XLVII:65-437, 1937.

and physical injuries, and (2) internal action, or true toxic action.[1] It seems likely from the data presented that the lethal effect of copperas is the result of chemical and physical injury rather than true toxic action. Fish have been kept for three or four months in solutions of 125 and 500 parts per million without any apparent harm to the organism.[2]

Chlorinity. The saline characteristics of any aquatic environment is of primary importance in that the degree of salinity is one of the factors which determines the ecological organization of any aquatic environment. Further, since this factor is variable, it is important that the range of variability, factors influencing the variability, and the periods of variability all be studied. Since the method of arriving at salinity is obtained by chlorine titration, this factor is by some authors expressed as *chlorinity*.

Probably the most comprehensive studies of salinity in this area have been done by Wells, Bailey and Henderson[3] first, and later by Cowles.[4]

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[1] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fisheries. XLVII:65-437, 1937.

[2] R.A. Littleford, "Survival of Four-Spined Stickleback, *Apeltes quadracus*, in Copperas Dilutions," Unpublished, 1-8

[3] R.C. Wells, R.K. Bailey and E.P. Henderson, "Salinity of the Water of the Chesapeake Bay", Department of the Interior, U.S. Geol. Surv., Prof. Paper 154C:105-152, 1929.

[4] R.P. Cowles, "A Biological Study of the Offshore Waters of the Chesapeake Bay", U.S. Dept. of Commerce, Bur. Fish. Bull. XLVI, #1091: 277-381, 1930.

It was noted by Wells and others that the chlorinity of the Chesapeake decreased from the mouth of the bay to its head. It was further observed that the east side of the bay tended to have waters which were more saline than those on the west side. The deeper waters were more concentrated relative to this factor than were the surface waters.

The foregoing was later confirmed by Cowles. The range of chlorinity of the surface water was 4.7 (head of the bay) to 28.94 (mouth of the bay). The range of chlorinity for the bottom waters was 6.00 to 17.00 (Baltimore area) and 26.32 (mouth of the bay). The minimum salinity point occurs in the spring, the concentration increasing progressively during the summer and fall; finally reaching a maximum in winter. Cowles points out that precipitation exerts a negligible effect on bay salinities.

In the environs of Solomons Island, it was found that wide variations existed relative to salinities of the surface as well as bottom waters.[1] The chlorinity range of the surface water was between 5-8, the maximum being attained between October and December. The range of salinity of the bottom was between 9 and 13. The investigators found that such factors as tides and rainfall did exert a significant difference on the chlorinity of this area. Subsequent investigations in this area yielded similar results in that the mineral surface figures for chlorinity are reached and maintained during the spring months.[2] The upward trend

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[1] C.L. Newcombe, W.A. Horne and B.B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in the Chesapeake Bay", Journal of Marine Research, II, 2:87-116, 1939.

[2] C.L. Newcombe and A.G. Lang, "The Distribution of Phosphates in the Chesapeake Bay", Proceedings of the American Philosophical Society, 81, #3:393-420, 1939.

commences in April reaching a peak during November and December. The highest chlorinity readings for the bottom waters were obtained later in the summer. It was noted that the lighter, less saline waters from the bay tributaries made their greatest movement over the spring and summer months.

In the Curtis Bay region, Olson found insignificant differences in salinity.[1] The gradient existing between the stations is inconsequential. A minimum value of 2.0 was recorded for March and a maximum of 8.0 in September. As would be expected, stratification was present only at the deeper stations.

A direct relationship was observed by Nash between light penetration and salinity. Increased light penetration occurring downstream is accompanied by an increase in chlorinity.[2] This agreement is applicable to seasonal as well as vertical salinity.

Oxygen. The value of dissolved oxygen in aquatic environments cannot be overestimated. In any habitat accomodating plants and animals there exists an immediate interplay of factors in which the animals and plants utilize the oxygen for their respiratory process and release carbon dioxide as a byproduct of their metabolic activity. Phytoplankton, as in all plant forms, is predominantly anabolic and hence require large quantities of carbon dioxide for the photosynthetic process, the

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[1] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biol. Lab. Pub. #43:140, November 1941.

[2] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab. Pub. #64:147-174, Dec. 1947.

process by which this is accomplished.

The role played by carbon dioxide will be given subsequently. The oxygen necessary for the katabolic process of aquatic organisms and for the decomposition of certain compounds is obtained by that atmospheric oxygen which enters into solution and by that oxygen which is made available as a byproduct of photosynthetic activity. All conditions being equal, the three factors: oxygen, carbon dioxide and plankton form the triangle of aquatic life; anyone of which if found wanting, causes this triangle to cease existing.

Oxygen consumption was noted by Hall to be greatly increased by higher temperatures.[1] He further found that oxygen consumption was retarded by an increase in hydrogen-ion concentration. His results tend to show that marine fish take approximately 46 per cent of the dissolved oxygen from the environment.

As a result of an investigation of 510 lakes and lakelets in northeastern Wisconsin, Juday and Birge concluded that the dissolved oxygen content of the surface waters ranged from 3.4 mg. to 12.4 mg/l. of water. As would be expected, bog lakes were oxygen-poor."[2] The degree of oxygen consumption was in close agreement with the quantity of vegetable extractives. The presence of the latter is indicated by the brown color imparted to the water.

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[1] F.G. Hall, "The Influence of Varying Oxygen Tension Upon the Rate of Oxygen-Consumption in Marine Fishes", Am. Jour. Physiol., 88:212-218, 1929.

[2] C. Juday and E.A. Birge, "Dissolved Oxygen and Oxygen Consumed in the Lake Waters of Northeastern Wisconsin", Transaction of Wisconsin Academy of Science, Arts and Letters, 27:415-486, 1932.

It was demonstrated by Rawson, that because of the bottom oxygen consumption, the oxygen deficit appeared greater than is usually expected in the thermocline of the body of water investigated.[1] The exhaustion of oxygen-supply in deeper waters was extreme during the period of winter stagnation. The oxygen range in bottom waters at midsummer appeared to be inconsistent from year to year.

Definite oxygen stratification in certain regions of the Chesapeake Bay was observed by Newcombe and Horne.[2] This stratification tended to loose its identity in the upstream areas. Stratification of oxygen was found to exist from the first of June until the first of October. The concentration of oxygen of the upper layer is approximately 6cc./l. The concentration at a depth of 10 meters is approximately 2cc./l. while that of the bottom is imperceptibly low. The oxygen-poor bottom layer is accompanied by a high saline concentration above which the chlorinity decreases in concentration as the oxygen concentration increases. A saturation of 150 per cent was reported in January in the bay waters.[3] This high figure was explained by the presence of an abundance of phytoplankton. In summer, a 33 per cent saturation was reported; this concentration was a result of surface-bottom mixing. The oxygen values for the bottom waters were progressively lower from June to August; the lowest value was obtained in the latter month.

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[1] D.S. Rawson, "Physical and Chemical Studies in Lakes of Prince Albert Park, Saskatchewan", Jour. Biol. Bd. Canada, II,#3:227-283, 1936.

[2] C.L. Newcombe and W. Horne, "Oxygen Poor Waters of the Chesapeake Bay", Science, 88, #2273:380-81, 1938.

[3] C.L. Newcombe, W. Horne and B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in Chesapeake Bay", Jour. Mar. Res., 2:87-116, 1939.

A variation of dissolved oxygen from 1[illegible].9 p.p.m. (in March) to 5.0 p.p.m. (in late summer and early autumn) was observed by Chandler in western Lake Erie.[1] At times, a positive or negative deviation from the normal value occurred which was in proportion to the plankton or detritus content of the lake. A variation not greater than 2.0 p.p.m. did not occur between the surface and bottom waters.

The waters of Buckeye Lake were found to be bountifully supplied with oxygen.[2] The lower values were found to occur in the warmer summer months, this being in conformity with the laws of reciprocity between gases and the water-absorbing capacity of these gases. The lowest oxygen value (1.4 p.p.m.) occurred in a bog hole.

A seasonal variation of dissolved oxygen concentrations in surface as well as in the bottom waters of the Patuxent River was noted by Nash.[3] The descent of oxygen values of the surface water began in March and reached a minimum of 2.3 c.c./l. in August. The bottom waters also demonstrated a comparable seasonal variation with the exception that minimal values were found to occur in June. It was also found that a surface-bottom variation of .3 c.c./l existed during the overturn period and that this variation increased to 2.2 c.c./l. during the latter months of spring and into early summer.

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[1] D. Chandler, "Limnological Studies of Western Lake Erie", Ohio Jour. Sci., XL,#7:291-336, 1939.

[2] W. Tressler, L. Tiffanny and W. Spencer, "Limnological Studies of Buckeye Lake, Ohio", Ohio Jour. Sci. XL,#5:261-290, 1940.

[3] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biological Laboratory Publication #64:147-174, December, 1947.

The deficiency of dissolved oxygen resulting from pollution factors has become, unfortunately a more serious problem. Ellis has shown that vital activity of most aquatic forms is dangerously impaired or ceases when the dissolved oxygen concentration drops below 4.0 to 3.5 c.c./l.[1] Oxygen poor environments thus established give rise to the less desirable facultative and obligatory anaerobic forms.[2]

Paramecia which are subjected to anaerobic conditions for a brief time recover when placed in aerobic environments.[3] Prolonged anaerobic conditions result in a cessation of physiological activity, blistering and cytosysis. An approximately neutral pH of the water increases the longevity of the organisms under decreased oxygen concentrations.

Towsand, Ericksen and Earnest found that large sections of Grays Harbor were polluted as shown by the low value of dissolved oxygen concentration.[4] The area in the environs of the dead and distressed salmon indicated a concentration of dissolved oxygen of 1 p.p.m. at the surface and 0.24 p.p.m. at a depth of 15 feet. Examination of the dead salmon indicated visible signs of leisons, tumors and regions of bloody

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[1] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fisheries, XLVII:65-437, 1937.

[2] J. B. Lackey, "Oxygen Deficiency and Sewage Protozoa: with Description of Some New Species", Biol. Bull. LXIII, #2:287-295, 1932.

[3] J. A. Kitchling, "The Effects of a Lack of Oxygen and of Low Oxygen on Paramecium", Biol. Bull. LXXVII:339-353, 1939.

[4] L.D. Towsand, A. Ericksen and D. Earnest, "Progress Report on Field Investigations and Research", Wash. State Pollution Commission December, 1938

infiltration entirely wanting. It was clearly shown that the reaction of the fish at the site of pollution exhibited the same physiological reactions or comparable reactions to those fish in the laboratory which died of oxygen deficiency. On this basis, the investigators concluded that the fish kill was attributed to a lack of oxygen or some extrinsic factor impeding normal respiratory functions.

Critically low concentrations of dissolved oxygen were found generally throughout the Curtis Bay area.[1] Although this condition was present in the cooler months, it was particularly acute in the summer months when the temperature of the water was above 25 degrees centigrade. It was also observed that oxygen deficiency at some stations was a result of copperas disposal. Olson concluded that the delitorious effects of copperas appeared to be one of oxygen depletion of the subsurface waters over the entire area in summer and locally at other times.

Carbon dioxide. As previously stated (page 17), phytoplankton requires a bountiful supply of this gas to carry on the process of photosynthesis. The carbon dioxide supply is obtained from several sources among which is that derived from the process of oxidation which is constantly occurring in all living organisms, that derived from atmospheric carbon dioxide which is dissolved in the water, that derived from the decomposition of organic substances, that derived from rain and that derived from bicarbonates found in the aquatic habitat. The concentration of this gas in the water is variable, since in the process

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[1] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biol. Lab. Pub. #43:140, November, 1941.

of photosynthesis light is required. That is to say, that during the light hours when the process of food manufacture is carried on by phytoplankton, the carbon dioxide is extracted from the surface water leaving a lower concentration. At this time the oxygen being in the excess. At night, with the photosynthetic reactions at a stand-still, the carbon dioxide content of the surface stratum of water is increased. Obviously turbidity of the water appreciably alters the concentration of this chemical factor inasmuch as it reduces the amount of light required to produce the process of photosynthesis. It may therefore be concluded, on the basis of the foregoing, that the amount of carbon dioxide present in most bodies of water may function as an index to the productivity and ecological balance of that aquatic environment.

Carbon dioxide present in the water is expressed in three ways: free carbon dioxide, half-bound carbon dioxide (that which converts monocarbonates to bicarbonates) and bound or fixed carbon dioxide (that which converts calcium oxide to calcium carbonate.)

The investigation of the lake waters of northeastern Wisconsin by Juday, Birge and Meloche[1] demonstrated that the surface waters of those lakes lacking inlets or outlets (seepage lakes) yielded positive acid reactions with a free carbon dioxide range of 0.3 to 10.7 mg./l. The surface water of those lakes having an outlet (drainage lakes) yielded positive alkaline reactions with a range of 0.7 to 10.7 mg./l. of carbon dioxide. The bound carbon dioxide in the seepage lakes ranged

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[1] C. Juday, E. Birge and V. Meloche, "The Carbon Dioxide and Hydrogen-Ion Content of Lake Waters of Northeastern Wisconsin", Transaction Wisconsin Acad. Sc. Arts and Letters, 29:1-82, 1935.

from 0.2 to 11.3 mg./l. while the range of the drainage lakes was 1.0 to 39.0 mg/l. It was found that the annual variation of bound carbon dioxide in seepage lakes was small, while in some of the drainage lakes, the difference rarely ranged above 2.0 mg./l. Surface waters having a free carbon dioxide annual variation of 0.0 to 14.7 mg./l. was reported. This range is a result of the photosynthetic activity in these lakes. The distribution of free carbon dioxide varied in the different lakes ranging from a lake in which there was an even distribution throughout the lake to those lakes in which the carbon dioxide in the deeper waters was more concentrated.

In the Prince Albert Lakes, it was noted by Rawson that the free carbon dioxide of the surface water was 1.3 c.c./l. in the colder months before the ice break.[1] This value was reduced after the ice-break. A concentration of 1.5 c.c./l. of carbon dioxide was observed from the beginning to the middle of June, at the end of which time the water ranged from neutral to alkaline until September. The concentration of free carbon dioxide of the lower stratum of water was found to be 4.6 c.c./l. in April (a hangover of winter stagnation). With vernal circulation, the free carbon dioxide was reduced to 1.8 c.c./l., resulting in a more or less evenly distributed concentration over the entire lake. During the warmer months it was found that the carbon dioxide concentration increased on the bottom and declined again in June. With the advent of the summer stratification period, the carbon dioxide value

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[1] D. Rawson, "Physical and Chemical Studies in the Lakes of Prince Albert Park, Saskatchewan", Journal Biol. Board of Canada, II, #3:227-283, 1936.

began to quickly rise reaching a maximum range of 9.0 to 11.2 c.c./l. in the middle of August. Autumnal overturn gradually reduced the carbon dioxide factor to nil.[1]

The bound carbon dioxide of the upper stratum was 21.8 c.c./l. in early spring, rising to 32.8 c.c./l. by the middle of spring and continuing through the summer with a variation of not more that 2 c.c./l. The concentration in the lower stratum may be characterized by a rise during vernal overturn, a decline in June followed by another rise at summer stratification and another decline at autumnal overturn. The values are equalized throughout the lake at the overturns.[2]

Variations of the free carbon dioxide concentration between the stations in Buckeye Lake were explained by Tressler, Tiffany and Spencer to be caused by a deep hole.[3] High winds were responsible for the mixing and replenishment of the exhausted supply of surface carbon dioxide. An inverse correlation was found between high temperatures and the abundance of dissolved oxygen with carbon dioxide; the latter being depleted by phytoplankton in the photosynthetic activity. Fixed carbon dioxide was reported to have increased in the summer.

In western Lake Erie, Chandler reports free carbon dioxide was present from December to May; but found carbon dioxide wanting during

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[1] D. Rawson, "Physical and Chemical Studies in the Lakes of Prince Albert Park, Saskatchewan", Jour. Biol. Bd. of Canada, II,#3:227-283,1936

[2] Ibid, p. 276

[3] W. Tressler, L. Tiffany and W. Spencer, "Limnological Studies of Buckeye Lake, Ohio", Ohio Jour. Sci. XL, #5:261-290, 1940.

the remainder of the year.[1] The highest value was observed in April following the ice-break. An even distribution of carbon dioxide was found in the area investigated.

Experimenting with Puffer Fish, Hall found that increased hydrogen-ion concentration resulting from carbon dioxide, more acutely affected the respiration of the fish than did the addition of hydrochloric acid at the same hydrogen-ion concentration.[2]

Phosphorus. The relationship of phosphorus salts to the biotic factor of marine and fresh water has been extensively studied by many investigators. McHargue and Peter investigating the springs and streams of Kentucky concluded that the phosphorus concentrations were influenced by geological strata-character.[3] Mississippian and Pennsylvanian areas yielded much smaller amounts than the Ordovician areas.

The phosphorus content of five lakes in Idaho and Washington, as determined by Kemmerer, Bovard and Boorman, was found to range from 0.013 to 0.026 mg. per liter.[4]

A seasonal Variation in the phosphorus content was observed by

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[1] D. Chandler, "Limnological Studies of Western Lake Erie", Ohio Jour. Sci., XL, #7:291-336, 1939.

[2] F. Hall, "The Influence of Varying Oxygen Tension Upon the Rate of Oxygen Consumption in Marine Fishes", Am. Jour. Physiol. 88:212-218,1929

[3] J. McHargue, and A. Peter, "The Removal of Mineral Plant Food by Natural Drainage Water", Kentucky Agricultural Exp. Sta. Bull.237-333-362, 1921.

[4] G. Kemmerer, J. Bovard and W. Boorman, "Northwestern Lakes of the U.S.: Biological and Chemical Studies with Reference to Possibilities in Production of Fish", Bull. Bur. Fish., 39:51-140, 1923.

Atkins and Harris[1] in the ponds investigated. These investigators concluded that phosphorus was utilized by phytoplankton early in spring and by summer, the available supply was exhausted. The lack of phosphorus, conditioned the growth of algal forms. The supply of phosphorus was replenished during the winter months.

Atkins[2] and Brandt[3] working independently on the content of phosphorus in sea water arrived at similar conclusions, e.g., A) that the phosphorus content attained a maximum in the autumn and winter months and reached a minimum in the spring and summer months and B) that the deeper ocean waters contained a constant supply of phosphorus.

In an investigation to determine the inorganic chemical factors in pond water that may act as conditioning constituents in plankton growth and hence fish production, Wiebe made an intensive study of the principal forms of inorganic nitrogen and soluble and total phosphorus.[4] As a result of the study of the pond waters at Fairport, Iowa, Wiebe concluded that soluble phosphorus acts as a conditioning factor. Since the ponds were fed by the waters of the Mississippi River, the investigator

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[1] W. Atkins and G. Harris, "Seasonal Changes in the Water & Heleoplankton of Fresh Water Ponds", Proc. Royal Dublin Soc., 18:1-21, 1924.

[2] W.R. Atkins, "The Phosphate Content of Fresh and Salt Water in Its Relationship to the Growth of Algal Plankton", Jour Mar. Biol. Assn. 13:119-150, 1923.

[3] K. Brandt, "Ueber den Stoffwechsel in Meere Wissensch", Meeresuntersuch 18:187-429, 1929.

[4] A.H. Wiebe, "Investigations on Plankton Production in Fish Ponds", U.S. Bureau of Fisheries, Doc. 1082.

studied the latter in an attempt to determine the variation of these chemical factors.[1] Wiebe concludes that the maximum phosphorus value coincides with the phytoplankton increase and that the soluble phosphorus content may act as a limiting factor. Fischer maintained that upon fertilization of ponds by ground basic slag or super phosphate, the production of carp was significantly increased.[2] Hutchinson is of the opinion that phosphates are of extreme importance to all autotropic forms though the concentrations are very low.[3]

The phosphorus content of the lakes investigated by Juday and others did not decrease during the spring and summer although a heavy population of plankton was present.[4] Phytoplankton production and the soluble phosphorus content of these waters did not appear to correlate. It was noted that the lower strata of the water in the lakes contained less soluble phosphorus in summer.[5] When the phosphorus content of the

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[1] A.H. Wiebe, "Dissolved Phosphorus and Inorganic Nitrogen in the Water of the Mississippi River", Science, 73,#1902:652, June 1931.

[2] H. Fischer, "The Problem of Increasing the Production in Fish Ponds by the Use of Chemical Fertilizers", Internat. Res. Science and Prac. Agr., 2:822-830, 1924.

[3] G. Hutchinson, "Ecological Aspects of Succession in Natural Populations", Am. Nat., LXXV:406-418, 1941.

[4] C. Juday, E. Birge, G. Kemmerer and R. Robinson, "Phosphorus Content of Lake Waters of Northeastern Wisconsin", Transactions Wisconsin Acad. Sci., Arts and Letters, XXIII:233-248, 1928.

[5] C. Juday and E. Birge, "A Second Report on the Phosphorus Content of Wisconsin Lake Waters", Transactions Wisconsin Acad. Sci., Arts and Letters XXVI:353-382, 1931.

lakes was correlated with the presence of three species of bryophytes found on the bottom of the lakes investigated, results indicated that the lakes in which the bryophytes were found appeared to have higher phosphorus concentrations.[1]

The maximum concentration of phosphate in the Chesapeake Bay, according to Newcombe and Lang, occurred in summer and the minimum values were found to occur in the fall, winter and early spring.[2] Subsurface waters in the upper regions of the bay were found to contain more phosphorus than those in the lower regions of the bay. Significant differences were reported between light hours and darkness, e.g., phosphorus concentrations were found to be higher from sunset to sunrise. Daily variations in the phosphate content of the bay waters over a four month period from June to September were observed.[3] Maximum values for this factor were recorded in August with descending values early in September. The latter is coincident with reduced turbidity of surrounding waters, beginning at the time of the lowering phosphate concentration and extending into autumn. It was also noted that the chlorinity of the water and the phosphorus content in the headwaters of the Patuxent River was in inverse proportion, e.g., increase in the phosphorus concentration

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[1] C. Juday, E. Birge and V. Meloche, "Chemical Analysis of the Bottom Deposits of Wisconsin Lakes II. Second Report", Transactions of Wisconsin Acad. Sci., Arts and Letters, 33:94-114, 1946.

[2] C. Newcombe and A. Lang, "The Distribution of Phosphates in the Chesapeake Bay", Proc. Am. Phil. Soc. 81,#3:393-420, 1939.

[3] C. Newcombe & H. Brush, "Variations in the Phosphorus content of Estuarine Waters of the Chesapeake Bay near Solomons Island", Jour. Mar Research, ~~III~~,#1:76-88, 1940.

with decrease in chlorinity. It was further observed that the upper regions of the Patuxent River demonstrated higher phosphate concentrations that the surface water of the bay.[1] Further, hourly samples revealed appreciable variations, the latter being more characteristic of shallow regions where mixing is more prevalent. Higher phosphate concentrations were also observed in the deeper bay waters.

Nitrates. The nitrogenous requirement of the protoplasm of aquatic organisms is provided by the nitrates found in the water. Juday and others maintain that the nitrogen requirements of organisms is met by most aquatic environments.[2] Phytoplankton forms in their anabolic process avail themselves of the nitrates to synthesize proteins. Upon the death of the aquatic organisms, either by natural causes or otherwise, they disintegrate; the decomposition of which results in the formation of either ammonia or nitrates. Protein decomposition is aided by bacteria. The bacteria involved in this process are classified into four groups: those which oxidize ammonia to form nitrites, those which oxidize nitrites to nitrates, those whose action ultimately end as ammonia and those which change nitrates to nitrites. Since these bacteria are found in the aquatic habitats, the end products which they produce are likewise found there.

The nitrate-nitrogen values of the Mississippi River at Fairport,

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[1] C. Newcombe, W. Horne and B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in Chesapeake Bay", Journal Mar. Res., II,#2:87-116, 1939.

[2] C. Juday, E. Birge, G. Kemmerer and R. Robinson, "Phosphorus Content of Lake Waters of Northeastern Wisconsin, Transactions of Wisconsin Acad. Sci., Arts and Letters, XXIII:233-249, 1928.

Iowa, as reported by Wiebe was found to range from 0.051 to 0.914 p.p.m. at the surface and 0.060 to 0.776 p.p.m. at the bottom.[1] Wiebe is of the opinion that inorganic nitrogen is not a conditioning factor.

The high nitrite-nitrogen values observed by Rakestraw were in direct accord with corresponding high values of nitrate-nitrogen and phosphate phosphorus in the upper stratum of water.[2] However, high nitrate-nitrogen values were not indicative of high nitrite-nitrogen values, particularly in the bottom waters. With the spring bloom of diatoms, nitrate-nitrogen concentrations dropped.

Analysis of Waskesiu Lake by Rawson demonstrated that the amounts of nitrates in the water were distributed over a rather wide range, e.g. 0.05 to 0.20 p.p.m.[3] Rawson is of the opinion that Waskesiu Lake is unusually rich in nitrogenous substances; this substantiates his conception of Waskesiu as an essentially eutropic lake.

In the surface waters of the ocean and lakes, Hutchinson noted marked seasonal changes, which are determined by the organisms inhabiting the waters.[4] Spring values of nitrate-nitrogen and phosphate-phosphorus were lowered as a result of increased light and temperature thus

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[1] A.H. Wiebe, "Dissolved Phosphorus and Inorganic Nitrogen in the Water of the Mississippi River", Science, 73,#1902:652, June 1931.

[2] N. Rakestraw, "The Occurrence and Significance of Nitrite in the Sea", Biol. Bull. 71:133-167, 1936.

[3] D. Rawson, "Physical and Chemical Studies in Lakes of the Prince Albert Park, Saskatchewan", Jour. Biol. Bd. of Canada, II,#3:227-283, 1936.

[4] G. Hutchinson, "Ecological Aspects of Succession in Natural Populations", American Naturalist, LXXV:406-418, Sept. 1941.

yielding conditions which were more conducive to photosynthetic activity. The significant reduction in the nitrate and phosphate concentrations were inversely correlated with oxygen and pH factors.

It has been shown by Harvey that fertilization of offshore sea water with nitrates, phosphates and iron supported diatomaceous forms.[1] The productivity resulting from this type habitat was moderate. Further, this investigator is of the opinion that diatom-productivity was increased perceptibly more in a nitrate medium than in a phosphate medium.[2] It was shown that 10.4 more nitrate nitrogen was used by the organisms than was phosphate-phosphorus. Tressler proposed that high nitrate values are indicative of lake-productivity.[3] The range in value of the area investigated was from 1.00 p.p.m. to 0.050 p.p.m. The lower values were obtained at the end of summer.

The nitrate range in the estuarine waters of the Chesapeake Bay as reported by Nash was from 0.00 to 8.2 X 10 mg. atoms of N per liter.[4] The nitrate values decline downstream. This decrease in concentration is due in part to the consumption of the nitrates in its downstream progress and to the ingression of nitrates in the fresh less saline waters. The nitrate-nitrogen values for the bottom waters were

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[1] H. Harvey, "Substances Controlling Growth of a Diatom", Jour. Mar. Biol., 23:499-520, 1939.

[2] H. Harvey, "Growth of Phytoplankton", Jour. Mar. Biol.24:115-123,1940

[3] W. Tressler, L. Tiffany and W. Spencer, "Limnological Studies of Buckeye Lake, Ohio", Jour. Sci., XL,#5:261-290, 1940.

[4] C. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab. Pub. 64:147-174, Dec. 1947.

generally higher and never less than the surface value. Winter concentrations were higher than at any other season.

<u>Nitrites</u>. As previously stated, bacterial action is responsible for the decomposition of protein compounds to ammonia, nitrates and nitrites. It can be seen that since nitrite-nitrogen is the intermediate unstable form, its presence in the water can be interpreted as an index to the nitrogen cycle equilibrium.

In investigating the Clyde Sea area, Orr found that the range of nitrite-nitrogen was from 0.001 to 0.003 mg./l.[1] In order to ascertain the effects that algae might have on the nitrite concentration, the algae were reared in the water under varying experimental conditions and the values were then recorded.

It was found that the nitrite concentrations were appreciably raised even after the productivity of plankton ceased. It was this investigator's opinion that such factors as nitrate concentration, intensity of light and nature of the flask influenced the results significantly.

It was also observed that nitrite values in the summer ranged from 0.001 to 0.01 mg./l. in the upper stratum of water. The values for the lower stratum were generally greater than the surface. Orr concludes that nitrite-nitrogen variations of sea water may be a result of a) action of bacteria, b) ultra violet light, c) algal plankton, and d) ingression of nitrites from fresh waters and the atmosphere.

The range of nitrite-nitrogen as recorded by Rawson in Lake

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[1] A. Orr, "Nitrite Content of Sea Water", Journal Mar. Biol., 14:55-56, 1927.

Waskesiu was from 0.00 to 0.001 p.p.m.[1]

It was maintained by Rakestraw that the nitrite distributions and concentrations were possibly correlated with such biological factors as bacterial and plankton distribution and with such physio-chemical factors as dissolved oxygen concentration, temperature, density and intensity of illumination.[2] This investigator found that nitrite concentrations were greater at decreased winter temperatures. With increased temperature and corresponding consumption of nitrites by plankton, the value was decreased. Density and concentrations of nitrites were in direct correlation. Whenever this was not in accord at higher values, it was observed to be a result of plankton-productivity.

Except for the short decrease in early spring due to the initial bloom of plankters, the surface value of nitrite-nitrogen was low in winter followed by an increase in spring with the maximum values being reached between June and September.

Muddy bottoms tended to yield higher nitrite-nitrogen concentrations. Further, it was found that oxidation of organic compounds were greater in shallower than in deeper waters.

Theamounts of nitrite-nitrogen found in Buckeye Lake was negligible.[3] Tressler and others are of the opinion that this quasi-libera condition

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[1] D. Rawson, "Physical and Chemical Studies in Lakes of the Prince Albert Park, Saskatchewan", Jour. Biol. Bd. of Canada, II, #3:227-283, 1936

[2] N. Rakestraw, "The Occurrence and Significance of Nitrite in the Sea", Biol. Bull. 71:133-167, 1936.

[3] W. Tressler, L. Tiffany and W. Spencer, "Limnological Studies of Buckeye Lake, Ohio", Ohio Jour. Sci., XL, #5:261-290, 1940.

relative to nitrite-nitrogen concentrations, is indicative of an absence of sewage pollution.

The range of nitrite-nitrogen in the estuarine waters of the Chesapeake Bay ranged from 0.00 to 0.6 X 10^{-3}mg. atoms per liter.[1] Some determinations with a maximum range of 1.1 X 10^{-3} were also obtained. The bottom waters were more richly supplied with nitrite-nitrogen than the surface. Further, seasonal variations were evidenced by the fact that significantly higher values for nitrite nitrogen were obtained from July to October. These values were not duplicated during the other months.

In the Patuxent River, Nash found that the nitrite nitrogen ranged from 0.0 to 1.5 X 10^{-3} mg. atoms per liter.[2] Higher concentrations were obtained at those stations in the bay or lower half of the estuary, e.g. 0.2 X 10^{-3}mg. atoms per liter for the surface waters and 0.3 X 10^{-3} for the bottom waters. The deeper waters yielded higher values than the surface waters. This was attributed to the muddy bottoms which possess greater nitrite-nitrogen regeneration. However, this condition was not characteristic of the waters of the upper estuarine waters.

Silicates. This compound is of particular interest since it is the main constituent of diatom-shells; one of the waters most important primary producers. The role played by diatoms in the economy of any aquatic environment cannot be ignored. Further, silicates are incorporated in

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[1] C. Newcombe, W. Horne and B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in Chesapeake Bay, Jour. Mar. Res., II,#2:87-116, 1939.

[2] C. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab. Pub. 64:147-174, Dec. 1947.

the skeletal structures of many other important aquatic forms. This factor is probably one of the more variable of the chemical factors involved in aquatic habitats.

Stratification is not uncommon, although both surface and bottom concentrations may be high. Higher surface values, when present, are possibly due to the influx of fresh water from the rivers, which are more bountifully supplied; while higher bottom concentrations are due to the dissolution of diatom shells which after death because of their weight, fall to the bottom. The absence of silicate-silicon from the upper stratum may be indicative of productivity, however, the inherent lack of this compound does not act as a limiting factor in phytoplankton-productivity.

The estimated value of silica on the floors of the various lakes investigated by Juday ranged from 14.6% to 52.7% (dry weight), the second highest in mineral value.[1]

The four climactic periods noted by Meloche and coinvestigators, relative to diatom production, occurred in January, April, June and October; the latter being the most productive month.[2] On the other hand, silica concentrations appeared to decline in November and January and rise in early spring. Summer yields which were proportionately low, were followed by higher concentrations. It appeared that the relation

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[1] C. Juday, E. Birge and V. Meloche, "Chemical Analysis of Bottom Deposits of Wisconsin Lakes II, Second Report, Transactions of Wisconsin Acad. Sci. Arts and Letters, 33:94-114, 1946.

[2] V. Meloche, G. Leader, L. Safranski and C. Juday, "The Silica and Diatom Content of Lake Mendota Water", Transactions of Wisconsin Acad. Arts and Letters, XXXI:363-376, 1938.

between silica content and diatom population is not manifested, except in the October bloom. The range for this factor was between 0.4 to 2.5 p.p.m. Seasonal circulation resulted in a uniform distribution of diatoms and silicate-silicon.

The examination of the estuarine waters of the Chesapeake Bay for silica content, yielded results which were high and commensurate with water of low salinity. The highest values were obtained in the bay between April and October when the range varied from 19 X 10^{-3} to 30 X 10^{-3}.[1] Lower values ranging from 3 X 10^{-3} to 20 X 10^{-3} were obtained in winter. Bay waters yielded lower values than the less saline river waters, the concentration for the latter ranged from 50 X 10^{-3} to 120 X 10^{-3} mg. atoms/l.

Tressler and others found the silicon content of the waters of Buckeye Lake to range from 1.6 to 8.0 p.p.m.[2] The lower values resulted from an increase of biological activity in the lake during that season. Further, it was found that the lack of estival rain was not conducive to high silicon concentration.

The range of silicon in the Patuxent River according to Nash,[3] varied from 8 X 10^{-3} to 329 X 10^{-3} mg. atoms per liter. The lower values were observed to be confined in a narrower range as the water increased in chlorinity. Surface values averaged 13 per cent higher than

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[1] C. Newcombe, W. Horne and B. Shepherd, "Studies on the Physics & Chemistry of Estuarine Waters in Chesapeake Bay", Jour.Mar.Res., #:2: 87-116, 1939.

[2] W. Tressler, L. Tiffany and W. Spencer, "Limnological Studies of Buckeye Lake, Ohio", Ohio Jour. Sci., XL,#5:261-290, 1940.

[3] C. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biological Laboratory Publication #64:147-174, Dec. 1947.

the water of the lower stratum. Silicates present in the area were predominantly a result of the influx of river waters rich in silicate content, since the muddy estuary floor does not lend itself to silicate regeneration. Because of this silicate-silicon concentrations may be used as a fresh water index.

Iron. Iron compounds are one of the chemical constituents of aquatic environments. It is believed by Gran[1] that habitats either low or wanting in iron, condition the growth of plants, while Harvey[2] and Thompson and Bremner[3] observed that diatom-productivity and iron concentrations appear to be inversely related. However, in certain areas, iron compounds particularly ferrous sulphate and flocculating ferric hydroxide in high concentrations, because of their toxic effect on macro-and microscopic aquatic organisms; are serious pollutants. While ferrous iron probably does occur naturally in the hypolimnion of certain waters according to Hutchinson[4], it is neutralized by substantial concentrations of bicarbonates. The deliterious effects of copperas (ferrous sulphate) has been variously investigated. Weigelt observed that copperas in tapwater in the concentration of 2,721 p.p.m.

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[1] H. Gran, "On the Condition for Production of Plankton in the Sea", Conseil Perm. Internat. Explor. de la Mer, Rapp. et Proc. Verb., 75: 37-46, 1931.

[2] H. Harvey, "Supply of Iron to Diatoms", Jour. Mar. Biol., 22:205-219, 1937.

[3] T. Thompson and R. Bremner, "The Occurrence of Iron in Water of Northeast Pacific Ocean", Conseil Perm. Internat. Explor. de la Mer., Jour. du Conseil, 10:39-47, 1935.

[4] G. Hutchinson, "Chemical Stratification and Lake Morphology", Proc. National Acad. of Sci., 24,#2:63-69, 1938.

was fatal to trout and California salmon in thirty-one to sixty-six minutes.[1] Clark investigating the effects of this substance on carp, shiners and suckers, demonstrated that toxicity was evidenced in four to twenty-four hours with concentrations of 2.9 p.p.m. in distilled water.[2] Carpenter maintains that a concentration of 3.5 p.p.m. in distilled water was lethal to minnows (Leucisous phoxinus) within a period of three hours.[3] Ellis observed that goldfish, Crassius auratus, sustained copperas in concentrations of 100 p.p.m. in hard water over relatively long periods, however, concentrations of 1000 p.p.m. caused death within two to ten hours. In the case of the four-spined stickleback, Apeltes quadracus, Littleford found a wide difference in the toxicity of copperas which was contingent upon a particular environmental complex.[5] At a temperature of 24.0 - 2.0°C., it was found that any concentration greater than 125 p.p.m. was lethal to some extent, while at a temperature of 12.0- 2.0°C, one hundred per cent survival was obtained in a

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[1] C. Weigelt, O. Saare and L. Schwale,"Dee chadegung von Frescherei and Fischzuucht durch Industrie and Hans Avervasser", Archev.Fur Hugiene 3:39-117, 1885.

[2] H. Clark and G. Adams, "Studies of Fishlife and Water Pollution", Forty-fourth Annual Report of the State Bd. of Hea. Mass., Published. Doc. #34, 6:336-345, 1913.

[3] K. Carpenter, "The Lethal Action of Soluble Metalic Salts on Fishes", British Jour. Exp. Biol., 4:378-390, 1927.

[4] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fish., XLVII:65-437, 1937

[5] R. Littleford, "Survival of Four-Spined Stickleback, Apeltes quadracus, in Copperas Dilutions", Unpublished.

concentration of 500 p.p.m. Temperature variations could be correlated with changes in the pH of the solution, and it was concluded that the toxic effect of copperas in brackish water was the result of a lowering of the pH of the solution below the normal limits of adaptability of the organism. It was suggested that the lethal effect of copperas was a result of the chemical and physical injury rather than true toxic action. This conclusion was supported by the fact that some fish had been kept for periods of several months in concentrations ranging from 125 to 1,000 p.p.m. without apparent harm.

According to Truitt, the polluted areas of the Patapsco River were not severe at the time of his investigation.[1] No significant change in the waters of the Chesapeake Bay was observed as a result of the pollution of the Patapsco River. Subsequently, however, Truitt investigated the effects of ferrous sulphate, the most serious pollutant of the area.[2] The study included the period from the time of copperas disposal to the formation of the floc and ensuing deposition on the bottom. The biological significance of this pollutant in its various forms was also studied. It was found that adherence of the floc to plankters pulled them to the bottom in the process of settling, further, the gilled forms suffered asphyxiation by the deposition of the floc on the gill lamellae.

The high ferrous sulphate values recorded for the Patapsco River

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[1] R. Truitt, "Annual Report Chesapeake Biological Laboratory", Chesapeake Biol. Lab., #34, 1939.

[2] R. Truitt, "Annual Report", Chesapeake Biol. Lab., #40, 1940.

were found in the areas of copperas disposal.[1] The concentrations ranged from a trace to 15 mg. per liter, depending upon the proximity to the source. These investigators are of the opinion that ferrous iron remains in this condition for sometime, during which period the copperas draws seriously upon the dissolved oxygen content of the area. A subsequent oxidation to the ferric form occurs.

Total iron concentrations were recorded to ascertain the course, attenuation of the pollutant and to determine the iron forms (soluble and insoluble) resulting from ferrous sulphate. The extent of precipitation and the stage of oxidation was found by a comparison of the values of soluble, insoluble and ferrous iron. The range of total iron concentrations was found to be highest in the environs of copperas disposal, and diminishing proportionately at varying distances from the source (.447 p.p.m. to 18.9 p.p.m.).

The range of soluble iron was found to be from 0.082 to 6.26 p.p.m. This form of iron is an index to the copperas products which have yet to flocculate.

The values given for insoluble iron ranged from 0.284 p.p.m. to 10.3 p.p.m.

Olson and his coworkers found that both planktonic forms and macroscopic forms were affected by the pollutant. A decided upset in the ecological balance of the area under investigation was noted.

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[1] R. Truitt, "Annual Report", Chesapeake Biological Laboratory, #40, 1940.

Although a widening of the polluted area of the Patapsco River was noted by Truitt, toxic effects to aquatic organisms was not observed.[1]

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[1] R. Truitt, "Annual Report", Chesapeake Biological Laboratory, #40, 1940.

CHAPTER II

MATERIALS AND METHODS

At each of the designated stations (Plate I), water samples were collected for chemical and microbiological determinations by means of a Foerst bottle, while a number 20 Plankton net was used for the collection of macroplankton. Surface and depth samples were taken at the offshore stations. The Jean-B (Plate V, Figure 1) was chartered from the Atlas Boat Company so that the offshore stations could be visited. The water collected was placed in numbered citrate bottles. The bottles used to contain the water for chemical analysis were "seasoned" bottles obtained from the University of Maryland and could be distinguished from those citrate bottles used to contain the plankton samples in that the former bore black rubber lid rings, while the latter bore red rubber lid rings. The preservative used was 10 per cent filtered neutralized formaldehyde (6c.c. per 250c.c. citrate bottle). The temperatures were read from a typical reversing thermometer.

Biological Analysis. The plankton samples were arranged in order and allowed to settle for a minimum of two weeks, after which time, the water of known volume was siphoned off by layers from the top to bottom to assure a minimum loss of material. The plankton concentrations, also of known volume, were placed in numbered 25 c.c. vials. Quantitative plankton determinations were made by examination of 1 c.c. of the concentrate in a Sedgwick Rafter counting cell, under high magnification.

Chemical Analysis. The following components of the water samples were determined quantitatively by chemical analysis according to the method indicated.

Carbon dioxide. Both "fixed" and "free" carbon dioxide were determined volumetrically according to the method proscribed by the American Public Health Association.[1] The free carbon dioxide was determined by titration of the sample with N/44 Na_2CO_3 or N/44 HCL (depending upon whether the original sample was alkaline or acid in reaction) using phenolphthalein as the indicator.

"Fixed" carbon dioxide was determined by titration to the methyl orange end point with N/44 HCL.

The basis for the method is the fact that carbonates are alkaline to phenolphthalein, bicarbonates are neutral and free carbon dioxide is acid. Methyl orange is not affected by carbon dioxide, so that bases present as carbonates can be titrated directly with standard acid. Hence, if water is neutral or acid to phenolphthalein, the "half-bound" carbon dioxide is equal to the "fixed" carbon dioxide. If the water is alkaline to phenolphthalein, it contains no free carbon dioxide and the "half-bound" carbon dioxide will be less than the "fixed" carbon dioxide by an amount equivalent to that determined by titration with acid until the solution is neutral to phenolphthalein.

In applying the aforementioned method, it is necessary to use only carbon dioxide free distilled water in the preparation of all solutions. Standard acid and alkali solutions should be stored in hard glass bottles and should be checked frequently against each other.

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[1] American Public Health Association, "Standard Methods for the Examination of Water and Sewage", American Public Health Association, New York: pp. 69-71, 1936.

Silica. The principle of this method is the comparison of the yellow color formed by the reaction of silica with molybdic acid with standard colors of various picric acid solution. The color comparisons are made in a Klett-Summerson colorimeter using a blue filter.

It is important to make these analyses as quickly as possible after the samples are obtained since silica from glass bottles used for collection and storage may dissolve in the water on standing and thus yield higher values. It is also necessary to check the silica content of all distilled water used in the preparation of solutions or for dilution of samples which are high in silica content.

Although iron and phosphorus interfere in this procedure, these elements, except in the polluted areas, are not normally encountered in high enough concentrations in the water analyzed to offer any appreciable interference.

Phosphate. In this procedure, phosphomolybdic acid is reduced with stannous chloride and the resultant molybdenum blue is compared with the colors produced when standard phosphate solution is treated in the same way. The color comparison is made with a Klett-Summerson colorimeter using a green filter.

Inasmuch as Beer's Law is applicable over only a short range of concentration in this method, it is necessary to prepare several standards of varying concentrations and to use that standard which most closely approximates the color produced by the sample for comparison.

Although high concentrations of chloride in sea water introduce a "salt error" caused by change in intensity and hue of the color produced, there are so many errors inherent in the method that it is not necessary to allow for the salt content of the water in the Patapsco

River which is more or less about one-fourth that of sea water.

Arsenates produce a color similar to that of phosphates and hence, traces of arsenates would be included in the phosphate values.

Iron. The basis of this method is first, the destruction of organic matter in the sample by oxidation with potassium permanganate and sulfuric acid and second, development of a red color upon the addition of potassium thiocynate. This color is then compared with standards in a Klett-Summerson colorimeter using a blue filter.

This color development does not conform to Beer's Law so that it is necessary to prepare several standard solutions of varying concentrations as in the phosphate method.

Sulphate ion has an adverse effect upon the color of the thiocynate complex and hence (SO_4) is introduced into the standard solution to compensate for this.

Iron utensils and iron hot plates should not be used during the preliminary evaporation of the sample because an error may result from accidental contamination.

Dissolved Oxygen. This method is the well known Winkler method based upon the reaction between the oxygen and manganous sulphate in alkaline solution. The resultant manganese hydroxides react with potassium iodide in the presence of sulfuric acid and the liberated iodine is titrated with sodium thiosulphate using starch as the indicator.

The greatest possible source of error in this method lies in the collection of the sample itself. Extreme care must be taken not to entrap air in the container during the sample-collection process.

Salinity. The determination is based upon the measurement of the volume of standard silver nitrate solution which is necessary to precipitate all of the chloride in the sample as silver chloride. Potassium chromate is used as the indicator.

The only precaution to be observed in this method is to be certain that all glassware has been scrupulously cleaned with dichromate sulfuric acid cleaning mixture.

Nitrite-Nitrogen. The red color which develops when an acetic acid solution of alpha napthylamine are added to a solution containing nitrite forms the basis of this procedure. The color is compared with standards in a Klett-Summerson colorimeter using a green filter. An artificial standard of basic fuchsin may be used instead of sodium nitrite solution with waters high in nitrite.

It is important to make these determinations on freshly collected samples because bacterial action causes a steady and rapid conversion of nitrites to nitrates and ammonia.

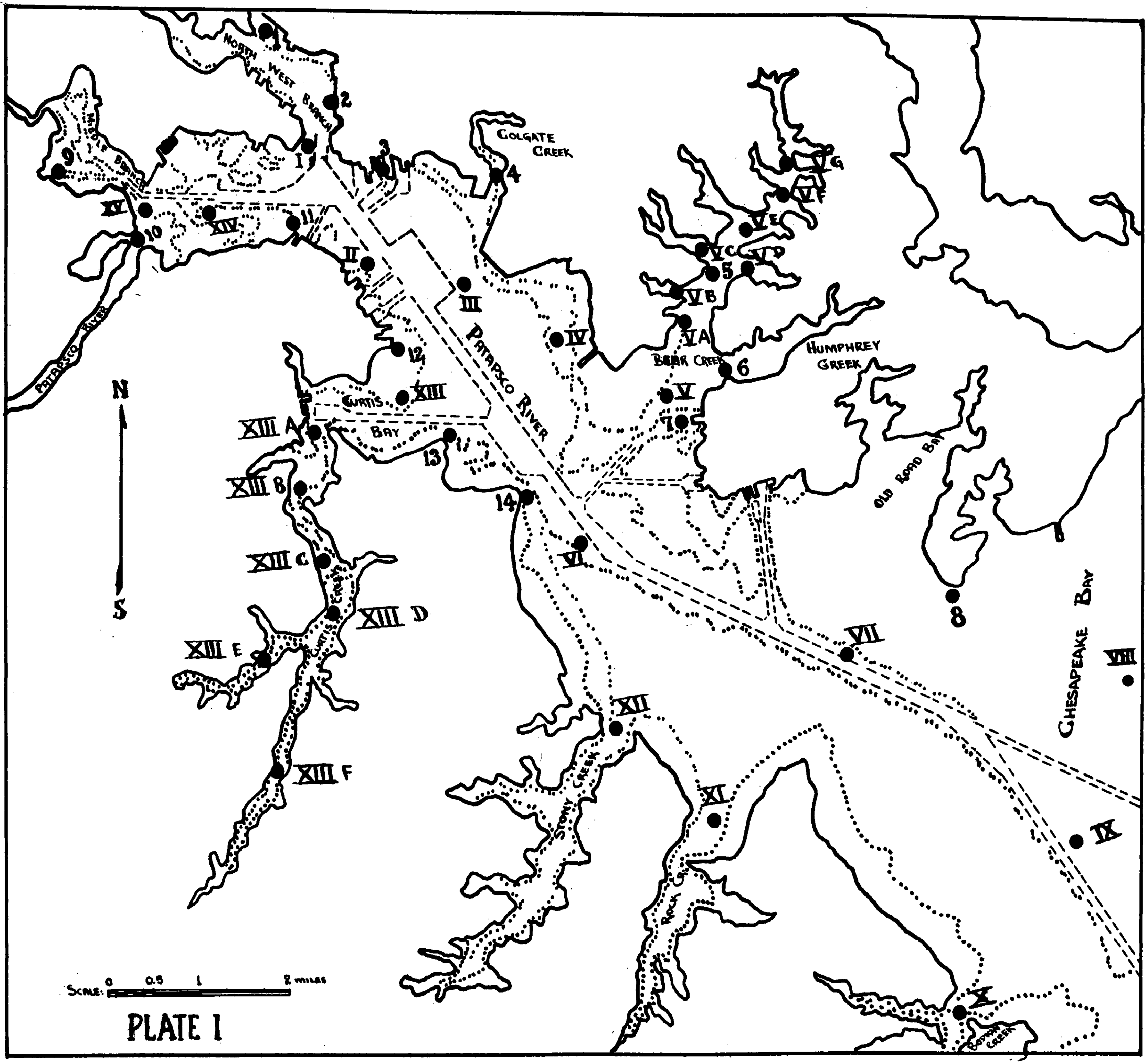
Nitrate-Nitrogen. Solutions containing nitrates give a yellow color when treated with a reagent made by treating phenol with fuming sulfuric acid. This color is intensified when the solution is made alkaline. The active reagent is 1,2,4 phenol-disulfonic acid. This reaction forms the basis of the procedure used. The color developed in the sample is compared with standards in a Klett-Summerson colorimeter using a blue filter.

Chlorides present up to 30 p.p.m. do not introduce a significant error but if present in greater concentrations, they must be removed. Likewise, carbonates, organic matter and large concentrations of nitrites must be removed for highest accuracy.

Ferrous Iron. Ferrous iron produces a deep color when treated with potassium ferricyanide and this color formation is used as the means of determining the iron quantitatively. The color produced is compared with standards in a Klett-Summerson colorimeter using a green filter.

To insure most accurate results, this test should likewise be determined in the field, since the ferrous ion is quickly oxidized to the ferric ion.

Hydrogen-ion Concentration (pH). The hydrogen-ion concentrations are determined electrometrically by means of a Beckman pH meter. Precautions taken involved washing the electrodes with distilled water after each reading and keeping the electrodes free from foreign matter.


North West Branch
Middle Branch
Patapsco River
Colgate Creek
Humphrey Creek
Bear Creek
Old Road Bay
Curtis Bay
Curtis Creek
Stony Creek
Rock Creek
Bodkin Creek
Chesapeake Bay
N
S
1
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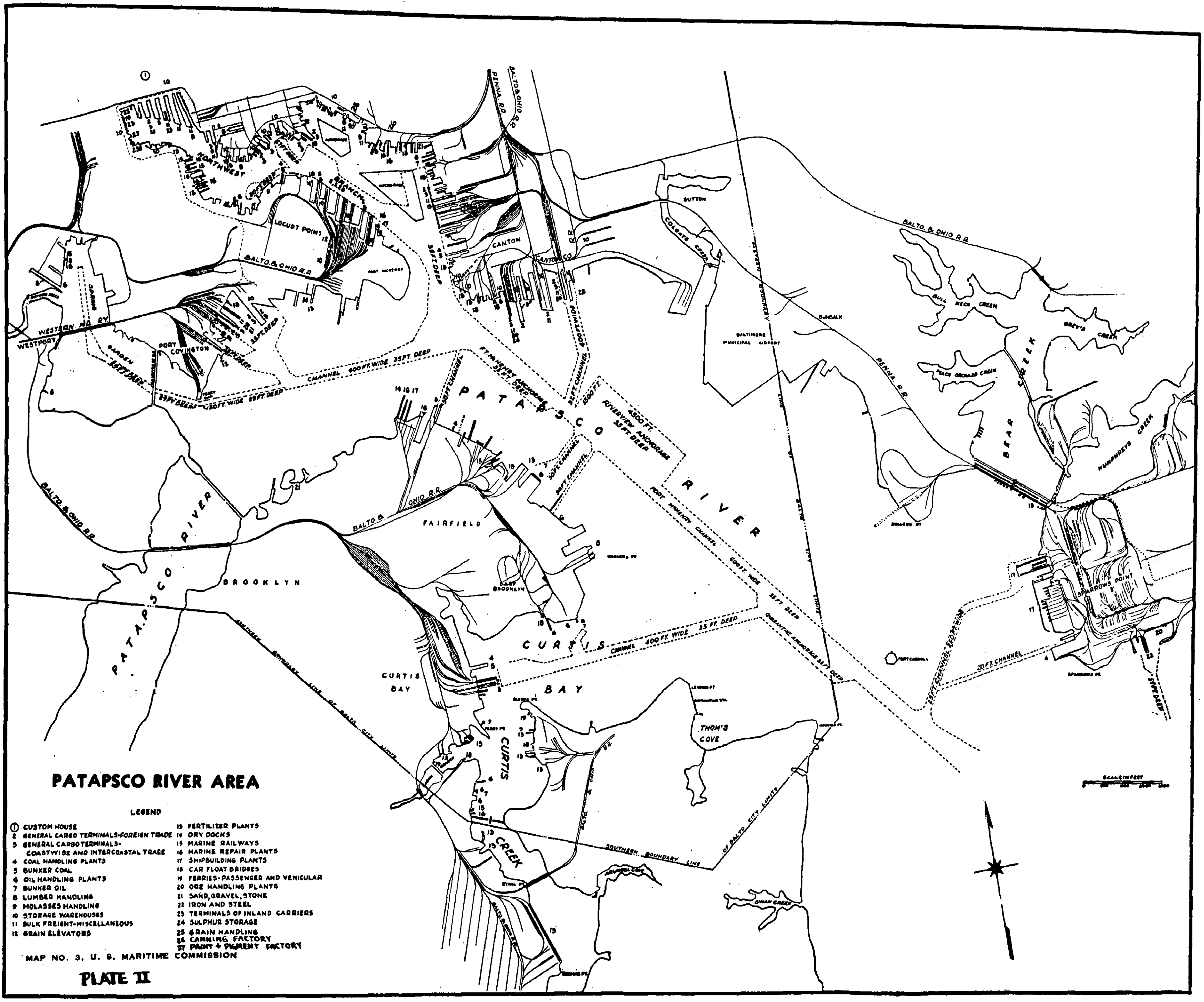
VA
VB
VC
VD
VE
VF
VG
VI
VII
VIII
IX
X
XI
XII
XIII
XIII A
XIII B
XIII C
XIII D
XIII E
XIII F
XIV
XV
Scale: 0 0.5 1 2 miles

PLATE I



PATAPSCO RIVER AREA

LEGEND

①	CUSTOM HOUSE
2	GENERAL CARGO TERMINALS-FOREIGN TRADE
3	GENERAL CARGO TERMINALS-COASTWISE AND INTERCOASTAL TRADE
4	COAL HANDLING PLANTS
5	BUNKER COAL
6	OIL HANDLING PLANTS
7	BUNKER OIL
8	LUMBER HANDLING
9	MOLASSES HANDLING
10	STORAGE WAREHOUSES
11	BULK FREIGHT-MISCELLANEOUS
12	GRAIN ELEVATORS
13	FERTILIZER PLANTS
14	DRY DOCKS
15	MARINE RAILWAYS
16	MARINE REPAIR PLANTS
17	SHIPBUILDING PLANTS
18	CAR FLOAT BRIDGES
19	FERRIES-PASSENGER AND VEHICULAR
20	ORE HANDLING PLANTS
21	SAND, GRAVEL, STONE
22	IRON AND STEEL
23	TERMINALS OF INLAND CARRIERS
24	SULPHUR STORAGE
25	GRAIN HANDLING
26	CANNING FACTORY
27	PAINT & PIGMENT FACTORY

MAP NO. 3, U. S. MARITIME COMMISSION

PLATE II

PLATE III

RELATION OF ATMOSPHERIC AND SURFACE WATER TEMPERATURES

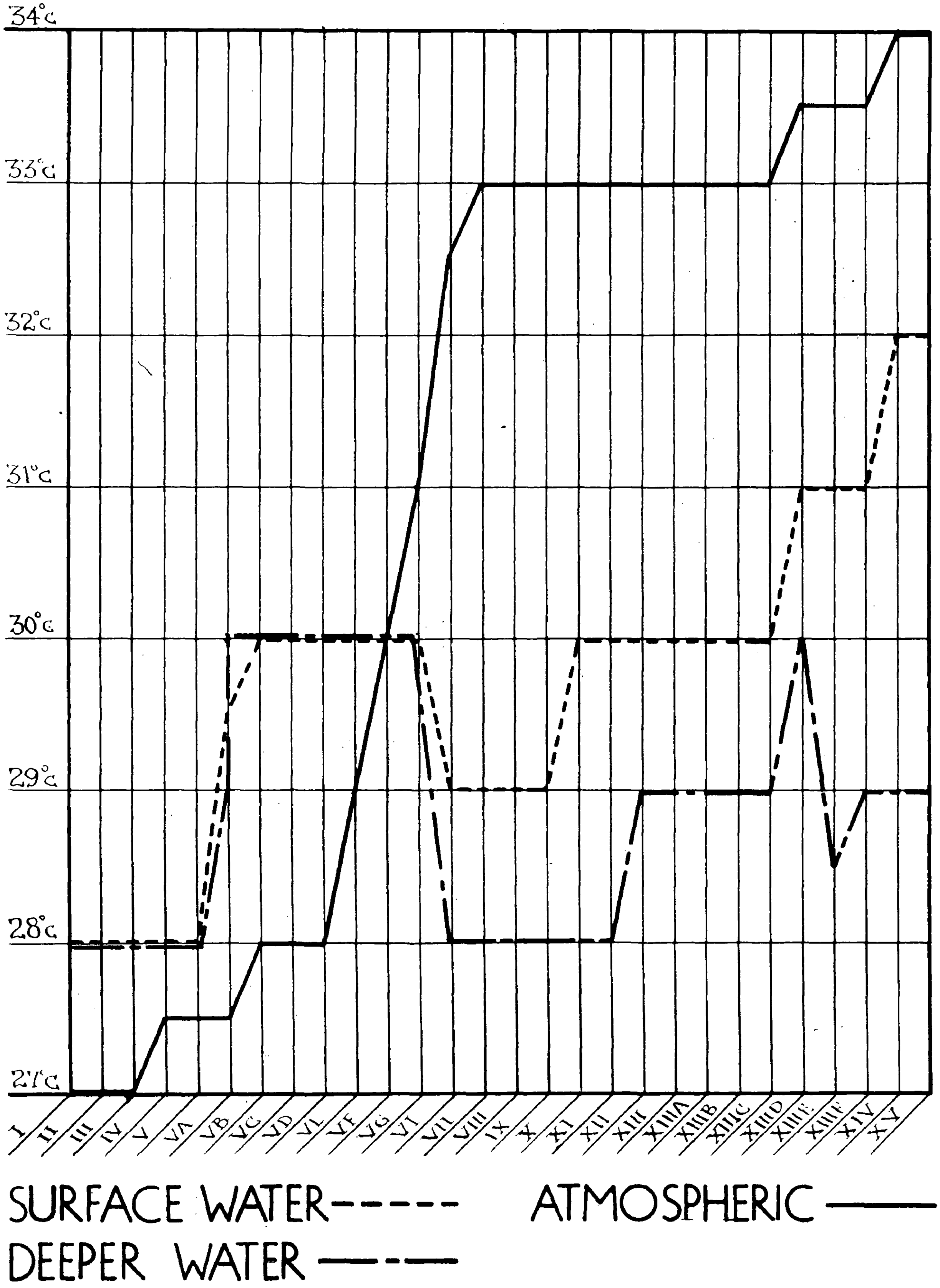


PLATE IV

TEMPERATURE —— SALINITY RELATIONSHIP

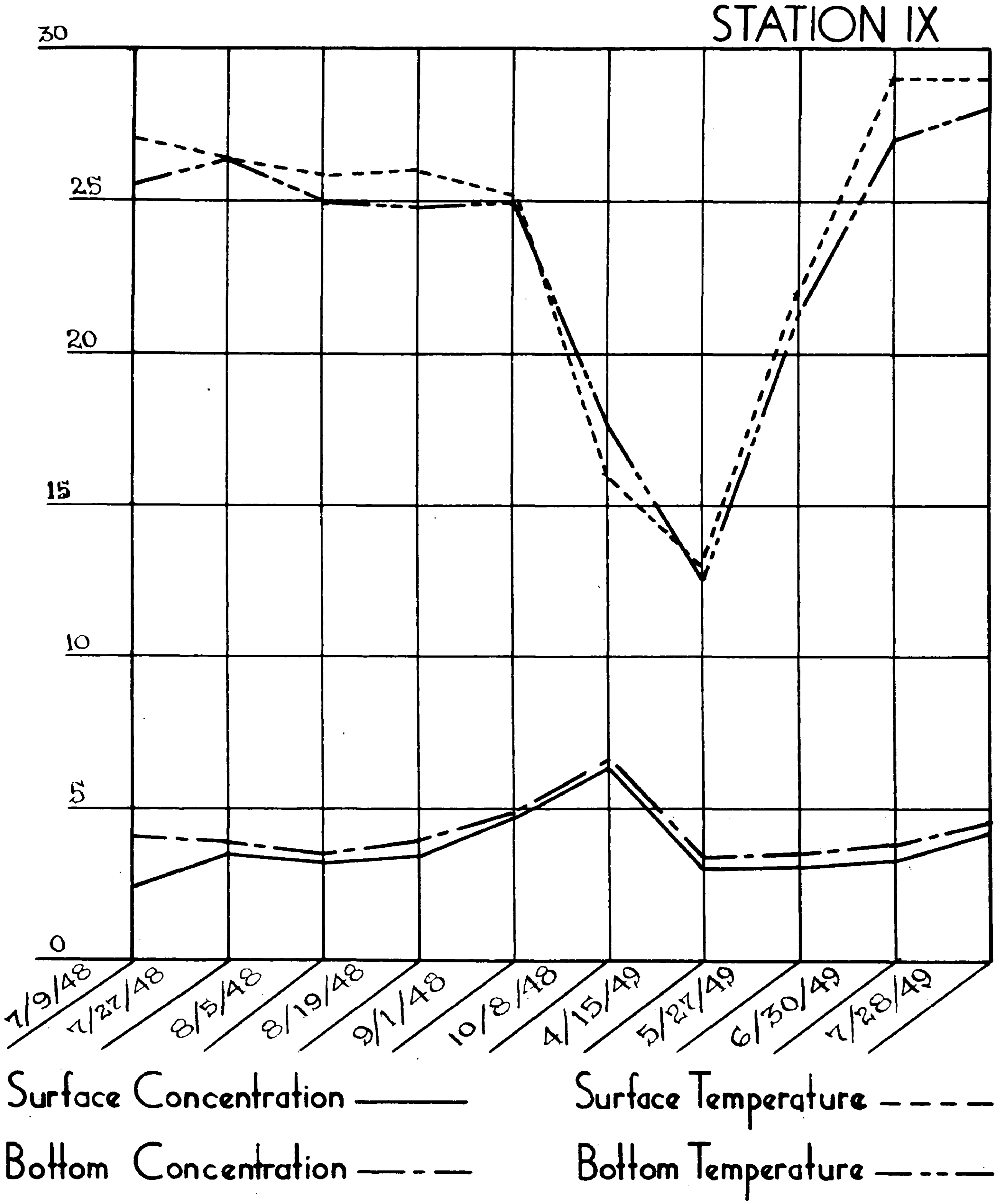


PLATE V

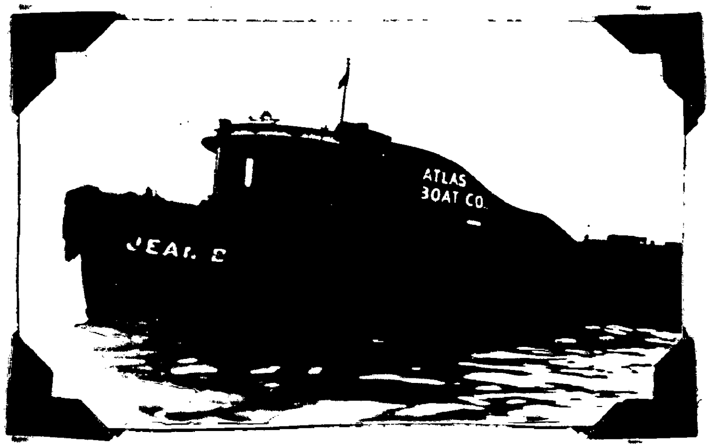


FIGURE 1

The Jean-B

FIGURE 2

Characteristic Color of
Water in Curtis Creek

CHAPTER III

RESULTS

The physical and chemical factors of the area investigated demonstrates a wide deviation from the characteristic properties of similar bodies of water. The greater divergence from the normal appears in the polluted areas, diminishing proportionately from the foci of pollution. Although the physical and chemical factors are given separately, their inter-relationship and interaction will be discussed subsequently.

Temperature. The temperature of both surface and bottom waters of the region investigated, particularly those of the deeper stations near the mouth of the river, closely resemble a "bell curve" (Plate VI, Figure 1). The lower temperatures occur between January and February and begin to rise gradually reaching a peak in July, after which time there is a gradual lowering of the temperature again reaching a minimum in January. The bottom water temperatures show a similar graphic resemblance which is not coincident with the surface waters in that the ascent, crest and descent occur later in the former because not only is its trend iniated by the temperatures of the upper stratum but also because it is not subject to fluctuations in atmospheric temperature. These curves, however, tend to converge graphically at two points, spring and fall.

As would be expected, water temperatures vacillate corresponding to fluctuations of atmospheric temperatures, although the former appears to be more resistant to change. The mean atmospheric temperature was for the most part found to be higher than the mean water temperature during the summer and lower in the winter. The surface

PLATE VI

TEMPERATURE

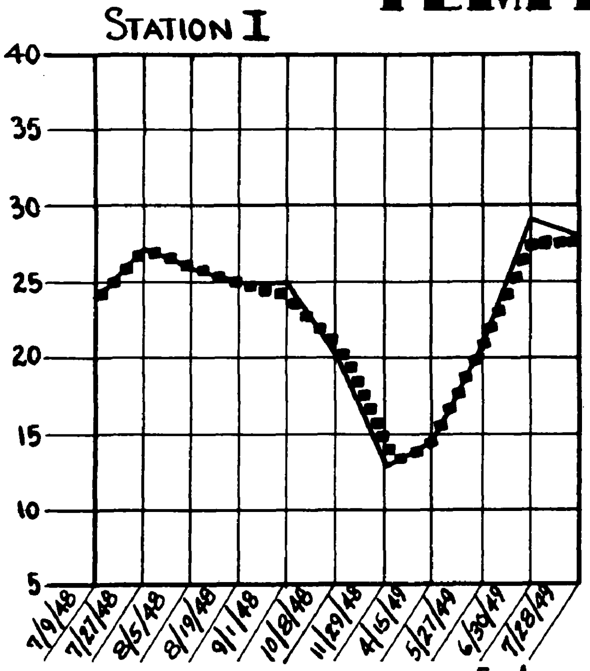


FIG. 1

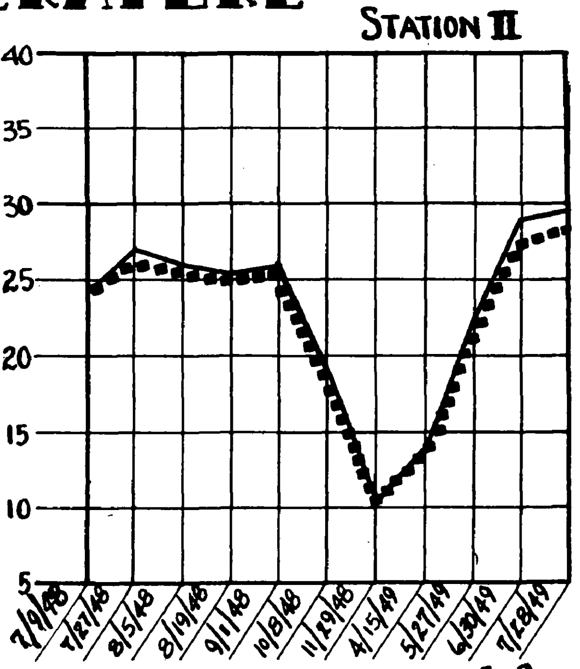


FIG. 2

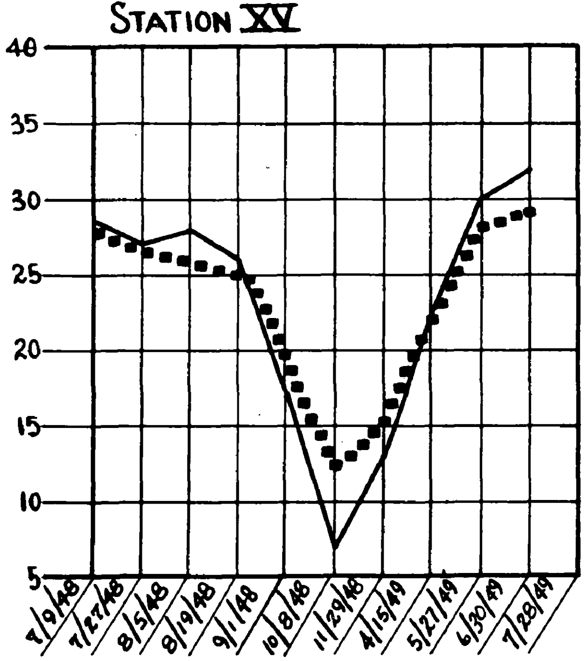


FIG. 3

SURFACE ——
DEPTH ▪▪▪▪▪▪

waters show these variations to a greater degree than do the sub-surface layers. Further, there appears to be an hourly fluctuation in which the atmospheric temperatures are lower in the early morning hours than the surface waters. The atmospheric temperature increases until the surface water and the atmospheric temperatures are the same, with the former lagging and the latter steadily climbing until the maximum is reached. This occurs approximately during mid-afternoon (Table 3 and Plate III).

The range of temperature of the surface water of the offshore stations was from 7.0°C. to 32.0°C., while that of the shore stations ranged from 7.0°C. to 33.0°C. The temperature of the deeper waters of the offshore stations ranged from 8.7°C. to 30.0°C. It will be noted that the highest and lowest values were those of the surface waters. The bottom waters were warmer in winter and cooler in the summer than those of the surface.

Stratification of water resulting from surface-depth differential is evidenced in the deeper waters. This stratification, however, does not exist at the more shallow stations, (Plate VI, Figure 2). The range of the surface-bottom variant is 0.0 to 3.0°C., the upper limits of the variations being encountered in the deeper waters, either in summer or in winter. The lesser variations occur at the stations located in the shallower water or in the deeper water in October and April. The former demonstrates that no stratification occurs in waters of little depth; the latter demonstrates the existence of vernal and autumnal circulation.

Water temperatures of the stations further removed from the mouth of the Patapsco River tend to show a wider range of variation,

TABLE 3. Temperature Readings for 7/28/49.

Station Number	Time	Atmospheric Temperature	Surface Water Temperature	Deeper Water Temperature
I	6:00 AM	27.0°C.	28.0°C.	28.0°C.
II	6:20	27.0	28.0	28.0
III	6:35	27.0	28.0	28.0
IV	6:50	27.5	28.0	28.0
V	7:10	27.5	28.0	28.0
VA	7:28	27.5	29.5	30.0
VB	7:40	28.0	30.0	30.0
VC	8:00	28.0	30.0	30.0
VD	8:15	28.0	30.0	30.0
VE	8:35	29.0	30.0	30.0
VF	9:03	30.0	30.0	30.0
VG	9:18	31.0	30.0	30.0
VI	10:02	32.5	29.0	28.0
VII	10:37	33.0	29.0	28.0
VIII	11:05	33.0	29.0	28.0
IX	11:22	33.0	29.0	28.0
X	11:45	33.0	30.0	28.0
XI	12:17 PM	33.0	30.0	28.0
XII	12:35	33.0	30.0	29.0
XIII	1:10	33.0	30.0	29.0
XIIIA	1:30	33.0	30.0	29.0
XIIIB	1:47	33.0	30.0	29.0
XIIIC	2:18	33.0	30.0	29.0
XIIID	2:30	33.5	31.0	30.0
XIIIE	2:44	33.5	31.0	28.5
XIIIF	3:00	33.5	31.0	29.0
XIV	3:35	34.0	32.0	29.0
XV	4:03	34.0	32.0	29.0

Plate VI, Figure 3). This is probably due to the decreased influence on the part of the more stable waters of the Chesapeake Bay.

There appears to be a significant relationship between temperature and chlorinity which is characteristic for most estuarine waters (Plate IV). This correlation is observable for the deeper as well as the surface waters. It will be noted that, in general, increased temperatures are accompanied by increased salinities. As the temperature of the water decreases, a corresponding decrease in salinities is also evidenced. This condition is characteristic for other stations of the estuary investigated.

Although no significant difference exists between the temperatures of the polluted and non-polluted regions of the Patapsco River, the magnitude of its effect is considerable. This will be shown later.

Hydrogen-ion Concentration. The pH (hydrogen-ion concentration) of the Patapsco River shows a wide range for both surface and bottom waters, the latter yielding the wider range. pH values sufficiently low to condition the growth of plankton has been found to be a result of three chemical factors, mainly, (1) the disposal of ferrous sulphate which upon hydrolysis lowers the pH, (2) discharge of variable amounts of free acid from chemical manufacturing plants and (3) distillery wastes which draw upon the dissolved oxygen content of the water.

The values observed for the offshore surface waters ranged from pH 2.1 to pH 9.2. The pH of the offshore bottom waters ranged from pH 2.0 to pH 9.5. The pH range of the shore stations was found to be from pH 2.0 to pH 9.2.

It will be observed that waters in the vicinity of certain industrial areas were very strongly acid, (Plate VII, Figures 1, 2 and 3) while those approaching the mouth of the river became normally alkaline or neutral (Plate VII, Figure 4). The higher acid values were found in the water of Station V through VG (Bear Creek area) and Stations XIII through XIIIF (Curtis Creek area). Consult Table 4 and Table 5.

The average pH for the surface waters of the Bear Creek area was found to be 5.28 while that of the deeper waters was 5.6 with a range from pH 2.1 to pH 7.6. The average pH during the summer months was found to be 4.68 for the surface and 4.78 for the deeper waters. It will be noted that no significant difference is found between the pH of the surface and bottom waters of this region. It will also be observed, however, that the pH tends to be lower in the summer than at other seasons of the year.

The pH values in the Curtis Creek area were found to be on a whole, much lower than in any other area investigated. The hydrogen-ion concentration ranged from pH 3.3 to pH 6.0 for the surface and pH 3.1 to pH 6.2 for the deeper waters. The average pH for the surface samples in this region was pH 3.99, while that of the bottom samples was pH 3.79. The hydrogen-ion concentration during the summer was not significantly different from that of other seasons of the year, yielding an average pH of 3.92 for the surface and 3.79 for the bottom.

Consistently low pH values also occurred at Station 4 and at Station 6 (Plate VII, Figure 1 and 2) and only occasionally at Stations 1, 2, 5 and 13.

The low pH values of the water found in Bear Creek has its origin in Humphreys Creek, into which are emptied large quantities of pickling

TABLE 4. pH Values of Water Samples Taken from Bear Creek Area

Date	Station VAs	VAd	Station VBs	VBd	Station VCs	VCd	Station VDs	VDd	Station VEs	VEd	Station VFs	VFd	Station VGs	VGd
7/9/48	3.6	4.49	5.7	—	5.3	—	5.25	—	5.25	—	6.05	—	6.21	—
7/27/48	2.1	2.0	2.5	2.5	2.3	2.6	2.5	2.5	2.4	2.4	4.4	3.4	2.7	4.4
8/5/48	4.0	—	3.8	—	4.1	—	3.9	—	4.2	—	5.0	—	6.4	—
8/19/48	4.8	5.9	4.5	5.7	4.9	6.0	6.2	6.3	6.4	6.8	6.8	6.7	6.7	6.8
9/1/48	7.6	7.5	7.5	7.5	7.5	7.6	7.5	7.4	7.4	7.4	7.4	7.4	7.5	7.3
10/8/48	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.4	7.2	7.2	7.2	7.2
11/29/48	5.8	6.0	4.3	4.2	5.0	5.0	4.8	4.6	6.0	4.6	6.8	6.0	5.8	5.5
4/15/49	7.3	7.5	3.6	4.0	3.7	3.7	3.6	3.6	4.0	5.5	4.3	4.9	5.6	5.3
5/27 49	4.1	6.8	3.9	6.6	4.6	4.6	5.4	6.3	4.8	6.5	6.7	6.9	6.8	6.7
6/30/49	3.4	6.1	5.5	6.2	6.2	4.[illegible]	6.0	4.6	6.4	6.5	6.5	6.7	6.8	6.6
7/28/49	3.6	6.5	3.5	3.6	3.7	3.6	3.5	3.7	3.5	3.6	3.9	3.8	4.4	4.3

TABLE 5. pH of Water Samples Taken from Curtis Creek Area

Date	Station		Station		Station		Station		Station		Station	
	XIII As	XIII Ad	XIII Bs	XIII Bd	XIII Cs	XIII Cd	XIII Ds	XIII Dd	XIII Es	XIII Ed	XIII Fs	XIII Fd
7/27/48	3.3	3.4	3.3	3.3	3.5	3.3	3.5	3.1	4.4	--	3.7	--
8/19/48	3.6	3.1	3.6	3.7	3.9	3.3	3.9	3.7	4.5	3.6	4.2	--
10/8/48	4.0	3.9	4.0	3.9	4.2	4.0	4.2	4.0	6.0	4.1	4.6	--
4/15/49	3.7	3.7	4.1	3.8	4.2	4.0	4.2	4.1	4.3	4.2	4.3	4.1
5/27/49	6.0	6.2	3.8	4.0	3.8	3.7	3.8	3.4	3.9	3.5	3.8	3.8
6/30/49	3.8	4.1	3.8	3.8	3.8	3.9	3.9	3.8	3.9	3.7	3.9	3.7
7/28/49	3.6	3.6	3.5	3.5	3.6	3.6	3.7	3.6	3.7	3.6	3.7	3.7

liquors from the steel industry. This is evidenced by the fact that at Station 4, the mouth of Humphreys Creek, ferrous iron has consistently been present. The hydrolysis of this ion quickly lowers the pH of the water.

The inflow of copperas from Humphreys Creek into Bear Creek reduces the pH of the water of the entire area extending from the head of the creek to the mouth. This distance is approximately five miles in length. The effects, however, are not directly evident in the waters of the lower Patapsco River.

Hydrogen-ion concentrations of lethal value (below pH 4.5) have also been observed in the Curtis Creek area (Table 4). These low values are also a result of effluents from certain chemical plants in that area, see map (Plate II). The polluted area includes that region extending from Curtis Creek through Marley and Furnace Creek, approximately seven miles in length. Likewise, these low values do not persist in the Patapsco River.

The low pH of the water at Station 4, Colgate Creek, emanates from chemical waste products from the Glidden Chemical and Pigment Company. This will be discussed subsequently.

Station IX will be taken as the example used to demonstrate normal hydrogen-ion concentrations. It will be noted that the water shows a characteristic slightly alkaline pH (Plate VII, Figure 4). The average pH of this station is 7.45 for the surface with a range of 7.2 to 7.9. The average pH for the bottom was found to be 7.52 with a range from pH 7.2 to pH 8.0. It can be observed from the comparison of the surface and bottom pH values, that the latter are generally higher and never lower in alkalinity than those of the surface water. Further, a surface-

PLATE VII

pH

STATION 4

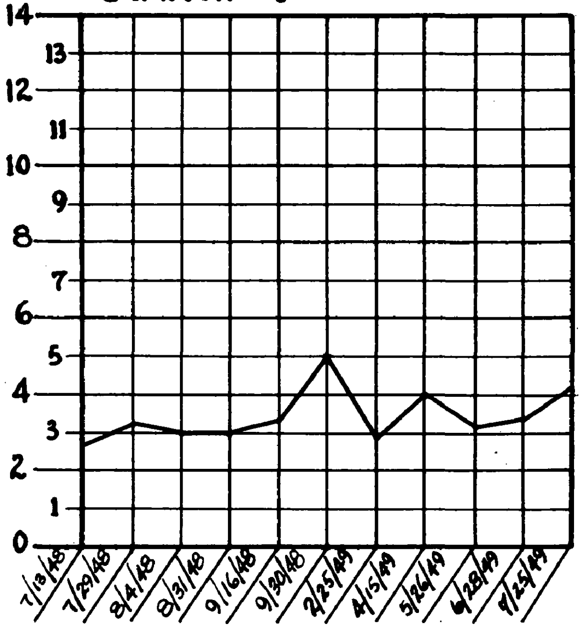


FIG. 1

STATION 6

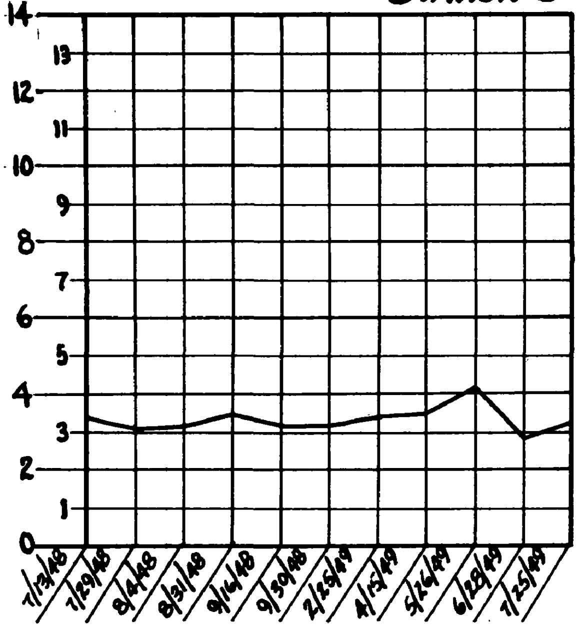


FIG. 2

STATION XIII D

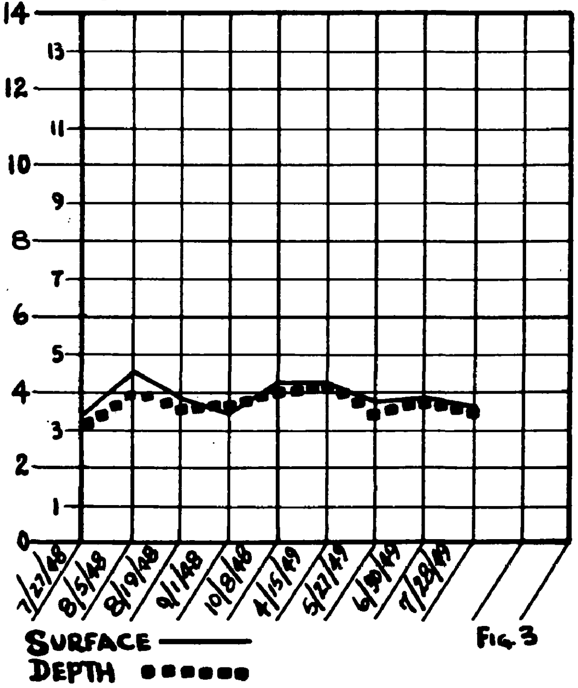


FIG. 3

STATION VII

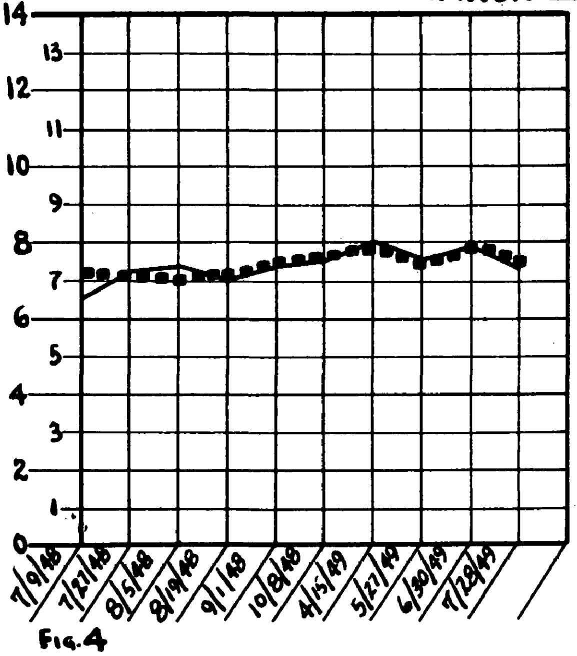


FIG. 4

bottom comparison also demonstrates that fluctuations appear to be greater for the bottom than for the surface stratum of water. A significant difference in pH was observed neither relative to stratification, nor to seasonal variation; although in certain instances the pH was higher from August to December, the increase in the hydrogen-ion concentration never exceeded 0.3.

Salinity. The salinity of the surface offshore area investigated ranged from 0.60 p.p.t. to 6.37 p.p.t., while the lower stratum of water ranged from 2.2 p.p.t. to 6.5 p.p.t. The chlorinity range for the shore waters was found to be from 0.1 p.p.t. to 6.5 p.p.t. The lower values for both shore and offshore surface and bottom waters occurred in the upper reaches of the tributaries of the Patapsco River (Plate VIII, Figure 1). The higher values, as is to be expected, were found at those stations located at the mouth of the river nearer the more saline waters of the Chesapeake Bay (Plate VIII, Figure 2.). The average salinity for Station VIII was 3.76 p.p.t. for the surface and 3.95 p.p.t. for the bottom waters. The lower values normally occur in the spring with a gradual increase during the summer. The highest values normally occur in the fall. Stratification relative to salinity occurs at the shallower stations as well as the deeper stations, with the bottom waters generally exceeding the surface waters (Plate VIII, Figure 3). A surface bottom differential of 1.5 p.p.t. often exists in the deeper waters proximately located near the bay waters. Other stations demonstrate an average difference of less than 0.4 p.p.t. Precipitation was found to appreciably influence the salinity of the area investigated.

The salinity for the Bear Creek area averaged 3.39 p.p.t. for the surface and 3.64 p.p.t. for the bottom, the latter having the higher values. Although the overall average for this area is lower than that for the Patapsco River, it is probably a result of fresh water infiltration from the tributaries.

The salinity for the Curtis Creek area shows a wider range than the other stations (0.60 p.p.t. to 5.50 p.p.t.). Stratification appears to be more pronounced in this region even in the shallower areas. The average chlorinity for the area was found to be 2.93 p.p.t. for the surface waters and 3.4 p.p.t. for the bottom waters. The surface-bottom differential ranged from 0.00 to 4.35 p.p.t. with an average difference of 0.37 p.p.t.

A comparison of TABLE 6 clearly shows that the lower salinity values for the shore station were found at the head of the Patapsco River while the higher values occurred towards the mouth of the river. It will be further noted, that seasonal variations do not exist at the upper reaches of the river, while at the mouth, minimum concentrations were found to occur in winter with a gradual increase in the spring reaching the maximum in fall.

The wide variation in the chlorinity of the Patapsco River area is due to the combined effects of such factors as tides, precipitation, convection currents, influx of less saline waters from tributaries and vernal and autumnal circulation working more or less independently.

PLATE VIII

SALINITY

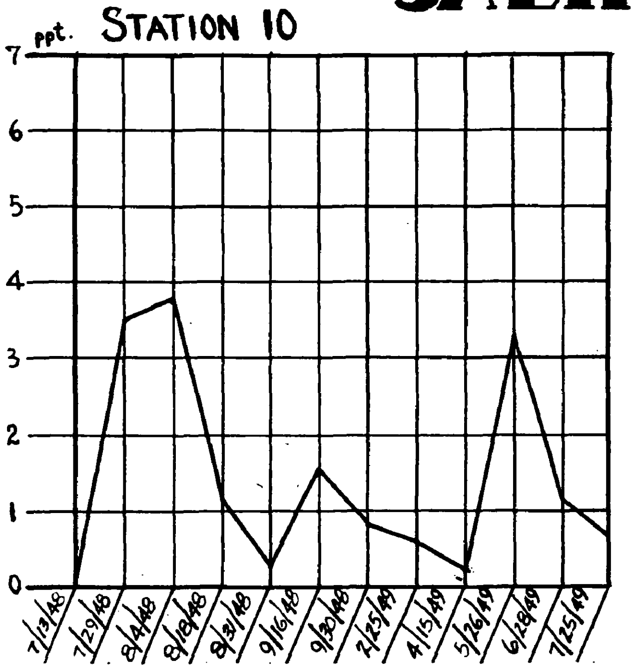


Fig. 1

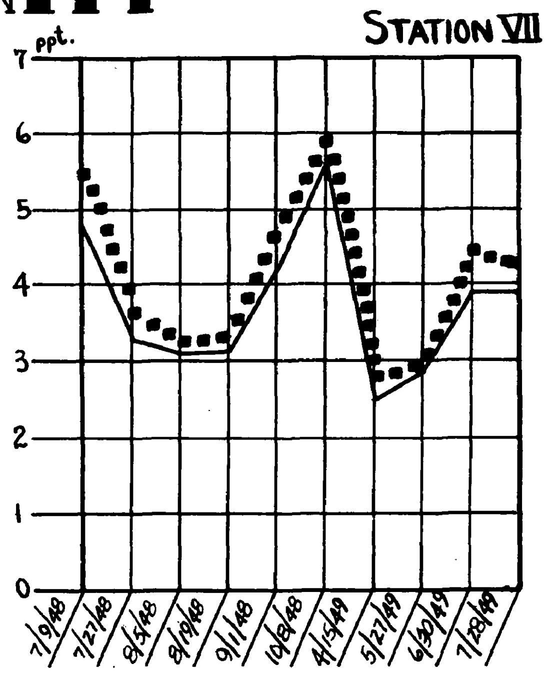


Fig. 2

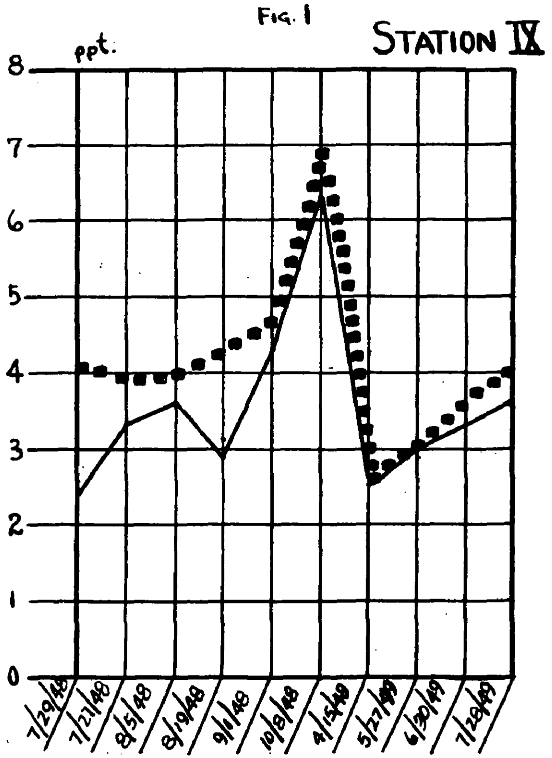


Fig. 3

SURFACE ———
DEPTH ▪▪▪▪▪▪▪

TABLE 6. Comparison of Salinity Values

Date	Station 10 Concentration p.p.t.	Station 7 Concentration p.p.t.
7/13/48	0.1	3.5
7/29/48	3.45	3.45
8/4/48	3.75	3.15
8/18/48	1.15	3.40
8/31/48	0.30	4.30
9/16/48	1.55	5.00
10/1/48	0.80	5.20
2/25/49	0.60	1.60
4/15/49	0.20	2.30
4/26/49	3.25	3.60
6/28/49	1.10	3.50
7/25/49	0.70	3.55

Oxygen. The dissolved oxygen in the area investigated ranged from 0.43 p.p.m. to 14.25 p.p.m. for the surface offshore waters and 0.45 p.p.m. to 9.81 p.p.m. for the lower stratum of water. Shore samples ranged from .14 p.p.m. to 9.2 p.p.m. Table 7 gives the averages for oxygen concentration for both surface and bottom offshore waters.

The supply of oxygen in the surface waters appears to vary with the seasons. The maximum concentrations occur in the winter with a decline in value beginning in spring and reaching a minimum in the summer. The oxygen factor is in inverse proportion to the temperature, see Plate IX, Figure 1. The lowest values for surface oxygen occur concurrently with the highest temperature readings and vice-versa. This condition exists throughout the unpolluted area investigated.

A similar seasonal variation of dissolved oxygen is found in the deeper waters. The higher and lower values occur simultaneously with the surface waters, the concentration of the former never exceeding the latter. The surface-bottom differential appears to be greatest during summer months and diminishes during the other seasons. The surface-bottom difference of dissolved oxygen ranges from 0.00 p.p.m. to 7.57

SUR. TEMP. - - -
DEPTH TEMP. ——

PLATE IX

SUR O₂ —··—
DEPTH O₂ —·—
pH —···—

O_2 — TEMPERATURE — pH

STATION 13

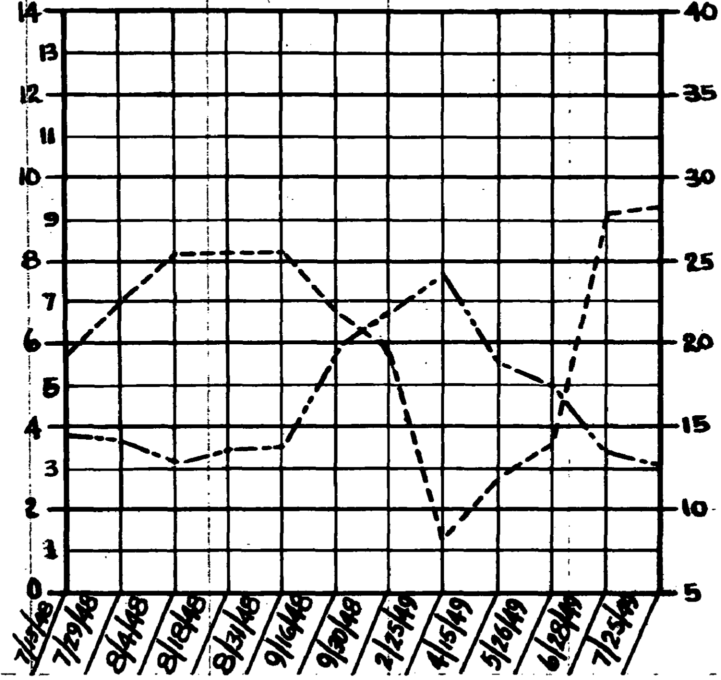


FIG. 1

STATION XV

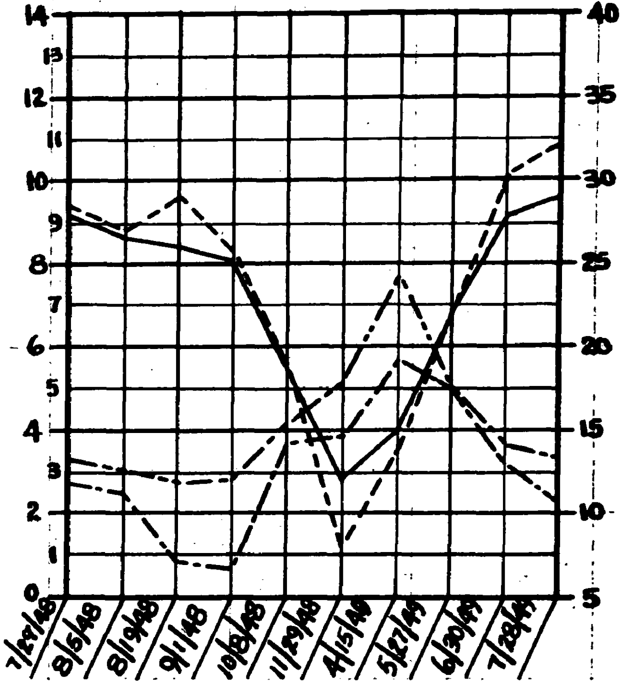


FIG. 2

STATION 6

STATION 5

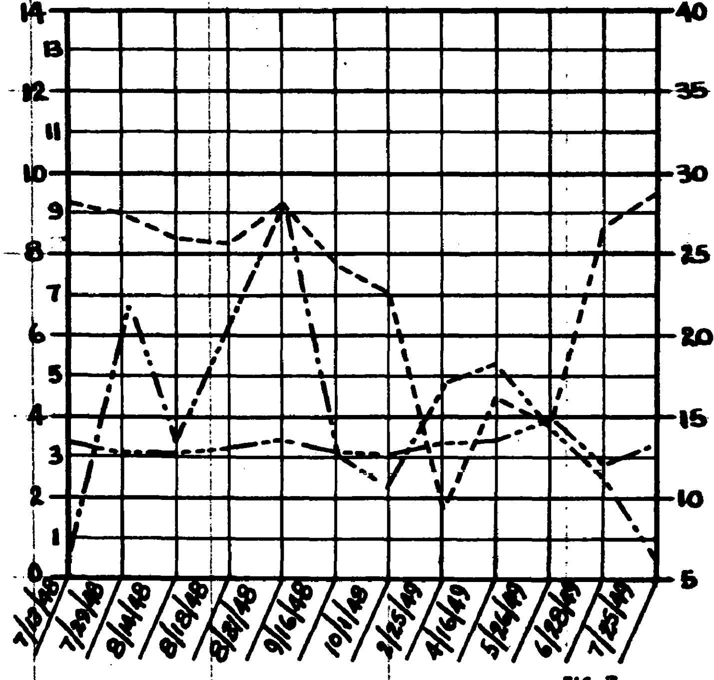


FIG. 3

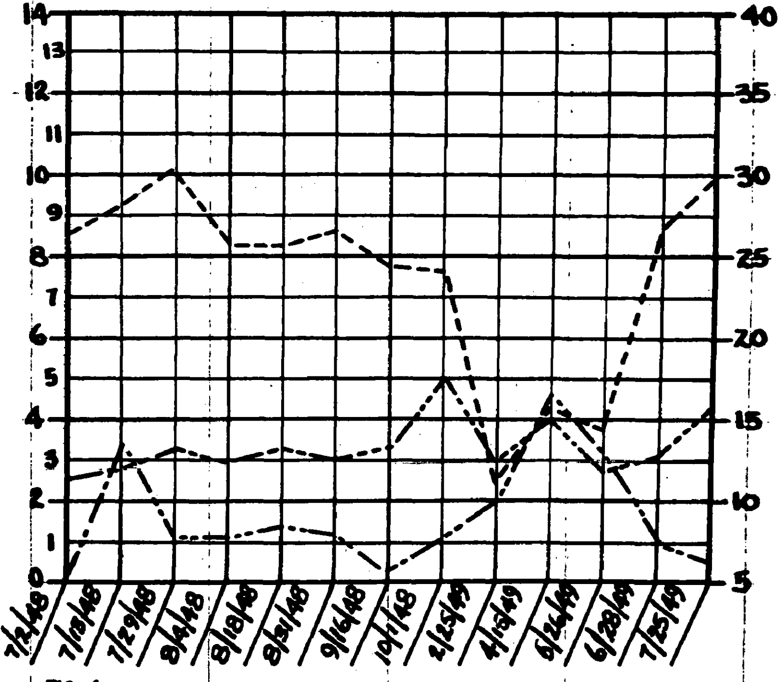


FIG. 4

p.p.m. with an average difference of 0.66 p.p.m.

Ellis reported that environments having concentrations of oxygen below 4 p.p.m. or 3.5 cc/l. failed to support life of most aquatic organisms.[1] If this be true in the area investigated in this study, critically low oxygen values occur frequently in the polluted areas. Table 8 shows oxygen values for the various stations throughout the area studied. Oxygen poor waters occur in Bear Creek and Curtis Creek throughout the entire year, however, critically low values are found more frequently, in the summer. Other stations (I, II, 1, 4, and 6) show, more or less consistently, harmful values throughout the year.

The detrimentally low values of dissolved oxygen do not normally extend beyond the mouths of Bear Creek and Curtis Creek. However, on several occasions critically low values have been observed extending from Bear Creek to Station VII and Station VIII, the Chesapeake Bay region. This has been found to be particularly true in the summer months when the waters of this region are already oxygen-poor as a result of increased temperature of the water. Deeper waters tend to demonstrate particularly acute oxygen deficits in this area.

Low oxygen values are in most cases inversely correlated with temperature and directly correlated with hydrogen-ion concentration, although the latter need not be true. See Plate IX, Figures 3 and 4. The relation of dissolved oxygen to the hydrogen-ion concentration is only significant in these areas where copperas disposal results in the reduction of the pH. Station I and II normally have hydrogen-ion concentrations which hover around neutral. In this case, the oxygen depletion

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[1] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fish., XLVII: 65-437, 1937.

TABLE 7. Average Oxygen Concentrations

Station	Oxygen in p.p.m.	Station	Oxygen in p.p.m.
Is	3.82	VIIIs	4.64
Id	3.33	VIIId	4.60
IIs	5.17	IXs	5.10
IId	4.19	IXd	5.00
IIIs	4.42	Xs	5.30
IIId	4.22	Xd	5.12
IVs	4.36	XIs	4.50
IVd	4.27	XId	4.58
Vs	4.43	XIIs	5.14
Vd	4.27	XIId	4.35
VAs	5.24	XIIIs	5.36
VAd	4.21	XIIId	4.54
VBs	5.85	XIIIAs	5.00
VBd	5.24	XIIIAd	4.31
VCs	5.74	XIIIBs	5.89
VCd	4.15	XIIIBd	4.04
VDs	5.55	XIIICs	6.04
VDd	5.10	XIIICd	5.14
VEs	6.33	XIIIDs	6.21
VEd	4.72	XIIIDd	4.45
VFs	5.65	XIIIEs	5.82
VFd	4.09	XIIIEd	4.82
VGs	5.66	XIIIFs	6.83
VGd	4.85	XIIIFd	4.61
VIs	5.24	XIVs	4.12
VId	4.69	XIVd	3.33
VIIs	5.16	XVs	4.15
VIId	4.48	XVd	3.15

TABLE 8. Dissolved Oxygen in p.p.m.

Date	Temperature Avg. C	Depth	I	II	IV	1	4	6
7/2/48	26.6	Surface	—	—	—	—	0.14	—
7/9/48	24.5	Surface	3.6	3.9	—	—	—	—
	24.0	15'	2.4	3.38	—	—	—	—
7/13/48	28.0	Surface	—	—	—	2.64	2.81	3.41
7/27/48	27.0	Surface	3.29	4.13	3.3	—	—	—
	26.5	15'	2.99	3.94	2.75	—	—	—
7/29/48	28.8	Surface	—	—	—	1.46	1.06	3.1
8/[illegible]/48	26.1	Surface	—	—	—	.44	1.06	3.48
8/5/48	26.0	Surface	7.1	6.45	3.02	—	—	—
	25.9	15'	7.3	4.68	2.69	—	—	—
8/18/48	25.7	Surface	—	—	—	.59	1.46	6.7
8/19/48	25.3	Surface	5.04	5.09	2.82	—	—	—
	25.1	15'	4.86	4.70	.94	—	—	—
	26.8	Surface	—	—	—	.61	1.23	9.18
9/1/48	25.8	Surface	1.23	7.47	2.86	—	—	—
	27.3	15'	2.51	5.30	.87	—	—	—
9/16/48	25.2	Surface	—	—	—	.56	.22	3.08
10/1/48	23.0	Surface	—	—	—	1.34	1.01	2.30
10/[illegible]	19.2	Surface	1.9	3.68	4.19	—	—	—
	19.5	15'	2.1	3.10	3.76	—	—	—

TABLE 8, Continued Dissolved Oxygen in p.p.m.

Date	Temperature	Depth	I	II	IV	1	4	6
11/29/48	7.6	Surface	4.08	3.9	5.15	—	—	—
	7.6	15'	3.8	3.7	3.95	—	—	—
2/25/49	9.0	Surface	—	—	—	2.57	1.9	4.87
4/15/49	14.5	Surface	7.16	5.54	7.68	4.2	4.6	5.2
	14.5	15'	5.26	5.49	5.70	—	—	—
5/26/49	14.7	Surface	—	—	—	.67	3.08	3.92
5/27/49	21.5	Surface	7.67	7.72	5.15	—	—	—
	21.5	15'	6.77	7.72	5.04	—	—	—
	26.5	Surface	—	—	—	.34	1.18	2.52
6/30/49	29.0	Surface	.67	7.22	3.86	—	—	—
	28.0	15'	.45	.56	3.25	—	—	—
7/25/49	30.0	Surface	—	—	—	.50	.73	.67
7/28/49	29.8	Surface	2.70	2.90	3.50	—	—	—
	28.5	15'	2.20	3.30	2.40	—	—	—

of these stations is probably a result of oil which has been found covering the entire area on every sample-collecting trip.

Life conditioning oxygen concentrations at Station 1 are a result of the decomposition of vegetable wastes from the canning factories in this area. Pollution of this type occurs along the northwest shore of the harbor for a distance of several miles.

Carbon dioxide. Of the chemical environmental factors investigated, none show a wider range of values nor a greater variation than does carbon dioxide. The offshore surface values range from .0758 cc/l. to 26.5 cc./l. The deeper waters have a carbon dioxide range of 0.758 cc./l to 24.23 cc/l. Shore samples demonstrate a corresponding wide range, e.g., from .510 cc/l. to 25.00 cc/l.

Carbon dioxide concentrations of the Patapsco River show typical seasonal variations. The supply of carbon dioxide appears to be most bountiful in early summer for both surface and bottom waters, the latter normally yielding the higher values. As the summer progresses, the amount of carbon dioxide rapidly diminishes reaching a minimum in October, at the time of autumnal circulation, when both surface and bottom concentrations coincide. A slight rise in values occurs in winter. With vernal circulation, when the concentrations of carbon dioxide are again more or less evenly distributed vertically, the values begin to rise gradually reaching the maximum again in summer.

The polluted areas of Curtis Creek and Bear Creek give no evidence of stratification relative to carbon dioxide. The surface waters are in some instances of equal value to the lower waters; in fact, frequently, they appear to have much higher values (TABLE 9 and TABLE 10). Relative to seasonal variation in the Bear Creek and Curtis Creek regions, however, it can readily be seen that the summer values are much higher than at other seasons of the year.

The surface-bottom differential ranges from 0.0 cc./l, to 12.74 cc./l. The highest difference occurs in summer while the absence of this difference occurs during vernal and autumnal circulation.

Silicates. Waters of such low salinity as that found in the Patapsco River are naturally high in silicate concentrations. It has been observed that the head waters of the Patapsco River and its tributaries yield somewhat higher values than those approaching the more saline bay waters. The surface waters of Station XV were found to be on an average of 48% higher than those of Station VIII. These differences are not as great as one would expect, since the difference in chlorinity are likewise not large.

The upper reaches of the Patapsco River are richly supplied with silicate-silicon throughout the year, although certain seasons demonstrate an increase in value. The highest concentrations for silicate-silicon in this area were observed in early summer with a sharp decline in value during the spring and autumn. This condition was characteristic for both surface and bottom samples of the head as well as the mouth waters of the Patapsco River.

For the most part, slightly higher silicate values were observed for surface waters. This condition was particularly obvious in the polluted waters of Bear Creek, Curtis Creek and those waters of the Northwest Branch of the harbor (TABLE 11.). The greater surface-concentrations were probably indicative of either poor diatom-productivity in this area or indicative of the influx of fresh water from the tributaries in which case the more richly supplied fresh water flows

TABLE 10. Free Carbon Dioxide Concentrations* Curtis Creek

Date	Depth	XIIIa	XIIIb	XIIIc	XIIId	XIIIe	XIIIf
7/27/48	Surface	18.91	19.10	11.51	11.49	7.16	8.89
	depth	13.30	20.25	14.80	24.23	——	——
8/5/48	Surface	1.30	2.6	1.5	1.3	.7	10.0
	depth	1.30	1.5	1.5	1.3	——	——
8/19/48	Surface	2.80	1.78	2.02	1.54	1.02	1.02
	depth	2.53	2.02	3.03	2.80	2.80	——
9/1/48	Surface	2.78	3.02	3.18	2.53	1.76	.758
	depth	2.78	3.02	3.18	2.53	1.76	——
10/8/48	Surface	.152	.126	.113	.101	.050	.076
	depth	.215	.202	.164	.164	.139	——
4/15/49	Surface	8.85	12.64	12.64	12.64	7.58	7.58
	depth	13.90	10.11	10.11	10.11	7.58	7.58
5/27/49	Surface	15.17	17.70	12.64	10.11	10.11	12.64
	depth	8.85	18.96	12.64	12.64	15.17	15.17
6/30/49	Surface	1.77	1.77	1.51	1.77	1.77	1.77
	depth	2.27	2.022	2.02	2.27	2.21	2.27
7/28/49	Surface	2.53	2.27	2.53	2.28	2.02	1.77
	depth	3.29	3.03	3.29	1.77	2.53	2.53

*Concentrations expressed in cc./l.

TABLE 9. Free Carbon Dioxide Concentrations* Bear Creek

Date	Depth*	Va	Vb	Vc	Vd	Ve	Vf	Vg
7/9/48	Surface	26.5	6.6	11.8	13.2	9.7	7.9	8.7
	depth	15.5	—	—	—	—	—	—
7/27/48	Surface	17.6	12.6	25.3	19.2	2.7	3.8	18.2
	depth	14.6	7.9	14.4	13.7	7.9	6.9	3.1
8/5/48	Surface	1.0	1.3	1.3	1.3	.7	.7	.5
	depth	—	—	—	—	—	—	—
8/19/48	Surface	.51	.76	.51	.76	.51	.51	.51
	depth	1.26	.76	1.26	.76	.76	.76	.51
9/1/48	Surface	.51	.51	.25	.51	.76	.51	.51
	depth	.76	.51	.51	.51	.76	.51	.51
10/8/48	Surface	.076	.076	.076	.101	.076	.101	.152
	depth	.076	.076	.051	.101	.076	.101	.051
11/29/48	Surface	.51	.51	.76	.51	.51	.76	.51
	depth	.63	.88	.51	.51	.63	.51	.51
4/15/49	Surface	7.58	12.64	12.64	10.11	6.32	6.32	6.32
	depth	10.11	7.58	8.85	8.85	3.79	5.06	5.06
5/27/49	Surface	20.22	10.11	12.64	5.06	7.58	5.06	13.9
	depth	7.58	6.32	7.58	3.79	5.06	5.06	6.32
6/30/49	Surface	2.78	.75	1.01	.76	.76	.76	.76
	depth	1.26	.75	1.01	1.01	.76	.76	.76
7/28/49	Surface	2.78	3.03	2.78	3.29	2.02	1.01	.76
	depth	1.52	2.53	2.78	2.02	2.53	1.52	1.01

*Concentrations in cc./l.

over the denser more saline waters. The latter was exemplified by Station XIIIF, at which station the average surface value was found to be .1154 g/l and .0665 g/l for the deeper water. However, the silicate values were in some instances higher for the bottom waters than for the surface waters. This was particularly true at shore stations more proximally located to the Bay. This is possibly due to silicate-fixation by diatoms, a process in which an amorphous opaline silica is found which is most insoluble.

The surface-bottom differential varied from 0.0 g/l. to 0.0489 g/l. The apparent lack of difference either occurs more or less continously in the shallower waters or seasonally at the time of vertical mixing. The greater difference is normally found in summer and winter.

Ferrous Iron. The quantitative values of copperas, ferrous iron, is indicative of the degree of pollution and the oxygen engaging power of the water. The highest concentrations are found at the source of disposal with diminishing values, more or less proportionate to the distance from the foci of pollution.

Ferrous iron was generally found throughout Bear Creek, Colgate Creek and Curtis Creek, However, no trace of this ion was found in the lower reaches of the Patapsco River although, the effects of its presence in other bodies of water were observable. The range of ferrous iron was found to be from a trace to 1080.0 p.p.m. The highest value was found in Colgate Creek near the Paint and Pigment plant. Similarly high concentrations of copperas, 986.0 p.p.m. were found at Station 6, the mouth of Humphreys Creek. The highest value observed at the mouth of Bear Creek was 420.0 p.p.m.

A triangle of delitorious effects (Plate X) results from the disposal of ferrous iron into aquatic environments. First, the hydrolysis of ferrous sulphate quickly causes a sharp decline in the hydrogen-ion concentration, resulting in the formation of basic ferrous salts. The subsequent oxidation of ferrous iron to ferric iron is done at the expense of the dissolved oxygen in the water, which in most cases is already poor. For the most part, the rust colored colloidal ferric hydroxide is formed which later coalesces and is finally precipitated. The inherent chemical effects produced by the presence of copperas is graphically represented in Plate XII, Figure I and Figure 2.

Of no less importance, relative to pollution, is the flocculation and settling out of ferric hydroxide. One of the characteristics of colloidal particles is that of carrying a charge. Within the acid range, colloidal ferric hydroxide bears a positive charge. The size of most planktonic forms is likewise, within the range and therefore, they too carry a charge. Since this charge is opposite to that of the colloidal iron, it results in a mutual attraction of one for the other. In this process, not only are the plankters destroyed by asphyxiation, because of the inability of oxygen to diffuse through the iron coating; but also these organisms are destroyed *en masse* by precipitation in the "salting-out" of the ferric hydroxide.

Ferrous iron in the Curtis Creek area has its origin from the Krebs Pigment Plant and in Colgate Creek from the Glidden Chemical and Pigment Company. These plants in the process of the manufacture of a white paint pigment from titanium dioxide, produce ferrous sulphate as a byproduct. Ilmenite sand, $FeTiO_3$ is the source of titanium dioxide. The former is treated with sulphuric acid which results in the formation of ferrous and ferric sulphate. The latter is further reduced

TABLE 11. Silicate-Silicon Values for July 28, 1949

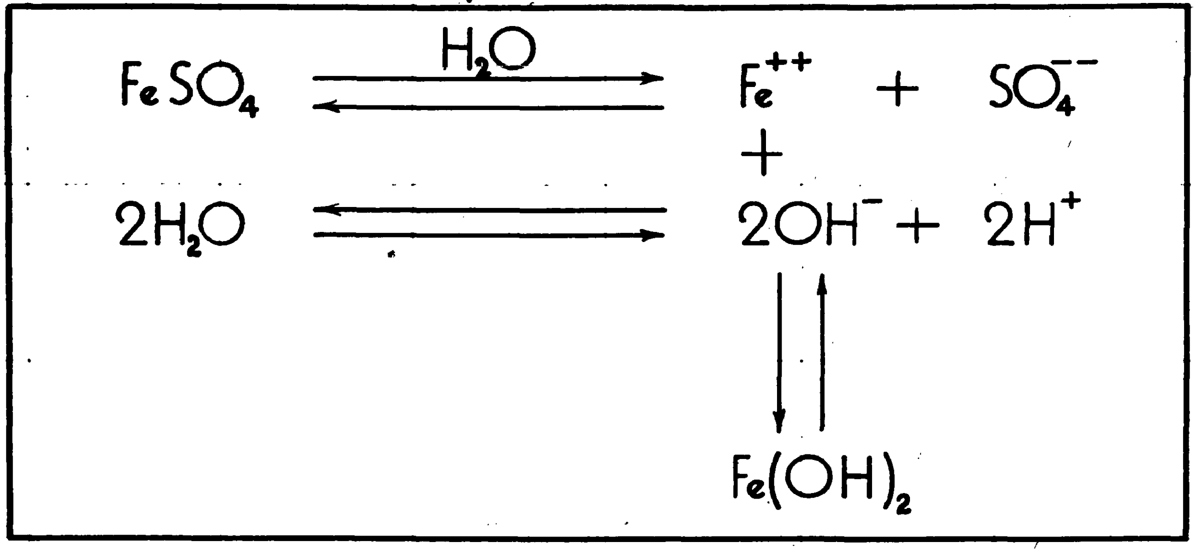
Station	Depth	Concentration*	Station	Depth	Concentration*
I	Surface	.0971	VIII	Surface	.0485
I	Depth	.0850	VIII	Depth	.0475
II	Surface	.0931	IX	Surface	.0521
II	Depth	.0842	IX	Depth	.0672
III	Surface	.0926	X	Surface	.0801
III	Depth	.1112	X	Depth	.0906
IV	Surface	.0913	XI	Surface	.0796
IV	Depth	.0879	XI	Depth	.0808
V	Surface	.1040	XII	Surface	.0898
V	Depth	.0771	XII	Depth	.0858
Va	Surface	.0918	XIII	Surface	.0971
Va	Depth	.0912	XIII	Depth	.1012
Vb	Surface	.0923	XIIIa	Surface	.0892
Vb	Depth	.0892	XIIIa	Depth	.0827
Vc	Surface	.0910	XIIIb	Surface	.0865
Vc	Depth	.0932	XIIIb	Depth	.0855
Vd	Surface	.0880	XIIIc	Surface	.1110
Vd	Depth	.0857	XIIIc	Depth	.0940
Ve	Surface	.0895	XIIId	Surface	.1035
Ve	Depth	.0875	XIIId	Depth	.0970
Vf	Surface	.0742	XIIIe	Surface	.1142
Vf	Depth	.0762	XIIIe	Depth	.0969
Vg	Surface	.0825	XIIIf	Surface	.1154
Vg	Depth	.0774	XIIIf	Depth	.0665
VI	Surface	.0687	XIV	Surface	.1012
VI	Depth	.0699	XIV	Depth	.0911
VII	Surface	.0677	XV	Surface	.0948
VII	Depth	.0688	XV	Depth	.0780

* grams/liter

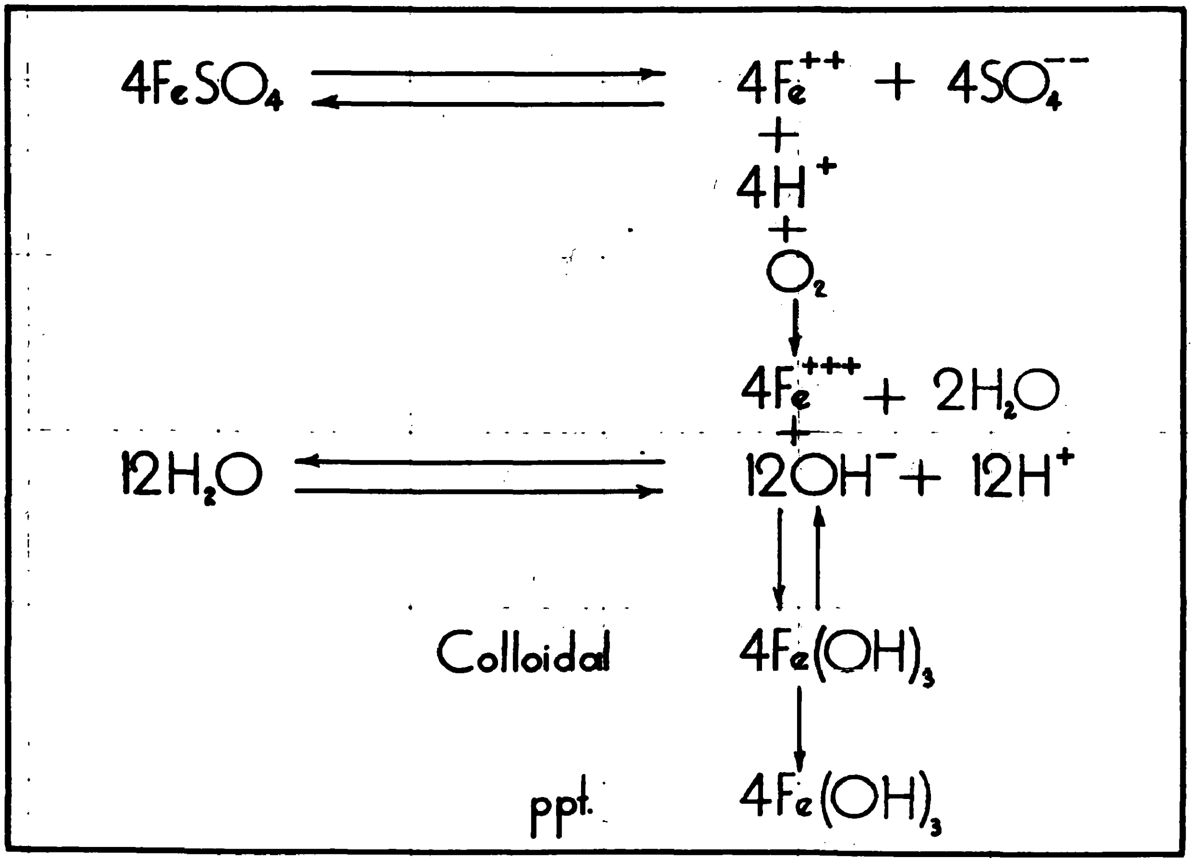
PLATE X

REACTION OF COPPERAS DECOMPOSING

$FeSO_4$ HYDROLYSIS



$FeSO_4$ OXIDATION



to yield ferrous sulphate. The source of pollution in Bear Creek has its origin in Humphreys Creek into which are emptied pickling liquors from the Bethlehem Steel Corporation, which is reported to own the creek in its entirety.

Total Iron. Although the ferrous iron was not detected in the lower reaches of the Patapsco River, its effects were observable as indicated by the total iron concentrations found in this region. Total iron concentrations reveal the course and attenuation of the iron-forms resulting from copperas decomposition, when analysed in the light of the soluble and insoluble iron present.

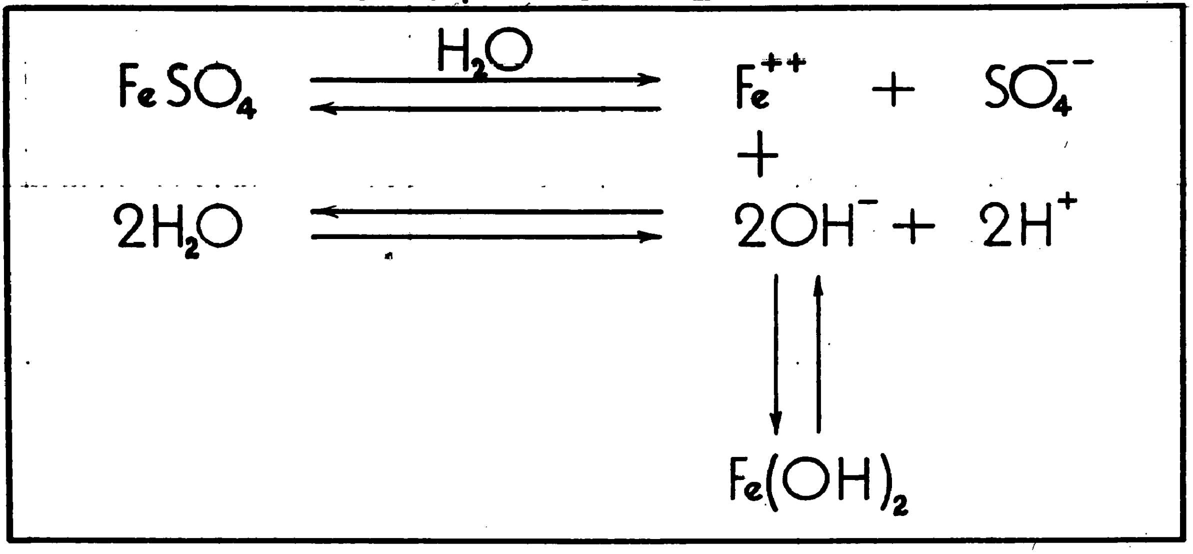
The range of total iron in the offshore areas studied was .1 p.p.m. to 29.7 p.p.m. for the surface waters and .2 p.p.m. to 34.8 p.p.m. for the bottom waters. The higher total iron values were found in the polluted areas of Bear Creek, Colgate Creek and Curtis Creek. The highest values were located in the immediate environs of the copperas disposal, diminishing in value from the source. For example, in Curtis Creek the highest concentrations were found at Station XIIIc, from this point, the values decreased both up and down the stream.

The total iron concentrations, on an average, were found to be higher in Curtis Creek than in any other offshore area studied. The average for this factor was found to be 6.30 p.p.m. for the surface and 7.06 p.p.m. for the deeper waters. Total iron values of Bear Creek were found to be appreciably less with concentrations of 2.69 p.p.m. for the surface waters and 2.46 p.p.m. for the bottom waters. However, at that part of Bear Creek where the waters of Humphreys Creek meet, the concentrations were significantly higher, showing the influence of the latter. See TABLE 12.

PLATE X

REACTION OF COPPERAS DECOMPOSING

$FeSO_4$ HYDROLYSIS



$FeSO_4$ OXIDATION

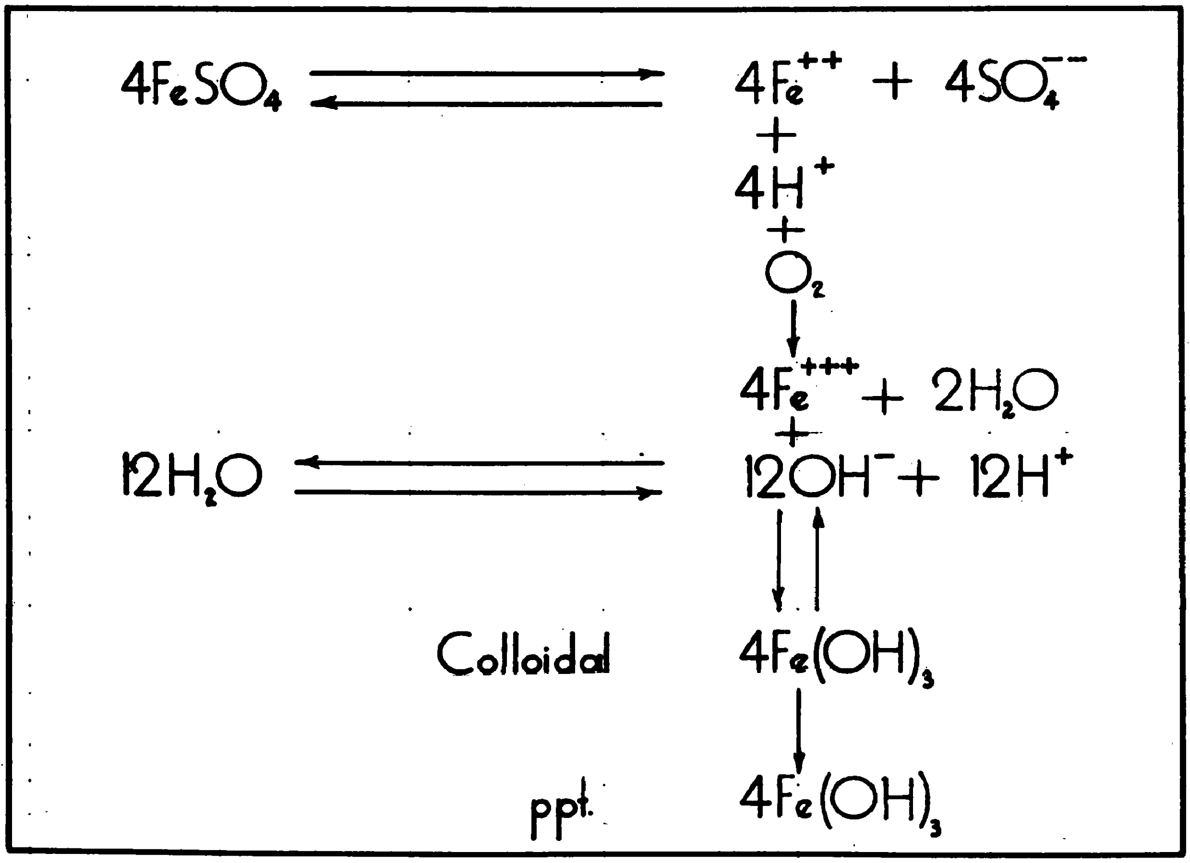


PLATE XI

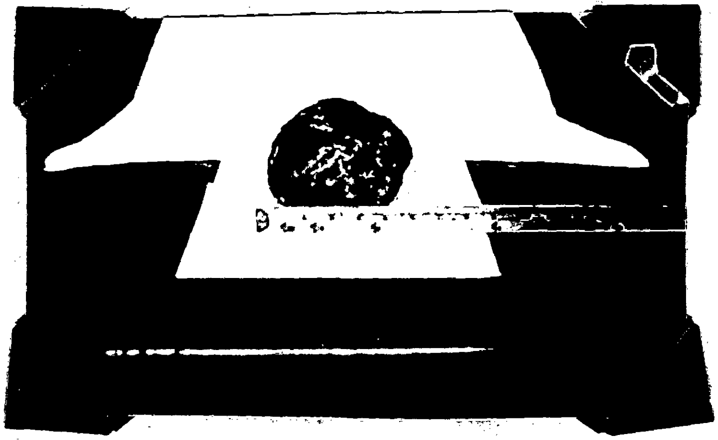


Figure 1

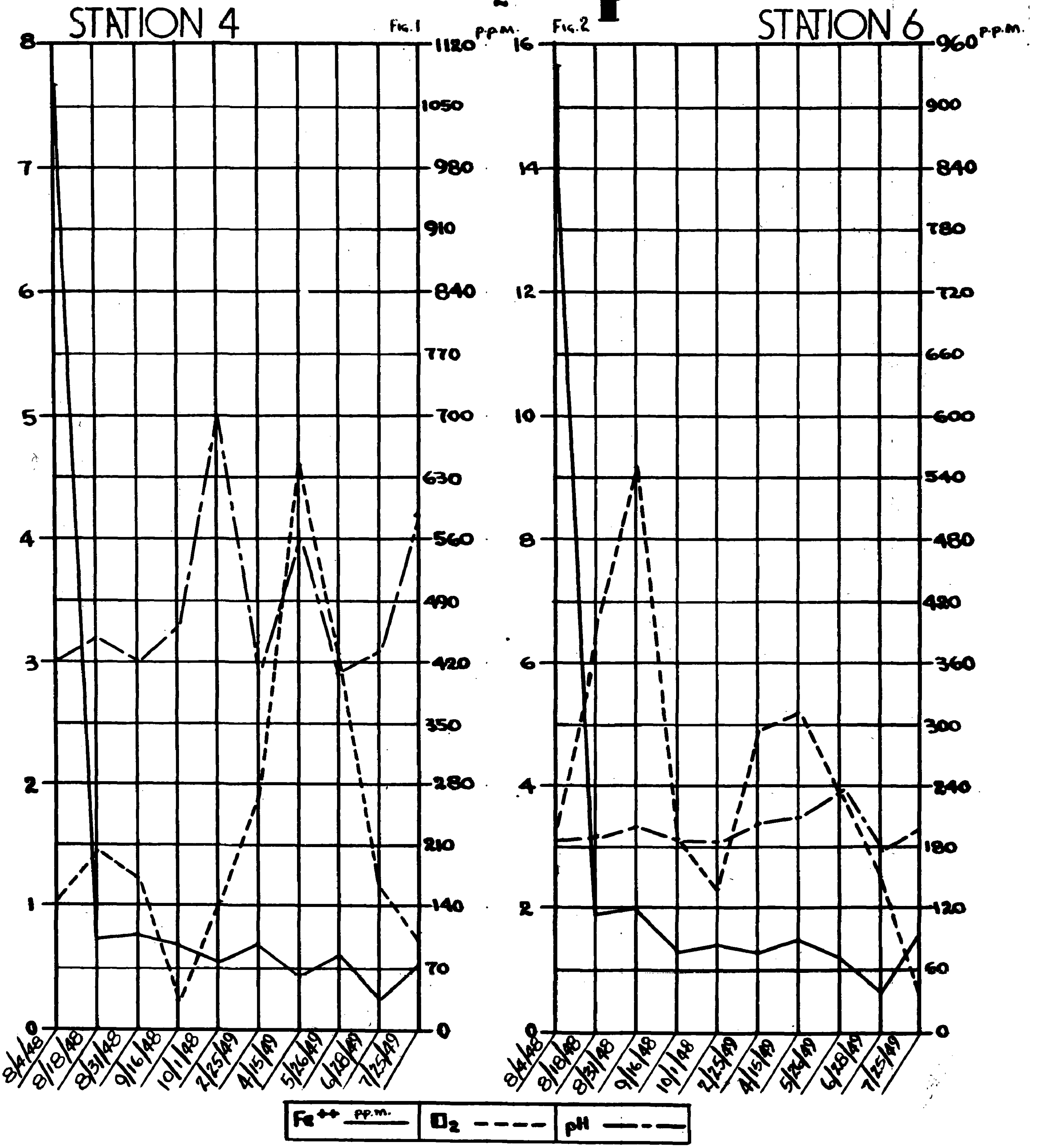
Grease Ball Taken
From Patapsco River

Figure 2

Oil and Debris Floating
in Patapsco

PLATE XII

Fe^{++} — O_2 — pH



The shore stations demonstrated a total iron range of 0.1 p.p.m. to 104.9 p.p.m., the highest concentrations were found at Station 4 and Station 6; Colgate Creek and Humphreys Creek respectively. The average concentration for Colgate Creek was found to be 44.6 p.p.m., while that of Humphreys Creek was found to be 36.2 p.p.m.

For the most part, the concentrations for total iron were higher for the bottom waters than they were for the surface waters in Curtis Creek. This, however, was not characteristic for the other stations studied; in fact, more frequently surface values exceeded bottom concentrations.

No significant difference was noted relative to seasonal variation for total iron.

The fact that the ferrous ion is immediately oxidized upon being released in the aquatic environment is evidenced by the fact that frequently there is no correlation between high ferrous iron concentration and total iron values. This is demonstrated in Plate XIII, Figure 1. The process of oxidation continues to occur in regions which are relatively distant from the source of copperas disposal. Obviously, this oxidative process, also continues to draw heavily upon the dissolved oxygen in the area in which this chemical reaction is in process, thus accounting, in part for the low values for oxygen.

The amount of dilution from Station 6. Humphreys Creek, which shows an average concentration of 36.2 p.p.m. to Station V, at the mouth of Bear Creek, approximately one mile, demonstrating an average total iron concentration of 4.9 p.p.m. for the surface; is 86.74 per cent. The dissipation of total iron from Station V to Station VIII, the mouth of the Patapsco River is 59.51 per cent, while the degree of dilution from

TABLE 12. Total Iron Averages For Shore and Offshore Stations

Station	Depth	Concentration*	Station	Depth	Concentration*
I	Surface	2.36	XI	Depth	1.43
I	Depth	1.81	XII	Surface	1.96
II	Surface	2.26	XII	Depth	2.57
II	Depth	2.04	XIII	Surface	3.33
III	Surface	2.25	XIII	Depth	2.18
III	Depth	2.10	XIIIA	Surface	8.15
IV	Surface	1.81	XIIIA	Depth	7.27
IV	Depth	1.67	XIIIB	Surface	7.87
V	Surface	3.06	XIIIB	Depth	7.80
V	Depth	2.93	XIIIC	Surface	7.55
VA	Surface	3.13	XIIIC	Depth	9.63
VA	Depth	2.93	XIIID	Surface	6.61
VB	Surface	2.54	XIIID	Depth	7.99
VB	Depth	2.33	XIIIE	Surface	5.33
VC	Surface	2.22	XIIIE	Depth	6.50
VC	Depth	1.86	XIIIF	Surface	6.17
VD	Surface	3.00	XIIIF	Depth	2.67
VD	Depth	2.94	XIV	Surface	3.63
VE	Surface	2.67	XIV	Depth	2.76
VE	Depth	2.35	XV	Surface	4.41
VF	Surface	2.29	XV	Depth	2.33
VF	Depth	2.27	1	Surface	3.94
VG	Surface	2.39	2	Surface	1.57
VG	Depth	2.63	3	Surface	1.88
VI	Surface	2.12	4	Surface	14.5
VI	Depth	1.23	5	Surface	3.63
VII	Surface	1.74	6	Surface	36.15
VII	Depth	1.55	7	Surface	2.40
VIII	Surface	1.76	8	Surface	2.12
VIII	Depth	1.94	9	Surface	3.33
IX	Surface	1.63	10	Surface	3.64
IX	Depth	1.99	11	Surface	2.02
X	Surface	3.80	12	Surface	1.94
X	Depth	2.82	13	Surface	2.40
XI	Surface	1.64	14	Surface	3.00

* p.p.m.

Station 6 is 96.13 per cent. In the light of the foregoing, it is obvious that the major part of the decomposition occurs in the tributaries of the Patapsco River, to a lesser degree in the river proper, and by the time the water reaches the Chesapeake Bay, this factor has become almost entirely wanting.

Soluble Iron. Soluble iron may be interpreted as an expression of the unprecipitated oxidized ferrous salts present in the water. Soluble iron has a range in the area studied of 0.00 to 22.4 p.p.m. for the offshore bottom waters. The highest concentrations were obtained in the Colgate Creek, Humphreys Creek, Curtis Creek and Bear Creek in descending order of values (TABLE 13).

The range observed at Station 4 was 0.20 p.p.m. to 102.00 p.p.m. with an average concentration of 34.14 p.p.m. Soluble iron at Station 6 ranged from 0.20 to 86.20 p.p.m. with an average concentration of 27.25 p.p.m. Curtis Creek yielded an overall average of 3.86 p.p.m. and Bear Creek showed an average concentration of 3.63 p.p.m. Except for a few cases, the surface values appeared to be higher than the bottom. This is to be expected in the light of the fact that oxidation in the upper stratum of water is completed, because of its contact with the atmosphere, before ferrous iron of the bottom water is decomposed. Further, the colloidal iron hydroxide remains in the surface waters until it has coalesced to a point where precipitation is forced. Finally, it is quite possible that some of the colloidal iron hydroxide has been filtered and calculated as soluble iron.

Soluble iron appeared to be most abundant where ferrous iron was most concentrated (Plate XIV). It will be noted that although ferrous iron was generally found in the greater concentration at Station 6,

PLATE XIII

SOL. Fe—TOTAL Fe — Fe^{OUS}

Fig. 1

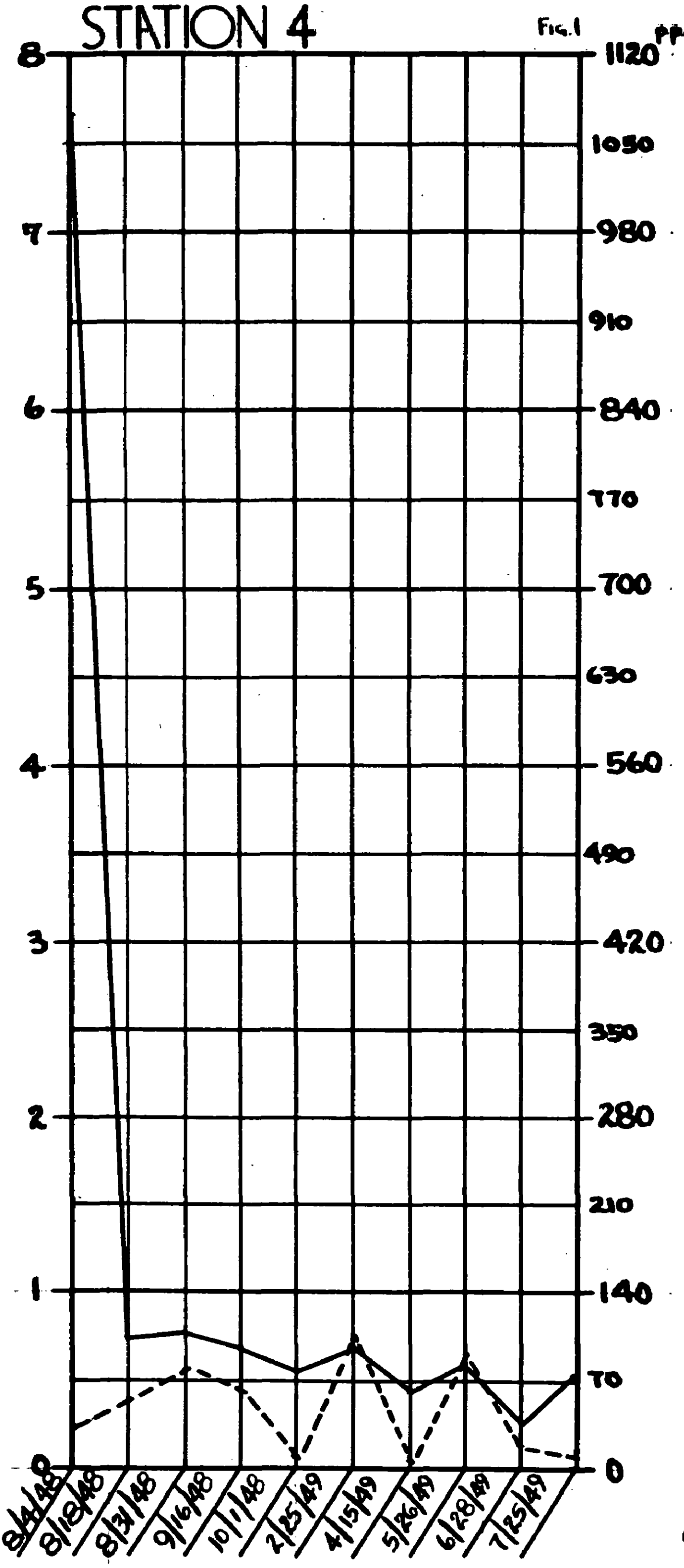
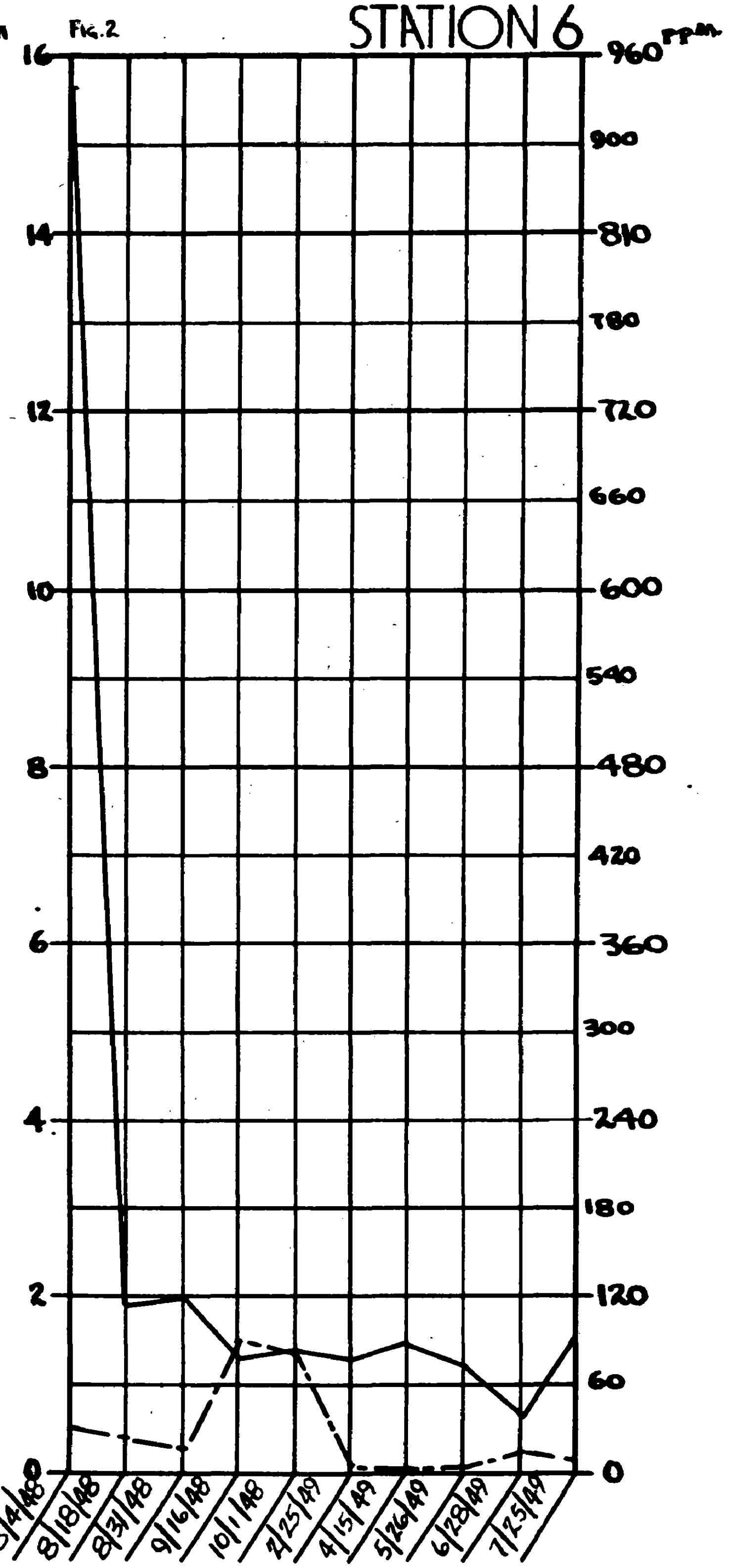


Fig. 2



Fe^{++} P.P.M. ______	TOT. Fe P.P.M. - - - -	SOL. Fe P.P.M. ___ _

TABLE 13. Average Soluble Iron Concentrations for Offshore and Shore Stations

Station	Depth	Concentration p.p.m.	Station	Depth	Concentration p.p.m.
I	Surface	1.85	XI	Depth	1.04
I	Depth	1.52	XII	Surface	1.15
II	Surface	1.23	XII	Depth	1.01
II	Depth	1.31	XIII	Surface	2.55
III	Surface	1.25	XIII	Depth	1.68
III	Depth	1.07	XIIIA	Surface	4.25
IV	Surface	1.15	XIIIA	Depth	3.26
IV	Depth	1.33	XIIIB	Surface	4.87
V	Surface	1.44	XIIIB	Depth	3.97
V	Depth	1.07	XIIIC	Surface	5.15
VA	Surface	1.44	XIIIC	Depth	6.07
VA	Depth	1.27	XIIID	Surface	3.87
VB	Surface	1.71	XIIID	Depth	4.95
VB	Depth	1.43	XIIIE	Surface	5.47
VC	Surface	1.71	XIIIE	Depth	4.16
VC	Depth	1.13	XIIIF	Surface	2.90
VD	Surface	11.82	XIIIF	Depth	1.15
VD	Depth	1.22	XIV	Surface	4.66
VE	Surface	2.13	XIV	Depth	1.68
VE	Depth	1.63	XV	Surface	2.01
VF	Surface	1.26	XV	Depth	1.33
VF	Depth	1.19	1	Surface	2.30
VG	Surface	1.60	2	Surface	1.53
VG	Depth	1.62	3	Surface	1.43
VI	Surface	.96	4	Surface	34.14
VI	Depth	.09	5	Surface	2.15
VII	Surface	1.42	6	Surface	27.25
VII	Depth	1.02	7	Surface	1.31
VIII	Surface	1.46	8	Surface	1.44
VIII	Depth	.97	9	Surface	1.70
IX	Surface	.83	10	Surface	1.37
IX	Depth	1.42	11	Surface	1.08
X	Surface	.77	12	Surface	1.16
X	Depth	1.39	13	Surface	1.67
XI	Surface	.83	14	Surface	1.78

there does not seem to be any correlation between the two factors. (Plate XIII, Figure 2).

From Station 6 to Station V, the soluble iron concentration has been reduced by 94.65 per cent and to Station VIII, the concentration was reduced 96.47 per cent. As in the case of total iron, soluble iron values reach their maximum dilution before they leave the region of their origin.

Insoluble Iron. Insoluble iron represents the extent and area of ferric hydroxide-precipitation, and can therefore, be directly correlated with the ferrous iron decomposition-factors. The insoluble iron range for the surface offshore area studied ranged from 0.30 p.p.m. to 3.90 p.p.m. The deeper offshore waters demonstrated somewhat higher average values ranging from 0.30 p.p.m. to 5.66 p.p.m. As expected, those stations yielding higher concentrations of other forms of iron showed a significant increase in this factor (Plate XIV). As in the case of soluble iron and total iron, the higher values for insoluble iron were found in Colgate Creek, Humphreys Creek, Curtis Creek and Bear Creek in descending order of concentration (TABLE 14).

From Station 6 to Station V, the amount of insoluble iron is reduced by 78.6 per cent from the latter station to Station VIII, the insoluble iron value has been decreased by 82.26 per cent.

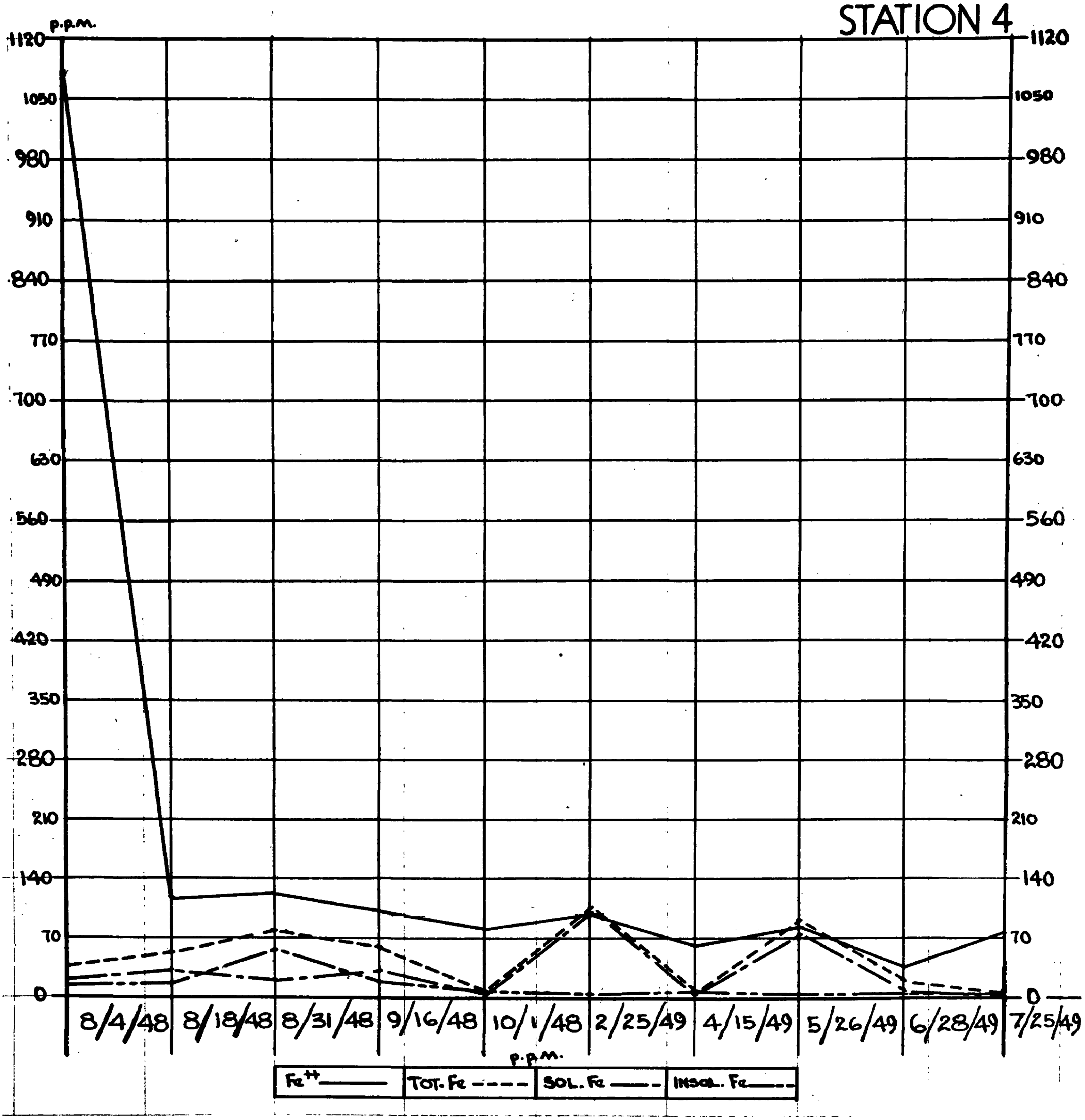
Nitrates. The concentrations of nitrate-nitrogen in the Patapsco River follows a cycle which is characteristic for both surface and bottom water. The range for this factor varied from 0.60 p.p.m. to 8.60 p.p.m. for the surface offshore waters and from 0.80 p.p.m. to 8.40 p.p.m. for the bottom offshore waters. TABLE 15 shows average concentrations for each station. The surface nitrate values, were generally exceeded by

TABLE 14. Insoluble Iron- Average Concentrations

Station	Depth	Concentration p.p.m.	Station	Depth	Concentration p.p.m.
Va	Surface	1.69	XIIIa	Surface	3.90
Va	Depth	1.66	XIIIa	Depth	4.01
Vb	Surface	.83	XIIIb	Surface	3.62
Vb	Depth	.90	XIIIb	Depth	4.54
Vc	Surface	.49	XIIIc	Surface	2.68
Vc	Depth	.73	XIIIc	Depth	5.66
Vd	Surface	1.18	XIIId	Surface	1.46
Vd	Depth	1.72	XIIId	Depth	1.92
Ve	Surface	.54	XIIIe	Surface	.38
Ve	Depth	.72	XIIIe	Depth	3.03
Vf	Surface	1.03	XIIIf	Surface	2.01
Vf	Depth	1.08	XIIIf	Depth	.77
Vg	Surface	.79	4	Surface	10.36
Vg	Depth	1.01	6	Surface	8.90

PLATE XIV

RELATIONSHIP OF IRON FORMS



bottom water values, except at those stations located at the head of the Patapsco River and its tributaries. In most instances, the surface nitrate values in Bear Creek and Curtis Creek were higher than the substratum of water. This probably results from the influx of less dense fresh waters which tend to flow over the more saline deeper waters.

Stratification was present at all stations and at all seasons except at vernal or autumnal circulation or at the shallower stations throughout the year; in which case the surface-bottom differential was completely wanting or so slight as to be considered negligible. Where stratification occurred, the range varied from 0.01 p.p.m. to 6.5 p.p.m.

Nitrate-nitrogen values show seasonal variation in the area investigated. The highest values were encountered in the winter with declining concentrations in the spring reaching a minimum in the early summer. Nitrate-nitrogen values begin to rise in the Patapsco River area in late summer reaching the maximum again in winter. See Plate XV, Figure 1.

The Patapsco River, as a whole is richly supplied with nitrate-nitrogen, however, in some regions this factor appears to be more abundant than others. This is particularly true in the upper reaches of the creeks which feed the river. The high nitrate-nitrogen value in these areas is probably a result of the influx of nutrient laden waters from upstream. After the initial dilution, caused by the fresher waters entering the river; the concentration remains more or less constant with a nitrate dissipation not exceeding 0.02 p.p.m. For example, the average value for nitrate-nitrogen upon entering the Patapsco River from Bear Creek, Station V, is 2.11 p.p.m. for the surface and 2.01 p.p.m. for the bottom waters. At Station VII the average values are found to be 2.07 p.p.m. for the surface and 2.19 p.p.m. for the deeper waters.

TABLE 15. Average Nitrate Concentrations for Offshore and Shore Stations

Station	Depth	Concentration p.p.m.	Station	Depth	Concentration p.p.m.
I	Surface	2.25	XI	Depth	2.22
I	Depth	2.18	XII	Surface	2.20
II	Surface	2.03	XII	Depth	2.20
II	Depth	2.26	XIII	Surface	2.11
III	Surface	2.16	XIII	Depth	1.94
III	Depth	1.91	XIIIA	Surface	2.28
IV	Surface	1.96	XIIIA	Depth	2.24
IV	Depth	1.87	XIIIB	Surface	2.17
V	Surface	2.11	XIIIB	Depth	1.99
V	Depth	2.01	XIIIC	Surface	2.32
VA	Surface	2.13	XIIIC	Depth	2.13
VA	Depth	2.05	XIIID	Surface	2.12
VB	Surface	2.17	XIIID	Depth	2.12
VB	Depth	2.01	XIIIE	Surface	2.31
VC	Surface	2.01	XIIIE	Depth	2.16
VC	Depth	2.05	XIIIF	Surface	2.28
VD	Surface	2.66	XIIIF	Depth	1.81
VD	Depth	2.69	XIV	Surface	2.03
VE	Surface	1.91	XIV	Depth	2.70
VE	Depth	1.93	XV	Surface	1.93
VF	Surface	2.01	XV	Depth	1.94
VF	Depth	1.79	1	Surface	2.46
VG	Surface	2.09	2	Surface	2.37
VG	Depth	1.92	3	Surface	1.89
VI	Surface	2.11	4	Surface	2.19
VI	Depth	2.19	5	Surface	1.05
VII	Surface	2.07	6	Surface	2.20
VII	Depth	2.19	7	Surface	2.01
VIII	Surface	2.00	8	Surface	2.11
VIII	Depth	2.15	9	Surface	2.16
IX	Surface	2.20	10	Surface	1.96
IX	Depth	2.28	11	Surface	1.06
X	Surface	2.10	12	Surface	2.10
X	Depth	2.18	13	Surface	1.94
XI	Surface	2.22	14	Surface	2.00

Surface values for Station VIII averaged 2.00 p.p.m. while the bottom values averaged 2.15 p.p.m. This condition need not be considered characteristic for the entire area. Lack of nitrate-nitrogen-utilization in its downstream course is probably indicative of poor productivity.

Nitrite-Nitrogen. Offshore surface nitrite-nitrogen values ranged from .003 p.p.m. to .500 p.p.m., while the range for the deeper waters ranged from 0.003 p.p.m. to 0.552 p.p.m. Shore samples demonstrated a significantly higher range which was found to be between 0.015 p.p.m. to 0.986 p.p.m. For the most part, surface nitrite values were equal or exceeded by the values in the deeper waters. This can be seen in the nitrite averages recorded in TABLE 16.

Nitrite-nitrogen demonstrates seasonal variation which is characteristic of some of the other chemical factors investigated. The highest concentrations were found to occur in winter. A gradual decrease in values was observed beginning in the spring, and reaching its lowest concentration in midsummer. This is followed by a similarly gradual assent which occurs in late summer and reaches a maximum in winter. As previously stated, the deeper waters tend to be more concentrated with nitrite-nitrogen throughout the year except when disturbed by vertical mixing, at which time the surface-bottom concentrations are more or less the same. This can be demonstrated in Plate XV, Figure 2.

As in the case of nitrate-nitrogen, nitrite-nitrogen tends to increase in concentration, in an upstream direction. For example, the surface nitrite concentration at Station Vg of Bear Creek is 27.2 per cent greater than that of Station Va. The deeper waters, however, demonstrate a slightly lower difference of 18.42 per cent. Similar differences are encountered in Curtis Creek.

Except for the vertical mixing at the time of vernal and autumnal circulation, the bottom waters of the deeper stations appear to be more concentrated than the surface waters relative to nitrite-nitrogen. The range of the surface-bottom differential varied from 0.00 to 5.04 p.p.m. The greatest difference is evidenced in the summer when stratification is at its maximum. The apparent lack of this difference is found only in the more shallow stations where stratification is wanting.

Although nitrite-nitrogen values follow the same general pattern, relative to upstream variation, as does nitrate-nitrogen; there appears to be no corresponding inverse correlation in specific instances relative to seasonal variations. In many cases, an increase in one or the other of these factors is not paralleled by a similar decrease in values by the other. Nor in this study has it been found that high nitrate values are associated, in most cases, with corresponding high values of nitrite-nitrogen.

No significant difference has been observed between the nitrite concentrations of the polluted waters and those of the non-polluted regions.

Phosphates. The concentrations of phosphates in the Patapsco River and the creeks that feed it are exceedingly high. Phosphate-phosphorus values ranged from 7.48 p.p.m. to 14.80 p.p.m. for surface waters from 7.91 p.p.m. to 15.93 p.p.m. for bottom waters and 7.97 p.p.m. to 11.06 p.p.m. for shore waters. Consult TABLE 17.

Seasonal variation was evidenced at all stations. The highest phosphate concentrations were observed in late winter. Phosphate-phosphorus began to decline in value in March with a sharp drop in value in April and continuing its gradual downward trend in May, June and July

TABLE 16. Average Nitrite Concentrations

Station	Depth	Concentration p.p.m.	Station	Depth	Concentration p.p.m.
I	Surface	.149	XI	Depth	.145
I	Depth	.126	XII	Surface	.130
II	Surface	.143	XII	Depth	.185
II	Depth	.192	XIII	Surface	.135
III	Surface	.146	XIII	Depth	.160
III	Depth	.145	XIIIA	Surface	.096
IV	Surface	.145	XIIIA	Depth	.106
IV	Depth	.155	XIIIB	Surface	.097
V	Surface	.123	XIIIB	Depth	.103
V	Depth	.160	XIIIC	Surface	.098
VA	Surface	.086	XIIIC	Depth	.099
VA	Depth	.124	XIIID	Surface	.099
VB	Surface	.093	XIIID	Depth	.106
VB	Depth	.146	XIIIE	Surface	.112
VC	Surface	.097	XIIIE	Depth	.118
VC	Depth	.098	XIIIF	Surface	.116
VD	Surface	.104	XIIIF	Depth	.188
VD	Depth	.120	XIV	Surface	.191
VE	Surface	.109	XIV	Depth	.189
VE	Depth	.131	XV	Surface	.193
VF	Surface	.113	XV	Depth	.227
VF	Depth	.160	1	Surface	.175
VG	Surface	.118	2	Surface	.135
VG	Depth	.152	3	Surface	.091
VI	Surface	.193	4	Surface	.147
VI	Depth	.143	5	Surface	.070
VII	Surface	.101	6	Surface	.118
VII	Depth	.110	7	Surface	.101
VIII	Surface	.101	8	Surface	.171
VII	Depth	.110	9	Surface	.154
IX	Surface	.093	10	Surface	.122
IX	Depth	.121	11	Surface	.135
X	Surface	.097	12	Surface	.150
X	Depth	.101	13	Surface	.172
XI	Surface	.123	14	Surface	.081

reaching a minimum in the latter month. These values begin to rise slowly from August to October at the end of which time there is a sudden upward surge in value reaching a maximum in winter. See Plate XV, Figure 3. The greatest range in variation was noted in the upper reaches of the river where the less saline waters are found.

Except for vernal and autumnal circulation, the surface waters were found to be exceeded by the deeper waters in phosphate-phosphorus concentrations, at most stations, particularly those nearing the mouth of the Patapsco River. Stratification was most apparent during the summer when the water as a whole was more heterogeneous. The surface-bottom differential during this season varied from 0.0 to 3.5 p.p.m. The absence of stratification was found, expectedly, at the shallower stations. As the waters became more homogeneous because of mixing, the surface-bottom difference demonstrated a corresponding narrowing of range. During winter stagnation the surface-bottom differential ranged from 0.0 to 1.5 p.p.m. Again, a surface-bottom difference was found wanting in the shallower waters.

The head waters of the Patapsco River, Bear Creek and Curtis Creek demonstrated significant differences relative to phosphate concentrations. The highest values for this factor were found in the upper reaches of these waters, while the lowest values were found at the mouth of the river; although the latter were by no means phosphate-poor. It will be noted that Station XIV, which collects water from the head of the Patapsco River, yielded an average concentration of 14.80 p.p.m. for surface waters and 15.38 p.p.m. for the bottom waters. Likewise, in Bear Creek (Station Vf and Vg) high concentrations of the head waters are further exemplified by the respective surface value averages of

13.03 p.p.m. and 13.38 p.p.m.; and bottom water values of 15.28 p.p.m. and 15.48 p.p.m. The amount of phosphate-dilution from Station V to Station VIII is 34.15 per cent for the surface and 46.52 per cent for the bottom. However, from Station Vg to V, the amount of phosphate dissipation amounts to 8.89 per cent for the surface and 0.72 per cent for the bottom. It is obvious that the amount of phosphate-phosphorus available for plankton utilization is not significantly decreased. This same condition is characteristic for Station I through Station V on the north side of the Patapsco River and Station XIV and XIII on the south side of the river. The foregoing condition does not exist in Curtis Creek. For example, phosphate-phosphorus of the surface water is reduced by 23.58 per cent while the deeper waters are reduced by 43.82 per cent from the head waters to the mouth of Curtis Creek.

Oil and Grease. Oil and grease is known to kill off all forms of organic life, except for a fungus which thrives in the area of severe pollution.[1] This pollution is an exceptionally serious one in the area investigated. So acute was this condition that several times during the year this study was conducted, the beaches of Bear Creek and Station 13 and 14 were completely covered with oil. On several occasions, the grease balls washed ashore were as large as speedballs, Plate XI, Figure 1. This condition was acute at every shore station 80 per cent of the time samples were collected.

The grease balls have their origin from Humphreys Creeks, another waste resulting from the steel industry, it has been reported that these

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[1] State of New York Conservation Department, "A Biological Survey of the Erie-Niagra System", Supplement to the Eighteenth Annual Report, 1928.

grease balls have been found as far as Annapolis. Oil coatings on the water have their origin from the oil refineries in the upper reaches of the Patapsco River, and from ships emptying their bilge after entering the harbor, and from the effluents from the Bethlehem Steel Company.

With the use of a Sedgwick-Rafter counting cell 1 ml. of plankton concentrate was examined under a magnification of 200 power. Some of the planktonic forms observed are listed in TABLE 16.

For the most part, surface waters did not tend to support more plankton than did the subsurface waters, in general, surface-bottom differences either quantitatively or qualitatively were non existent. This condition was found to exist in the polluted and occasionally in the unpolluted areas of the estuary at all seasons.

Seasonal variations relative to plankton populations, however, were noted. The maximum quantity was observed in spring with a decline as the season progressed, reaching a minimum in late summer. With the advent of autumn, plankton populations appeared to undergo a slight increase. The deeper waters demonstrated similar seasonal variations. Specifically, the algae appeared in greatest numbers in the spring in the headwaters of the river and tributaries where pH values were low or on the acid side. The diatoms, likewise, were found in greatest numbers in the spring and diminished in the summer with a slight rise in autumn. The protozoa were in larger numbers in the spring with slight decrease in population in the summer and fall, although the decrease was not, in most cases, a significant one. Along with the phytoplankton and protozoa, copepods appeared in increased numbers in the spring and diminished as the season progressed. Rotifers appeared to increase in numbers as the summer progressed reaching their maximum concentrations in the fall.

TABLE 17. Offshore and Shore Phosphate-Phosphorus Averages

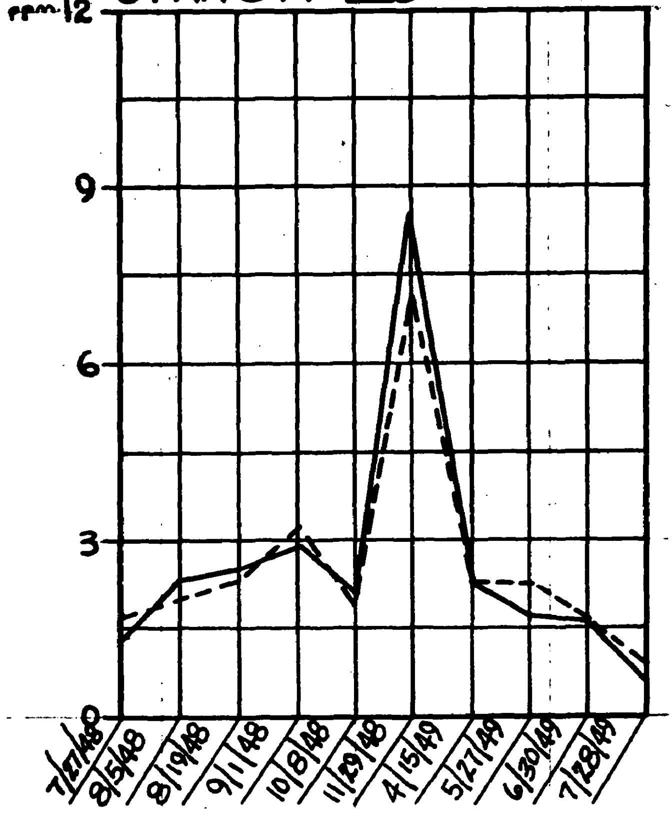
Station	Depth	Concentration p.p.m.	Station	Depth	Concentration p.p.m.
I	Surface	13.06	XI	Depth	8.4
I	Depth	12.87	XII	Surface	8.39
II	Surface	12.64	XII	Depth	7.91
II	Depth	13.06	XIII	Surface	7.48
III	Surface	13.39	XIII	Depth	8.09
III	Depth	12.73	XIIIA	Surface	8.72
IV	Surface	13.01	XIIIA	Depth	8.93
IV	Depth	14.00	XIIIB	Surface	9.05
V	Surface	12.33	XIIIB	Depth	9.04
V	Depth	15.37	XIIIC	Surface	9.36
VA	Surface	13.05	XIIIC	Depth	8.22
VA	Depth	13.49	XIIID	Surface	8.96
VB	Surface	13.1	XIIID	Depth	8.26
VB	Depth	15.3	XIIIE	Surface	10.50
VC	Surface	13.46	XIIIE	Depth	10.30
VC	Depth	15.93	XIIIF	Surface	9.80
VD	Surface	13.20	XIIIF	Depth	14.40
VD	Depth	15.70	XIV	Surface	14.80
VE	Surface	13.30	XIV	Depth	15.38
VE	Depth	15.35	XV	Surface	14.68
VF	Surface	13.03	XV	Depth	15.38
VF	Depth	15.28	1	Surface	10.69
VG	Surface	13.38	2	Surface	10.93
VG	Depth	15.48	3	Surface	9.53
VI	Surface	7.94	4	Surface	9.09
VI	Depth	8.13	5	Surface	8.99
VII	Surface	8.45	6	Surface	7.97
VII	Depth	8.46	7	Surface	9.79
VIII	Surface	8.12	8	Surface	9.37
VIII	Depth	8.22	9	Surface	9.61
IX	Surface	7.93	10	Surface	11.06
IX	Depth	8.80	11	Surface	9.01
X	Surface	8.01	12	Surface	10.17
X	Depth	8.63	13	Surface	9.06
XI	Surface	8.44	14	Surface	9.68

PLATE XV

NITRATE, NITRITE — NITROGEN AND PHOSPHATE

STATION VD

Fig. 1



STATION II

Fig. 2

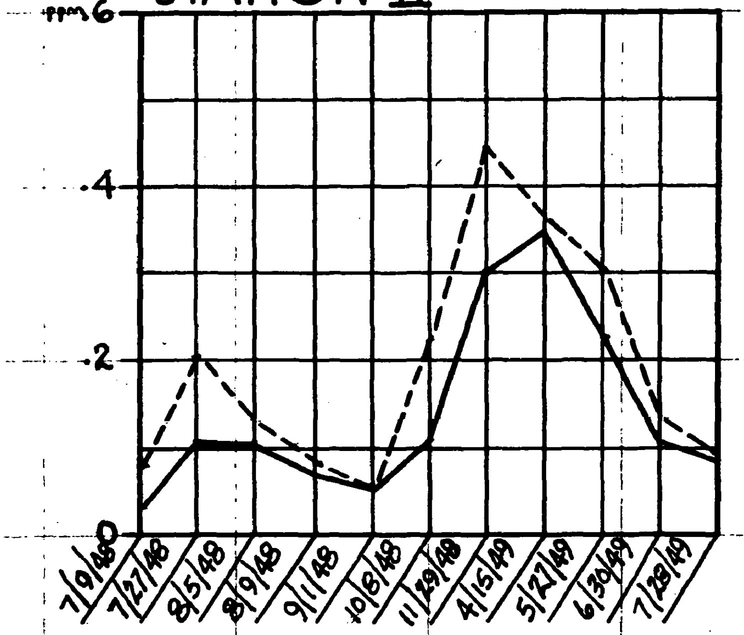
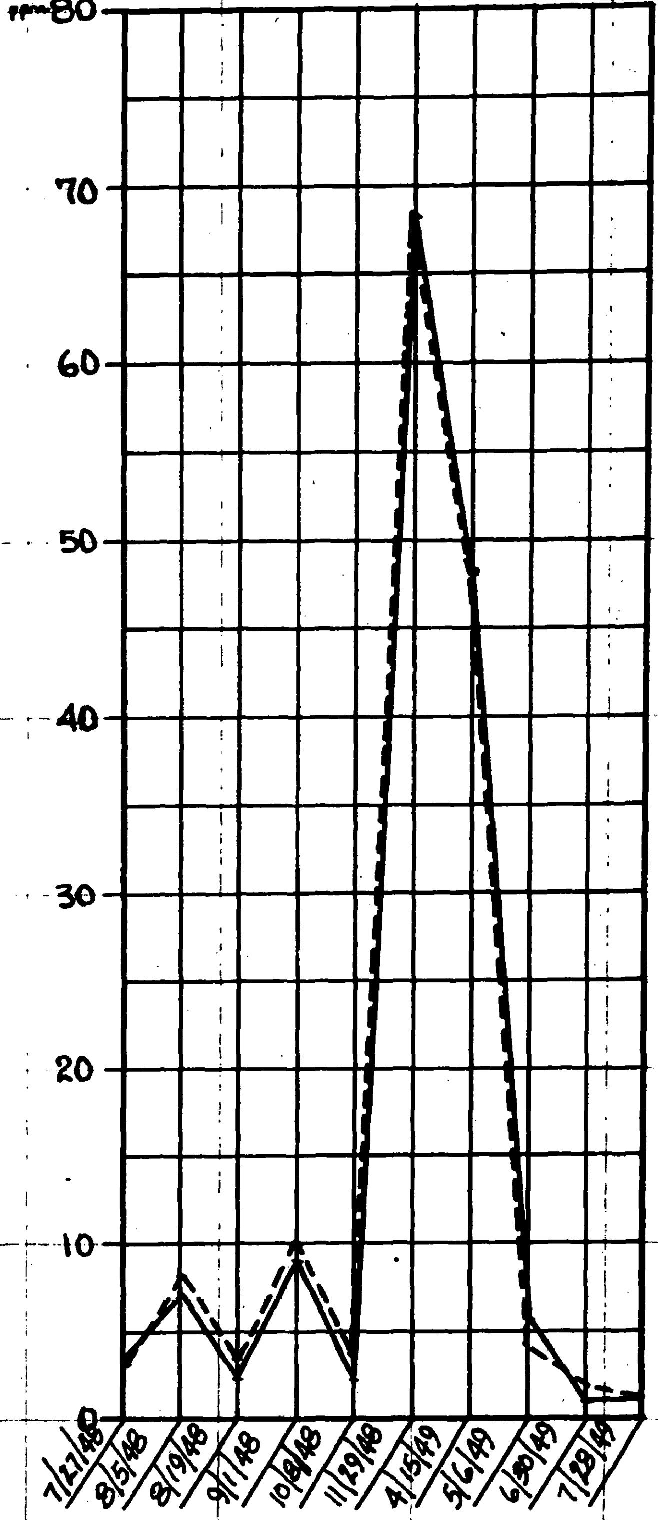


Fig. 3

STATION XIV



SUR. ——	DEPTH - - -	FIG. 1 - NITRATE	FIG. 2 - NITRITE	FIG. 3 PHOS.

It was observed that phytoplankton was the predominant form in spring and that these organisms maintain this numerical supremacy throughout the summer. Of the phytoplantonic forms, algae were for the most part in dominance in the headwaters of the Patapsco River and in Curtis Creek Area. The waters of Curtis Creek were so bountifully supplied with algae that the waters were grass-green. This condition existed from late spring throughout the summer. However, in Bear Creek, the predominant phytoplankters observed were the diatoms. Although algae did exist, identification of the forms in most cases was impossible due to the severe flocculation of iron hydroxide on the forms. Since algal forms favor lowered pH values, one would expect the waters of Curtis Creek to be environmentally more condusive to their growth particularly since the hydrogen-ion concentrations of this region were consistently much lower than other regions investigated. Zooplankton was found to be in the minority in the river and its tributaries throughout most of the year. Of the zooplankton observed, it was noted for the most part, the protozoa and the rotifers were in increased numbers toward the headwaters of the river. Copepods appeared to favor the more saline waters near the mouth waters of the estuary, since they were found in smaller numbers in an upstream direction.

The foregoing was characteristic for the unpolluted waters of the estuarine waters of the Patapsco River. In the polluted regions of the river and the creeks, the condition was quite different. In some instances, certain forms of phytoplankton, namely the algae, were wanting; the diatoms were found in relatively small numbers. In other cases, neither algae nor diatoms were in evidence. In still other cases, neither zooplankton nor phytoplankton were found. Diatoms appeared, in general, to be more resistant to pollution than either the algae or the protozoa (TABLE 19).

It was observed that the diatoms were least affected by low oxgyen concentrations and low pH values. Flocculation of iron appeared to be the conditioning factor for it will be noted that in the Bear Creek area, although concentrations of oxygen, which normally support planktonic growth did exist; a total absence of all forms was observed. Further, in Curtis Creek lowered pH values accompanied by relatively high oxygen concentrations and less severe floc produced some diatom growth. It seems possible that the severity of iron-flocculation, pH values and finally oxygen concentrations are in descending order the factors limiting the growth of diatoms.

Relative to algal growth, it appears that these organisms favor low pH values, but cannot withstand severe flocculation and low oxygen concentrations. This is supported by the condition which existed in Bear Creek where their absence was conspicuous.

The protozoa appeared to be most susceptible to unfavorable environmental conditions. For example, no evidence of the protozoa was encountered in the estuary or tributaries in which oxygen concentrations fell below 4.00 p.p.m. or regions in which the hydrogen-ion concentrations fell pH 4.5. This probably accounts for the absence of these organisms in the Bear Creek region and in parts of the Curtis Creek area and in the northwest branch of the harbor.

With reference to the relative abundance of the various specific plankton-forms, it will be observed from TABLE 18, that most widely distributed diatoms were _Cyclotella comta_, _Cyclotella Meneghiniana_, _Nitzschia palea_ and _Surirella pulchella_. Obviously wide distribution of plankton does not necessitate abundance of that particular form; for it was observed that although certain forms did not demonstrate a wide range of distribution in the estuary; when present, they were observed in abundance (TABLE 18). The foregoing condition was noted relative to all forms of zooplankton and phytoplankton. For example, Chorella variegata was observed in such tremendous quantities in the Curtis Creek area that it imparted a vivid green color to the water in that region, while in other regions of the estuary they were found to be very scarce or wanting.

The copepods were found in various stages of development at almost all of the stations. Their quantity varying from very scarce to very abundant, depending upon the locality. This is likewise true of the rotifers.

TABLE 18 Plankton-Forms and Relative Abundance Observed

Forms	No. Stations	Abundance
Diatoms [1]		
Achnanthes affinis Grun	1	*
Amphiprora paludosa W. Sm.	3	*
Amphora acutiuscula Ktz.	1	*
Amphora coffaeiformis (Ag.) Ktz.	3	**
Amphora ovalis Ktz.	3	*
Chaetoceros subtilis Cleve.	5	**
Chaetoceros sp.	2	*
Cocconeis diminuta Pant.	2	**
Cyclotella comta (Ehr.) Ktz.	10	****
Cyclotella glomerata Bachmann.	1	*
Cyclotella melosiroides (Kirch.) Lemm.	1	*
Cyclotella Meneghiniana Ktz.	16	*****
Cyclotella planktonica Brunnthaler	1	**
Cyclotella quadriiuncta Schrot	5	*****
Cyclotella sp.	7	**
Cyclotella striata (Ktz.) Grun	4	**
Cymbella affinis Ktz.	1	*
Cymbella sp.	2	**
Cymbella ventricosa Ktz.	1	*
Cymbella cistula (Hempr.) Grun.	1	*
Frustulia rhomboides (Ehr.) De Toni	1	*
Frustulia saxonica Rabenh.	1	*
Gomphonema olivaceum (Lyngb.) Ktz.	1	*
Hantzschia amphioxys (Ehr.) Ktz.	1	*
Melosira Borrerii Grev.	1	*
Melosira italica (Ehr.) Ktz.	1	*
Melosira moniliformes Ag.	2	**
Melosira nummuloides (Dillw.) C.A. Ag.	2	**
Melosira octogona A.S. (M. Heribaudii Brun)	1	*
Melosira sp.	1	*
Navicula ambigua Ehr.	2	**
Navicula cryptocephala Ktz.	1	*
Navicula elliptica Ktz.	2	**
Navicula (Diploneis) interrupta Ktz.	1	*
Navicula lanceolata (Ag.) Ktz.	1	*
Navicula peregrina (Ehr.) Ktz.	4	*****
Navicula sp.	6	*

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[1] Identifications by Paul S. Conger

***** - very abundant
**** - abundant
*** - average
** - scarace
* - very scarace

TABLE 18 Continued Plankton-Forms and Relative Abundance Observed

Forms	No. Stations	Abundance
Diatoms continued [1]		
Navicula viridis (Nitzsch) Ktz.	2	**
Nitzschia filiformis (W. Sm.) Hust.	2	**
Nitzschia Kutzingiana Hilse	1	*
Nitzschia obtusa W. Sm.	4	***
Nitzschia palea (Ktz.) W. Sm.	16	*****
Nitzschia (Bacillaria) *paradoxa* (Gmel.)	1	*
Nitzschia parvula Lewis	1	**
Nitzschia scalaris (Ehr.) W. Sm.	1	*
Nitzschia sigmoidea (Ehr.) W. Sm.	8	*****
Nitzschia sp.	3	***
Nitzschia Tryblionella Hantzsch var.	1	*
Nitzschia Tryblionella var. salinarum Grun.	1	*
Nitzschia vermicularis (Ktz.) Hantzsch	1	**
Pleurosigma sp.	2	**
Pleurosigma Spencerii	2	*
Rhoicosphaenia curvata (Ktz.) Grun	1	**
Skeletonema costatum (Grev.) Cl.	1	*
Stauroneis Spicula Hickie	2	**
Surirella angusta Ktz.	1	**
Surirella Gemma Ehr.	1	*
Surirella linearis W. Sm.	1	**
Surirella ovalis Breb	1	*
Surirella ovata Ktz.	2	*
Surirella suevica Zell	1	*
Surirella tenera Greg.	1	*
Synedra pulchella Ktz.	13	*****
Synedra sp.	4	*
Synedra Ulna (Nitzsch) Ehr.	4	**
Thalassiosira condensata Cl.	1	*
Chlorophyceae [2]		
Carteria sp.	5	**
Chalamydomas sp.	8	**
Chorella variegata	12	*****
Ankistrodesmus sp.	3	*

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1 Identification by Paul S. Conger
2 Identification by Robert A. Littleford

TABLE 18 Continued Plankton-Forms and Relative Abundance Observed

Forms	No Stations	Abundance
Chrysophyceae [1]		
Chrysococcus cinctus	4	*
Chrysococcus rufescens	5	*
Dinobryon	8	*
Cryptophyceae		
Cryptomonas sp.	10	****
Rhodomonas lacustrus	7	**
Dinoflagellates		
Amphidinium sp.	3	**
Gymnodinium gracilis	2	*
Noctiluca miliaris	2	*
Noctiluca sp.	1	*
Peridinium sp.	10	*****
Prorocentrum micans	7	**
Prorocentrum triangulatum	4	*
Euglenophyceae		
Trachelomonas eurystoma	9	*
Trachelomonas volvocina	5	**
Flagellates		
Domatomonas cylindrica	4	*
Ciliates		
Cyclidium sp.	5	*
Mesodinium sp.	8	*
Paramecium caudatum	3	**
Strobilidium humile	7	*
Strobilidium sp.	4	*
Tintinnidium fluviatile	1	*
Urotricha farcta	7	*

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[1] Identification by Robert A. Littleford

TABLE 18 Continued Plankton-Forms and Relative Abundance Observed

Forms	No. Stations	Abundance
Copepoda[1]		
Cyclops vernalis, Fischer	2	**
Cyclops sp.	1	**
Cyclops sp.	20	*****
Copepod nauplius	2	***
Eurytemora sp.	14	****
Eurytemora sp.	7	**
Eurytemora affinis	1	**
Nauplii sp.	1	*
Cladocera	3	****
Rotifers	8	**

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[1] Identifications by Paul L. Illg

TABLE 19. Relation Between Certain Physical and Chemical Factors and Plankton

Station No.	Temp.	pH	Oil	O_2 p.p.m.	Total Fe p.p.m.	Algae	Copepoda	Diatoms	Protozoa
Is	21.0	9.2	***	7.67	.16	—	—	—	—
Id	21.0	7.4	—	6.77	.10	—	*	—	—
IIs	22.5	6.8	***	7.72	.10	—	—	—	—
IId	21.5	6.9	—	7.72	.10	—	*	*	—
IIIs	22.0	7.1	***	7.84	.07	—	*	*	—
IIId	22.5	7.1	—	6.27	.08	—	—	*	—
IVs	22.0	7.2	—	5.71	.09	*	*	*	—
IVd	22.5	7.1	—	5.49	.04	***	*	***	*
Vs	22.5	7.4	***	6.33	.08	—	****	*	—
Vd	23.0	7.4	—	6.38	.09	—	*	—	—
VAs	23.0	4.1	***	7.28	[illegible]	—	*	—	—
VAd	22.0	6.8	—	3.47	.14	—	*	—	—
VBs	22.0	3.9	**	6.05	.30	—	**	—	—
VBd	23.0	6.6	—	5.60	.21	—	*	—	—
VCs	23.0	4.6	**	5.93	.23	—	—	—	—
VCd	23.0	4.6	—	3.36	.13	—	**	—	—
VDs	22.0	5.4	**	7.05	.07	—	**	—	—
VDd	22.5	6.3	—	6.94	.14	—	**	*	—
VEs	22.5	4.8	**	5.93	.17	—	**	—	—
VEd	22.5	6.5	—	2.85	.21	—	—	*	—
VFs	22.5	6.7	—	7.84	.12	—	—	*	—
VFd	22.2	6.9	—	4.37	.08	—	**	*	—
VGs	22.5	6.8	—	7.61	.08	—	—	**	—
VGd	22.2	6.7	—	3.08	.07	—	—	*	—

***** - very abundant

**** - abundant

*** - average

** - scarace

* - very scarace

— - wanting

TABLE 19. Continued Relation Between Certain Physical and Chemical Factors and Plankton

Station No.	Temp.	pH	Oil	O_2 p.p.m.	Total Fe p.p.m.	Algae	Copepods	Diatoms	Protozoa
VIs	22.0	7.4	—	7.72	.07	—	**	**	—
VId	23.8	7.4	—	7.16	.07	—	*	**	—
VIIs	22.0	7.7	—	5.32	.13	***	*	—	***
VIId	22.0	7.6	—	4.98	.14	**	*	*	****
VIIIs	22.0	6.8	—	4.03	.13	****	*	**	****
VIIId	21.5	7.3	—	4.09	.10	****	—	**	****
IXs	22.0	7.3	—	4.59	.10	**	—	**	**
IXd	21.5	7.5	—	5.65	.10	***	*	*	**
Xs	22.1	7.6	—	4.70	.14	*	—	*	*
Xd	22.5	7.6	—	4.31	.14	—	*	**	—
XIs	22.5	7.6	—	4.48	.07	*	—	****	—
XId	22.0	7.3	—	3.96	.07	*	—	****	—
XIIs	23.0	7.2	—	5.32	.05	*	—	****	—
XIId	22.0	7.0	—	4.09	.05	*	—	**	—
XIIIs	22.5	6.1	—	6.72	.20	*	—	**	—
XIIId	22.2	6.4	—	5.82	.20	—	***	—	—
XIIIAs	23.0	6.0	—	5.88	.30	****	****	*	—
XIIIAd	23.5	6.2	—	5.15	.21	****	—	—	—
XIIIBs	23.0	3.8	—	8.62	.31	****	**	—	—
XIIIBd	22.0	4.0	—	5.04	.25	****	—	*	—
XIIICs	24.0	3.8	—	8.12	.43	****	*	****	—
XIIICd	23.0	3.7	—	7.72	.30	****	*	*	—
XIIIDs	24.0	3.8	—	8.51	.48	****	*	*	—
XIIIDd	22.0	3.4	—	4.42	.78	****	*	*	—
XIIIEs	25.0	3.9	—	7.33	.31	****	*	*	—

TABLE 19. Continued Relation Between Certain Physical and Chemical Factors and Plankton

Station No.	Temp,	pH	Oil	O_2 p.p.m.	Total Fe p.p.m.	Algae	Copepods	Diatoms	Protozoa
XIIIRd	23.5	3.5	—	7.11	.59	****	*	*	—
XIIIFs	24.0	3.8	—	8.56	.47	****	*	*	—
XIIIFd	23.5	3.8	—	8.40	.39	****	*	—	—
XIVs	22.5	6.7	***	3.96	.07	*	*	—	—
XIVd	22.0	7.0	—	3.58	.07	*	*	****	—
XVs	22.0	7.1	**	5.15	.10	—	*	**	—
XVd	22.0	7.0	—	5.04	.20	*	****	****	—
1	15.2	6.8	****	0.67	.39	—	*	*	—
2	15.0	6.9	**	1.01	.25	—	*	—	—
3	14.4	7.1	*	3.25	.16	—	*	*	—
4	14.9	2.9	***	3.08	9.20	—	—	—	—
5	14.7	5.8	***	4.93	.35	*	**	*	—
6	14.2	4.0	****	3.92	.52	—	*	—	—
7	13.7	7.1	***	3.64	.16	—	*	*	—
8	14.3	7.2	*	3.25	.21	*	*	**	—
9	14.1	6.7	*	3.25	.58	—	*	*	—
10	14.8	0.6	**	2.91	.21	*	*	****	—
11	15.0	7.2	***	3.64	.12	*	*	*	—
12	14.7	7.2	**	4.59	.18	*	**	****	—
13	14.6	7.0	**	5.88	.16	*	*	*	—
14	14.6	6.2	—	5.43	.30	*	*	****	—

CHAPTER IV

DISCUSSION

From the preceding chapter it is apparent that the results varied seasonally from station to station relative to the physical and chemical factors investigated. A discussion of the factors and their interaction follows:

Temperature. The temperature characteristics of the Patapsco River and its tributaries are not unlike those of other estuarine waters of this geographic area. The lower temperatures appeared in January and February with a gradual increase reaching a maximum in July. The lowest temperature recorded in this study was 7.0°C for both surface and bottom waters while the highest temperature recorded was 32.0°C for the surface and 33.0°C for the deeper waters.

Marked temperature stratification was observed at the stations where deeper waters prevailed, while stratification at the shallower stations was slight or wanting. The surface-bottom varient did not exceed 3.0°C and expectedly, the deeper waters demonstrated this difference to a greater degree than did shallower waters. Similar results were obtained by Cowles,[1] Newcombe, Horne and Shepherd,[2] Newcombe & Lang,[3]

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[1] R.P. Cowles, "A Biological Study of the Offshore Waters of the Chesapeake Bay", U.S. Dept. of Commerce, Bur. Fish. Bull. XLVI, #1091: 278-381, 1930.

[2] C.L. Newcombe, W. Horne and B. Shepherd, "Studies on the Physics & Chemistry of Estuarine Waters in Chesapeake Bay" Jour. Mar. Research. II#2:87-116, 1939.

[3] C. Newcombe & A. Lang, "Distribution of Phosphates in Chesapeake Bay" Proceedings of American Philosophical Soc. 81,#3:393-420, 1939.

and Nash.[1]

The surface water temperatures vacillated with fluctuations of atmospheric temperatures, the former exhibiting a lagging effect. The mean atmospheric temperature was observed, in general, to be higher than that of the surface water in summer and lower in winter. It might be significant to note at this point that the summer of 1948 was atypical in that unseasonably low temperatures prevailed with large amounts of precipitation.

As previously mentioned (page 59), marked temperature differences between the polluted and non polluted areas investigated were not encountered.

<u>Hydrogen-ion Concentration</u>. The pH of the waters of the Patapsco River showed a wide variation ranging from very acid waters in the Bear Creek and Curtis Creek area to the characteristic alkaline waters at the mouth of the river. The low pH values of the waters of Colgate Creek are a result of the waste products from the Glidden Chemical and Pigment Co. The Glidden Chemical and Pigment Company is a manufacturer of white paint. In the process of its manufacture titanium dioxide is obtained from ferrous titanate ($FeTiO_3$), ilmenite sand. The extraction is accomplished by the use of sulfuric acid which removes the iron from the ilmenite, forming ferrous sulphate. The hydrolysis of the latter results in a drop of pH. This same condition is paralleled in Curtis Creek by the copperas disposed by the Krebs pigment plant. The discharge of the

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[1] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Laboratory Publication #64:147-174, December, 1947.

unclaimed free acids in the manufacturing process may be considered as the second factor responsible for low hydrogen-ion concentrations in these waters.

It was observed that, on an average, the pH values for the surface waters in the Curtis Creek area appeared to be somewhat higher than that of the deeper waters. For example, the average pH for the surface was 3.99 while that for the deeper waters was 3.79. This condition was not foand to be characteristic for the Bear Creek area. In the latter, the pH values were in reverse to that found in Curtis Creek. The surface waters appeared to be more acid than those of the bottom, having hydrogen-ion values of pH 5.28 and pH 5.60 respectively. The Bear Creek condition can probably be explained on the basis that the acid waters have their origin in Humphreys Creek into which the pickling liquors from the Bethlehem Steel Company are emptied. The lighter less saline waters (2.6 p.p.t.) of Humphreys Creek tend to flow over the denser, more saline waters of Bear Creek (3.39 p.p.t. for surface and 3.64 p.p.t. for bottom).

Seasonal variation relative to hydrogen-ion concentration was not in strong evidence. This does not seem unlikely since the effluents are emptied into these polluted areas throughout the entire year. It will be noted, however, that the pH values at Station IX remain more or less constant, ranging from pH 7.0- pH 7.9 for the surface and 7.2 to 8.0 for the bottom. It was observed that the bottom values were in general, greater and never less than the concentrations of the surface waters.

A comparison of the surface-bottom values reveals a fluctuation which appears to be more marked for the bottom waters. It might be concluded that in the unpolluted areas of the Patapsco River, a significant difference in hydrogen-ion concentration was noted neither relative to stratification nor to seasonal variation even though the pH values, though slight, were higher from late summer through the winter. This is in agreement with the studies of Brust and Newcombe,[1] Olson, Brust and Tressler,[2] and Nash.[3]

Points of view relative to the effect of pH on plants and animals in an aquatic environment are varied. Daily[4] is of the opinion that pH exerts little if any influence on the seasonal periodicity of phytoplankton. Hutchinson[5] questions the effect of pH on the population of any specie. However, he excluded ciliates in saprobiotic environments. Hiestand and Hale[6] maintain that oxygen-consumption of gastropod molluscs

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[1] H. F. Brust and C. L. Newcombe, "Observations on the Alkalinity of Estuarine Waters of the Chesapeake Bay Near Solomons Island, Maryland," Jour. Mar. Res. III, #2, 1940.

[2] R. A. Olson, H. F. Brust and W. L. Tressler, "Studies of Effects of Indust. Pollution in Lower Patapsco River Area", Ches. Biolog. Lab. Pub. #43:1040, November, 1941

[3] C. B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Laboratory Publication #64:147-174, December, 1947.

[4] W. A. Daily, "A Quantitative Study of the Phytoplankton of Lake Michigan Collected in the Vicinity of Evanston, Illinois", Butler University Botanical Studies. 4(6), 1938.

[5] G. E. Hutchinson, "Ecological Aspects of Succession in Natural Populations", The American Naturalist, LXXV: 406-418, 1941.

[6] W. A. Hiestand and D. M. Hale, "Respiration Studies with Fresh-water Molluscs: II Oxygen Consumption in Relation to Hydrogen-ion Concentration", Proc. Indiana Academy of Science, 47:293-298, 1938.

is proportionate to the hydrogen-ion concentration. Similar results were obtained by Hyman[1] with planaria. Hall[2] noted that oxygen consumption of puffer fish was checked by increasing the pH.

Salinity. The salinity-pattern of the Patapsco River follows the same general pattern as that for other estuarine waters. It was observed that the head waters of the Patapsco River were less saline than the waters at the mouth and that the deeper waters were more concentrated than the surface waters. This is in agreement with the work of Wells, Bailey and Henderson[3] and Cowles[4].

Stratification was found both at the shallower stations as well as the deeper water stations, although the surface-bottom differential of the former was for the most part, less pronounced than that of the latter. It was further observed that precipitation had an appreciable effect on the salinity, diluting the surface concentrations. As previously mentioned, the concentrations for this factor would have probably been markedly different had not the year during which this study was conducted, been so bountifully supplied with rain.

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[1] L.H. Hyman, "On the Action of Certain Substances on Oxygen Consumption: VI. The action of Acids", Biol. Bull. 49:288-322, 1925.

[2] F.G. Hall, "The Ability of Common Mackeral and Certain Other Marine Fishes to Remove Dissolved Oxygen from Sea Water". Amer. Jour. Phys. 93:417-421, 1930.

[3] R.C. Wells, R.K. Bailey, & E.P. Henderson, "Salinity of the Water of Chesapeake Bay". Department of the Interior, U.S. Geol. Surv., Professional Paper 145-C:105-152, 1929.

[4] H.F. Cowles, "A Biological Study of the Offshore Waters of Chesapeake Bay", U.S.D.I. Bur. of Fisheries Bull. 1019:278-381, 1930.

Seasonal variations were not in evidence at the head of the Patapsco River, while at the mouth; the lower concentrations were found to occur in winter with a gradual increase in spring reaching the highest concentration in the fall. Similar results have been recorded in the works of Newcombe, Horne, & Shepherd[1], Newcombe and Lang[2], and Nash[3].

Olson, Brust and Tressler[4] found insignificant differences in the salinities of the waters of Curtis Creek. This is not in agreement with the results of this study. The salinities for the stations in Curtis Creek demonstrated a wider range than many of the other stations. For example, the salinity for Bear Creek and its tributaries averaged 3.39 p.p.t. for the surface and 3.64 p.p.t. for the bottom waters, while that of Curtis Creek averaged 2.93 p.p.t. for the surface and 3.40 p.p.t. for the bottom. Although the overall average salinity of Curtis Creek was found to be less than that of Bear Creek, the range and surface-bottom differential was by far the greater in the former. In the case of the latter, the range of difference was found to be from 0.00 to 4.35 p.p.t., with an average difference of 0.37 p.p.t.

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[1] C. Newcombe, W. Horne and B. Shepherd, "Studies on Physics & Chem. of Estuarine Waters in the Chesapeake Bay". Journal Mar. Research II#2:87-116, 1939.

[2] C. Newcombe & A. Lang, 81,#3:393-420,1939, "Distribution of Phos.in Chesapeake Bay". Proceedings of the American Philosophical Society.

[3] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab., Pub.#64:147-174, Dec. 1947.

[4] R.A. Olsen, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biological Laboratory Publication #43:1-40, November, 1941.

In conclusion, it might be stated that the wide variation in the salinity of the estuarine waters of the Patapsco River is a result of the combined effects of tides, precipitation, convection currents, influx of less saline waters from the tributaries and vernal and autumnal circulation all working more or less independently.

Oxygen. In the unpolluted areas of the Patapsco River, this factor possesses the same characteristics of other typical bodies of water. Seasonal variation of oxygen concentrations was observed for both the surface and bottom waters. These variations are in conformity with those of other investigators. According to Nash[1], the values for this factor in the Patuxent River were also noted to vary on the surface as well as in the deeper waters. A decrease in concentration was noted beginning in March, attaining the lowest value in August. This was, likewise, observed in this study. In the Chesapeake Bay, seasonal variations comparable to those shown here were reported by Newcombe and Horne[2] & Newcombe, Horne and Shepherd.[3]

The foregoing investigators also found definite oxygen stratification in the Patuxent River and Chesapeake Bay respectively. In the latter

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[1] C.B. Nash, "Environmental Characteristics of a River Estuary", - Chesapeake Biological Laboratory Publication #64;147-174, Dec. 1947.

[2] C. Newcombe and W. Horne, "Oxygen Poor Waters of the Chesapeake Bay." Science, 88,#2273:80-81, 1938.

[3] C. Newcombe, W. Horne and B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in the Chesapeake Bay." Journal Marine Research, II#2:87-116, 1939.

body of water, Newcombe and others are of the opinion that stratification tended to become imperceptible in upstream areas. This condition was neither observed in the estuarine waters of the Patuxent investigated by Nash[1], nor in the present study of the Patapsco; although a difference in the surface-bottom varient was observed proportionate to the depth of the water from which the sample was collected. It is probable that the greater differences of the surface-bottom oxygen concentrations reported for the Chesapeake Bay then those observed in the estuaries are a result of greater density stratification of the bay waters. This greater density stratification in the Chesapeake Bay waters may account for the severer depletion of oxygen in the deeper waters during the summer months.

In the polluted areas of the Patapsco River and its tributaries, which comprises by far the greater part of the estuary; conditions are quite different. Concentrations of low value prevailed during most of the year throughout the Bear Creek and the Curtis Creek regions. The lowest values were observed to have occured in the summer. This is probably due to the combined effects of high temperatures coupled with low pH concentrations. The latter appears to make the situation even more acute. The condition of oxygen deficiency, whether a result of lowered temperatures, or to low hydrogen-ion concentration resulting from industrial pollutants or to the combined effects of the two, still makes the environment unfit for aquatic life. Oxygen consumption was observed by Hall[2],

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[1] C.B. Nash, "Environmental Characteristics of a River Estuary", - Chesapeake Biological Laboratory Publication #64;147-174, Dec. 1947.

[2] F.G. Hall, "The Influence of Varying Oxygen Tension Upon the Rate of Oxygen Consumption in Marine Fishes". Am. Jour.Physiol., 88:212-218 1929.

to be greatly increased by high temperatures and retarded by an increase in hydrogen-ion concentration. Ellis[1] has demonstrated that oxygen-poor environments (4.0 to 3.5 c.c./l.) either dangerously weakened or completely stopped vital physiological activities of most aquatic organisms. Environments thus become established which are conducive for the growth and maintenance of facultative and obligatory anaerobic forms. Experiments conducted by Kitchling[2] on paramecia revealed that those organisms placed in anaerobic environments for only short periods of time recovered. However, with prolonged periods of oxygen deficiency, the paramecia suffered blistering, cytolysis and cessation of vital activities.

Fish in the polluted areas of Grays Harbor, exhibited the same physiological reactions or comparable reactions to those fish in the laboratory which died from oxygen deficiency (Towsend)[3].

In the Curtis Creek area, critically low concentrations of oxygen were found by Olson[4]. The oxygen-poor waters were a result of copperas disposal. This situation is still manifested in this area as substantiated by the present research. The oxygen-poor waters of Bear Creek and

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[1] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fisheries. XLVII:65-437, 1937.

[2] J.A. Kitchling, "The Effects of a Lack of Oxygen and of Low Oxygen on Paramecium", Biol. Bull. LXXVII:339-353, 1939.

[3] L.D. Towsend, A. Erickson and D. Earnest "Progress Report on Field Investigations and Research", Wash. State Pollution Commission, December, 1938.

[4] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biological Laboratory Publication #43:1-40, November, 1941.

its tributaries and by Colgate Creek, likewise, are due to the influence of industrial pollution.

At other stations in the Patapsco River, life-conditioning oxygen concentrations result from fertilizer products and refuse oil. In the case of the oil, a thin film of this was found covering all of the shore stations and most of the stations at the upper reaches of the harbor. Aggravating the condition of oxygen depletion, in the head waters of the Patapsco along the northwest shore, in addition to the aforementioned factors, is one which results from the decomposition of vegetable wastes from the canning factories in this region. Truitt[1] in an Annual Report of the Chesapeake Biological Laboratory reported a similar situation in the Pocomoke River:

> "---- the Pocomoke River was investigated with regard to pollution by decomposing organic matter from tomato cannery waste. The effects produced by rapid decomposition of this material were indicated by abnormally low dissolved oxygen concentration and low pH values that were prevalent in the region extending from the source at Pocomoke City to points some distance downstream".

Although detrimentally low values of dissolved oxygen do not normally extend beyond the mouths of Bear Creek and Curtis Creek, it was observed that on several occasions these characteristically poor concentrations prevailed to Station VII and Station VIII, at the mouth of the Patapsco river.

<u>Carbon dioxide</u>. As stated in the results (page 74), the chemical factor exhibiting the widest range in concentration was carbon dioxide. On a whole, the range of the surface water concentration appeared to be

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[1] R. Truitt, "Annual Report", Chesapeake Biological Laboratory, #47, 1942.

wider than that of the deeper water, with the lower limits of both being the same and the upper limits differing by 2.27 c.c./l. In the case of the shore samples, the range was narrower. The seasonal variation of this factor follows a general pattern-high concentrations in spring, diminishing with the advent of summer reaching the lowest value in autumn. Stratification of carbon dioxide although evidenced in the unpolluted areas, was not observed in Bear Creek and Curtis Creek. In many instances not only were the concentrations of the deeper waters equal to the surface, but they at times exceeded the surface limits.

Silicate-silicon. The head waters of the Patapsco River and its tributaries contain higher values of silicate-silicon than do the more saline waters of the mouth of the river. The surface waters in the upper reaches of the river were approximately 46 per cent more concentrated than those at Station VIII and Station IX, Millers Island range lighthouse and Seven Foot Knoll respectively.

Although high values existed more or less at all times of the year at the stations near the mouth of the Patapsco River, the summer values were highest with lowered concentrations in spring and fall. Waters of stations located upstream were more concentrated in spring and decreased in value in summer. The estuarine waters exhibited this characteristic for both surface and bottom waters.

The silicate concentrations in the Patuxent River were found by Nash[1] to decrease in the lower reaches of the river. The surface waters of the Patuxent River averaged 13 per cent higher than the deeper waters.

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[1] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biological Lab. Pub. #64:147-174, December, 1947.

The greater concentrations of silicon in the surface waters result from the less saline head waters traveling downstream over the denser more saline waters of the Chesapeake Bay which travels upstream. Because of this phenomenon, Nash is of the opinion that silicate-silicon concentrations may be indicative of salinity. The present study tends to denote a similar condition.

The higher silicate values when obtained for the surface waters in the polluted waters of Bear Creek, Curtis Creek and the Northwest Branch of the estuary not only discloses the influx of fresh water from the tributaries, but probably and more significantly it indicates poor diatom-productivity. In some instances the silicate values were higher for the bottom than for the surface waters.

The surface-bottom differential of silicate-silicon varied from 0.0 g./l. to 0;0489 g./l. The greater differences were found to occur, for the most part, at the stations more proximally located to the Chesapeake Bay and at those stations where the depths were appreciable. Likewise, on the other hand, the absence of stratification and a difference between surface and bottom concentrations were generally observed in the shallower waters or seasonally at the time of vertical mixing. The greater differences were noted in the summer and winter.

Ferrous iron. One of the most important effluents resulting from industrial pollution of iron and steel mills and certain types of pigment manufacturing is ferrous sulfate $(FeSO_4.7H_2O)$ or copperas. The quantitative values of copperas are indicative of the degree of pollution and the oxygen-engaging power of the water. Copperas concentrations were greatest at the point of disposal and diminished proportionately from the site of origin.

The effluent was observed in Colgate Creek, Humphreys Creek, Bear Creek and Curtis Creek. Truitt[1] in the Annual Report of the Chesapeake Biological Laboratory, stated that pollution resulting from this effluent was not severe. However, in the Annual Report of the following year (Truitt-1940)[2], copperas was considered as the most serious pollutant of the Patapsco River. As a result of the latter investigation, Truitt concluded that the adherence of the floc to the plantonic forms, forced them to precipitate with the "salting out" of ferric hydroxide. He further noted that the injury suffered by fish was a result of the deposition of the floc on the gill lamellae. The injurious effects of ferrous sulphate were reported by Weigelt[3] on trout and California salmon. This investigation concluded that copperas in concentrations of 2,721 p.p.m. were fatal to these aquatic organisms. Concentrations higher than these have been observed in the estuarine waters investigated and it has been established by this study and those conducted by Truitt[4] and Olson, Brust and Tressler[5] that this effluent remains in this condition for a

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[1] R. Truitt, "Annual Report", Chesapeake Biological Lab., #34, 1939.

[2] R. Truitt, "Annual Report", Chesapeake Biological Laboratory, #40, (Laboratory Series), 1940.

[3] C. Weigelt, O. Saare and L. Schwale, "Des chadegung von Freacherei and Fischauucht durch Industrie and Mans Avervasser", Archev. Fur Hugiene, 3:39-117, 1885.

[4] R. Truitt, "Annual Report", Ches. Biological Laboratory, #40 (Laboratory Series), 1940

[5] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biological Laboratory Pub. #43:1-40, November, 1941.

considerable length of time before oxidizing.

The work of Clark and Adams[1] on carp, shiners and suckers clearly revealed that concentrations of 2.9 p.p.m. in distilled water was sufficiently concentrated to be toxic to these animals. Carpenter[2], who conducted research on the minnow, *Leuciscus phoxinus* noted that copperas in concentrations of 315 parts per million in distilled water was lethal in three hours.

Goldfish, *Crassius auratus*, were found by Ellis[3] to be killed in two to ten hours when placed in ferrous sulphate solutions of one-thousand parts per million. However, in hard water these fish were capable of surviving in concentrations of 100 parts per million for ninety-six hours without delitorious effects. The lethal action of pollutants has been considered by Ellis to be of two general types: (1) external action by a combination of chemical and physical injuries, and (2) internal action or true toxic action.

Littleford[4] whose research was conducted on the four-spined stickleback, *Apeltes quadracus*, concluded that at a temperature of 24.0°C. any concentration of copperas in excess of 1,000 parts per million was toxic

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[1] M. Clark and G. Adams, "Studies of Fishlife and Water Pollution", Forty-fourth Annual Report of the State Bd. of Hea. Mass., Pub. Doc. #34,6:336-345, 1913.

[2] K. Carpenter, "The Lethal Action of Soluble Metallic Salts on Fishes", British Jour. Exp. Biol., 4:378-390, 1927.

[3] M. Ellis, "Detection and Measurement of Stream Pollution", Bull. U.S. Bureau of Fish, XLVII:65-437, 1937.

[4] R. Littleford, "Survival of Four-Spined Stickleback, *Apeltes quadracus*, in Copperas Dilutions", Unpublished.

in less than two days. Only eight per cent survived a concentration of 1,000 parts per million at the end of twenty-four hours, three per cent survived 660 parts per million for five days, five per cent survived 500 parts per million for nine days, thirty-six per cent survived 200 parts per million for fifteen days, sixty-nine per cent survived 150 parts per million for fifteen days and 125 parts per million was not toxic. It was found that a decrease in temperature resulted in a decrease in the toxicity of copperas. Thirty- per cent survived a concentration of 20,000 parts per million for eight hours, twenty-nine per cent survived 10,000 parts per million for sixteen hours, thirty-four per cent survived 2,000 parts per million for twenty-four hours, while forty-six per cent survived 1,000 parts per million for fifteen days. At the same temperature, eighty per cent survived 660 parts per million fifteen days and 500 parts per million was found to be non toxic over the fifteen day period.

The presence of copperas in aquatic environments presents a triangle of injurious effects disrupting the ecological balance of the habitat. In the process of oxidation, the oxygen necessary for the respiratory requirements of the organisms is used and simultaneously, a lowering of the hydrogen-ion concentration occurs which, independently of other factors may prove lethal particularly at higher temperatures. The opinion relative to the mode of toxicity of copperas has been varied. Kitchling[1] noted that paramecia subjected to anaerobic conditions for prolonged periods of time in waters of low pH suffered physiological

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[1] J.A. Kitchling, "The Effects of a Lack of Oxygen and of Low Oxygen on Paramecium", Biol. Bull. LXXVII:339-353, 1939.

disturbances and subsequently death ensued. However, under conditions of normal pH, longevity was increased despite decreased oxygen concentrations. Littleford[1] is of the opinion that toxicity of copperas is a result of lowered pH and that a decrease in dissolved oxygen had little immediate effect of the fish observed. Towsand[2] on the other hand, reported the fish-kill was attributed to lack of oxygen impeding normal respiratory functions. Olson[3] reported that the effect of oxygen poor environments on protozoa, eggs and larvae is in all cases severe. It was observed that algae were for the most part affected to a lesser degree than diatoms by lowered pH.

On the basis of this study, it is probably not the result of any one factor, _per se_, that acts as a conditioning factor for plankton productivity, but the coordinate interaction of all three, oxygen deficiency, pH and flocculation. The latter will be discussed subsequently. It will be noted from TABLE 3 and TABLE 4 that the pH values of Bear Creek were not consistently low, while those of Curtis Creek were. On the other hand, oxygen values were consistently lower in Bear Creek than in Curtis Creek (TABLE 7). Colgate Creek and Humphreys Creek manifested correspondingly low concentrations in both factors pH and oxygen. It appears

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[1] R. Littleford, "Survival of Four-Spined Stickleback, _Apeltes quadracus_, in Copperas Dilutions", Unpublished.

[2] L.D. Towsand, A. Ericksen and D. Earnest, "Progress Report on Field Investigations and Research", Wash. State Pollution Commission, December, 1938.

[3] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biological Laboratory Publication #43:1-40, November 1941.

then that the low pH values in Curtis Creek act as a limiting factor, while in Bear Creek, the conditioning factor was oxygen depletion. Further, the absence of plantonic organism at some of the shore stations and the offshore stations in the upper reaches of the harbor may be attributed to the presence of oil and grease coating the water and reducing the supply of oxygen. The action of the decomposing vegetable wastes from the canneries increased the oxygen deficits already existing at those stations.

Of equal importance as a factor of pollution, is the flocculation and settling out of ferric hydroxide. Colloidal ferric hydroxide particles possess the characteristic of bearing a charge, which within the acid range is positive. Planktera, likewise, fall within this range and hence they too carry a charge, which is however, opposite to that of colloidal iron hydroxide. Since the charge carried by the plantonic forms is opposite to that of ferric hydroxide, a mutual attraction occurs. As a consequence, not only are the organisms killed by asphyxiation resulting from the inability of oxygen to diffuse through the iron coating, but also by the "salting-out" effect produced by the precipitation of ferric hydroxide.

The foregoing condition was reported by Olson in 1941 and was still in progress during the time this study was conducted.

<u>Total</u> <u>iron</u>. Olson and co-workers[1] studied the concentrations of total iron in Curtis Creek to determine the direction of movement and

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[1] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biol. Lab. Pub. #43:140, November 1941.

attenuation of ferrous iron subsequent to hydrolysis and oxidation as represented by the soluble and insoluble iron forms. The precipitation factor was obtained by a comparison of the concentrations of iron values. The range of values of total iron were found to vary from .447 p.p.m. to 18.00 p.p.m. The higher values being obtained proximally located to the site of copperas disposal. For the same area, the present study records an average of 6.3 p.p.m. for the surface and 7.06 p.p.m. for sub-surface waters.

The values for total iron in Bear Creek were found to vary greatly depending upon the location from which the samples were taken. The highest values were recorded at the mouth of Humphreys Creek where it enters Bear Creek. The average concentrations for the entire Bear Creek area was 2.69 p.p.m. and 2.46 p.p.m. for surface and bottom waters respectively. The concentration of total iron at the mouth of Humphreys Creek averaged 36.2 p.p.m. Colgate Creek yielded an average of 44.6 p.p.m.

The process of oxidation of ferrous iron begins immediately upon entrance into the water and continues until all of it is dissipated. For the duration of the chemical process the pH continues to fall and the oxygen of the water is engaged in the area of the reaction. This in part accounts for the low values of these two factors in the lower reaches of the bodies of water into which the effluents are disposed.

It was determined that in most cases ferrous iron was completely oxidized before its exit from Bear Creek and Curtis Creek into the Patapsco River. However, the same condition does not hold for Colgate Creek. This is probably explained by the fact that the distance from the site of disposal of copperas is only a half mile from the Patapsco River.

The amount of dissipation of total iron from the mouth of Bear Creek to the mouth of the Patapsco River was determined to be approximately 59.5 per cent and from Humphreys Creek to the mouth of the river, 96.1 per cent. It appears, therefore, that decomposition occurs predominantly in the tributaries of the estuary and that this factor is reduced to insignificancy before entering the bay.

Soluble iron. This factor is indicative of the unprecipitated ferrous salts which have been oxidized. According to Olson[1], the concentration of this factor is at a maximum at the source of contamination. This is substantiated by the fact that in this study the highest concentrations obtained were in Colgate and Humphreys Creeks. In Curtis Creek concentrations were highest in the vicinity of the copperas disposal. Hence, there appears to be some correlation between ferrous iron and soluble iron. In most cases, areas in which concentrations of the ferrous ions were great, also yielded correspondingly high values for soluble iron. This is in conformity with the findings of Olson.

With few exceptions, it was observed that soluble iron values in the upper stratum were higher than those of the deeper water. This would seem likely, inasmuch as the ferrous ion would tend to be oxidized more rapidly on the surface, because of its closer relationship to atmospheric oxygen, than would the ion in the deeper waters. Moreover, colloidal iron hydroxide remains in the surface waters until precipitation is forced. It might also be conceivable that some of the iron hydroxide may

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[1] Olson, R.A., Brust, Hl. and Tressler, W., "Studies of the Effects of Industrial Pollution in the Lower Patapsco River-Area-Curtis Bay Region", 1941. Chesapeake Biological Lab. Publication #43:3-40, 1941.

have been filtered and calculated as soluble iron.

Soluble iron, like total iron, is to a greater degree spent before entering the Chesapeake Bay. This fact is borne out by a 95 per cent reduction in concentration from the mouth of Bear Creek to the mouth of the estuary.

Insoluble Iron. The degree of precipitation and the regions in which this occurs is determined by a comparison of insoluble iron concentrations. For the most part, insoluble iron values were generally higher for sub-surface waters. Those stations located in the deeper waters appeared not only to have a somewhat wider range of values but also a higher average. Like other iron forms, insoluble iron, was more concentrated in those waters where the values of ferrous sulphate and total iron were high. Similar results were obtained by Olson in the Curtis Creek area in 1941. Values for this factor were greatest in Colgate Creek, Humphreys Creek, Curtis Creek and Bear Creek in descending order.

Dissipation of this factor appears to be very rapid at first and then diminishes very gradually. This is substantiated by the fact that from Humphreys Creek to the mouth of Bear Creek, concentrations were diluted by 78.6 per cent. However, in the Patapsco River, from the entrance to Bear Creek to Station VIII, Millers Island Range House, dilution is increased by only 3.66 per cent.

Nitrate-Nitrogen. The range for this factor is relatively wide in the estuarine waters of the Patapsco River. Surface waters not only demonstrated a wider range than sub-surface waters, but in general, they were also observed to be higher than that found in the lower stream. This is probably explained by the fact that the influx of the fresher waters from upstream tend to flow over the denser waters. This results in the stratification of nitrates. The surface-bottom variant ranged from .01 to 6.8 p.p.m.

Hutchinson[1] observed that decreases in nitrate-nitrogen and phosphates in the spring were coincident with an increase in oxygen and hydrogen-ion values. This he ascribes to the phosynthetic activity of phytoplankton. No such correlation was observed in this study.

It is significant to note that subsequent to the initial dilution of the inflowing downstream nutrient ladened waters, the concentrations for this factor remained quite stable. A dissipation of not more than 0.02 p.p.m. was not encountered. Nash[2] reported a decrease in downstream concentrations which he attributes to the ingression of fresh water and to its consumption by plankters. If then, attenuation of this factor <u>en route</u> down the estuary is indicative of plankton utilization, it might be justifiable to assume that plankton-productivity in the area investigated is discouragingly poor. This is not to be interpreted however, that with the proper physic-chemical balance restored, that the biological aspect would not also be restored to equilibrium. Rawson[3] considered concentrations of .05 to .20 p.p.m. as unusually rich in nitrogenous material. On the basis of the concentrations calculated, the

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[1] G.E. Hutchinson, "Ecological Aspects of Succession in Natural Populations". The American Naturalist, LXXV:406-418, 1941.

[2] C.B. Nash, "Environmental Characteristics of a River Estuary". Ches. Biol. Lab., Solomons Island, Md., Pub. #64:147-174, Dec. 1947.

[3] D. Rawson, "Physical & Chemical Studies in the Lakes of Prince Albert Park, Saskatchewan", Jour. Biol. Bd. of Canada, II, #3:227-283, 1936.

estuary studied is sufficiently supplied with nitrate-nitrogen to support a luxurient biological family. With concentrations of 0.60 p.p.m. to 8.60 p.p.m. for offshore surface waters and from 0.20 p.p.m. to 8.40 p.p.m. for offshore deeper waters, such an assumption does not appear inconceivable.

Nitrite-Nitrogen. This factor, just as the one previously discussed, tends to become more concentrated in the upper reaches of the estuary and its tributaries. For example, a 27.2 per cent increase in value was noted from the mouth to the head of Bear Creek. Corresponding increments were observed in Curtis Creek. Similar results were obtained by Nash[1] in the Patuxent River.

Significant differences between the nitrite-nitrogen concentrations of the sub-surface and surface waters investigated by Nash[2] and Newcombe and co-workers[3] were reported. In the case of the research done by Nash, these differences were reported to have become insignificant in the upper half of the estuary, but in the lower half, the bottom concentrations exceeded the surface ones by 60 per cent 85 per cent of the time. These investigators are of the opinion that increased values of sub-surface waters are a result of regeneration of this chemical factor in the muddy bottoms.

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[1] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab. Pub. #64:147-174, Dec. 1947.

[2] C.B. Nash, "Environmental Characteristics of a River Estuary", Chesapeake Biol. Lab. Pub. #64:147-174, Dec. 1947.

[3] C. Newcombe, H. Brush, W. Horne & B. Shepherd, "Studies on the Physics and Chemistry of Estuarine Waters in the Chesapeake Bay". Jour. Mar. Research. II#2:87-116, 1939.

These same investigators have observed that nitrite-nitrogen concentrations become greater in a downstream direction. Hence, a decrease of nitrate-nitrogen was accompanied by an increase of nitrite-nitrogen. Orr[1] found that nitrite-nitrogen was significantly raised during and even after plankton-production. Assuming then, that the interpretation of the foregoing investigators is correct, namely that an increase in nitrite-nitrogen values is a direct result of plankton-productivity, it would then appear that the estuarine waters of the Patapsco River are non-productive. This would tend to be supported by the fact that plankton populations in the estuary are not in evidence in great abundance.

One might question then, the appearance of the nitrate- and nitrite-nitrogen cycle in certain areas of the estuary. It seems possible that because of tides and meteorological conditions such as wind and precipitation, the movements of water into and out of the river might account for the regularity with which these cycles appear. Certainly, there is a mutual influence exerted between the Chesapeake Bay and its tributaries on the physio-chemical factors of each.

Phosphate-phosphorus. In the estuarine waters of the Patapsco River, phosphate-phosphorus was observed to be present in heavy concentrations (0.30 p.p.m. to 70.4 p.p.m.). Newcombe[2] noted that samples decreased in concentration from 0.413 to 0.044 mg. atoms P/m^3 when left in the sun for only fifteen minutes. Although precautions were taken

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[1] A. Orr, "Nitrite Content of Sea Water", Jour. Mar. Biology, 14:55-56, 1927.

[2] C. Newcombe, and A. Lang, "The Distribution of Phosphates in the Chesapeake Bay". Proceedings of the American Philosophical Society. 81, #3:393-420, 1939.

against prolonged exposure of the samples to the sun, it is possible that the values might have been higher, particularly since the calculations were made varying from one to five hours after their collection.

According to Atkins[1] and Brandt[2], phosphate values were observed to be characteristically at a maximum during the winter months and diminished in the spring, reaching their lowest values in the summer. Newcombe (1939)[3] (1940)[4] noted that in the Chesapeake Bay, concentrations were greatest during the months of August and September with lowered values in the spring and winter. He explains this deviation on the basis of accelerated regeneration and reduced utilization.

The greater concentrations of phosphate-phosphorus encountered in the head waters of the Chesapeake Bay, were justified by Newcombe on the basis of decreased light penetration resulting from increased turbidity of waters stemming from the Susquehanna River.

If these factors are capable of exerting such a strong influence on a body of water as large as the Chesapeake Bay, then it is likewise possible for these same factors to produce similar effects on the estu-

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[1] W. Atkins, "The Phosphate Content of Fresh and Salt Water in Its Relationship to the Growth of Algal Plankton". Jour. Mar. Biol. Assoc. 13:119-150, 1923.

[2] K. Brandt, "Ueber den Stoffwechsel im Meere Wissensch", Meeresuntersuch 18:187-429, 1939.

[3] C. Newcombe & A. Lang, "The Distribution of Phosphates in the Chesapeake Bay". Proceedings of the American Philosophical Soc. 81, #3:393-420, 1939.

[4] C. Newcombe & H. Brust, "Variations in the Phosphorus Content of the Estuarine Waters of the Chesapeake Bay Near Solomons Island, Maryland." Jour. Mar. Research, III#1 76-86, 1940.

arine waters of the Patapsco River. This then would account for the increased concentrations in an upstream direction.

Siewell[1] has demonstrated that the decomposition of dead organisms results in the regeneration of phosphorus in the sea. This investigator denies that so intensive a regeneration could be a result of plankton-metabolism. It appears likely then that this factor too may play an appreciable part in the phosphate regeneration in this study.

Plankton. It was observed that the unpolluted areas of the Patapsco River supported both phyto- and zooplanktonic forms. The surface waters of the estuary did not tend to have greater populations than the subsurface waters. This condition existed in spite of the greater availability of oxygen which is found in the surface layers and to the increased concentrations of nutrient compounds in the surface waters.

Plankton populations demonstrated seasonal fluctuations which varied with specific forms. In general, the diatoms, algae, protozoa and copepods appeared in greatest numbers in the spring. A decline in numbers was observed as the summer progressed. The rotifers appeared to increase in population during the latter part of the summer. This spring bloom of plankters is coincident with decreased values of nitrates and phosphates and hence probably accounts for the decline in concentrations.

In general, phytoplankton is the predominant form of aquatic life in the unpolluted as well as the polluted regions of the estuary. This numerical supremacy is achieved in summer and is maintained throughout

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[1] H.R. Siewell, "The Annual Organic Production and Nutrient Phosphorus Requirement in the Tropical Western North Atlantic", Jour. du Conseil Intern. pour L'Explor. de la Mer., X,#1, 20-32, 1935.

the year. In the waters of Curtis Creek, the algae were so numerous that they imparted a vivid green color to the waters. This condition existed throughout the summer and was also observed by Davis[1]. In Bear Creek, no evidence of algal forms of any kind were observed in significant numbers, this is probably a result of the flocculation of ferric hydroxide on these forms. In fact, the only distinguishable form of microplankton was the diatom. The original samples of water gave evidence of this condition at the time of collection, in that the brick-red color was always characteristic of the water of this area. After the customary two week "settling period" of the plankton samples, the rust colored sediment yielded an indiscernible substance, which under the microscope appeared as colloidal orange masses.

In the polluted regions of the river and its tributaries, the protozoa were most easily affected. Their absence is probably due to oxygen-deficiency or low hydrogen-ion values or to flocculating ferric hydroxide or any combination of these factors. For example, protozoa were not in evidence at Station I in neither the surface nor bottom waters. This can be explained on the basis of oxygen-deficient waters in this area. The low concentrations of oxygen were probably a result of the oil film on the water-surface and from oxidation of vegetable wastes from the canneries of this area.

Although the waters of Curtis Creek are oxygen-poor during the summer, it is conceivable that this condition would be much more acute

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[1] C. Davis, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area 2. The Effect of Copperas Pollution on Plankton." Chesapeake Biological Laboratory, Solomon's Island, Maryland", 72, 1948.

were it not for the fact that algae are so plentiful. Algal forms do not require large quantities of oxygen. In their photosynthetic activity, these aquatic plants liberate oxygen, which is available for use by the zooplanktonic forms. It is possible that the absence of algae in Bear Creek is not due to low oxygen concentrations nor to low hydrogen-ion values. Examination of TABLES 4, 5, 7 and 8 demonstrates that values for these factors were as low in Curtis Creek as they were in Bear Creek; hence, eliminating these two factors, one might conclude that ferric hydroxide is the most serious pollutant in tributaries of the estuary.

Olson[1], likewise, was of the opinion that phytoplankton forms, because of their low oxygen-engaging rate are able to withstand oxygen-defects with less injury resulting than can the animals. Relative to pH, these investigators observed that algae were less affected than the diatoms. In regard to the settling of ferric hydroxide, these investigators maintained that the smaller organisms suffered more severely. They noted that copepods were only slightly affected by flocculation.

It is significant that the north waters of the estuary in general, are not as productive as the waters on the south side of the estuary. This supports the chemical findings that pollution resulting from the industrial effluents is much more severe on the north side of the estuary. Further, with dissipation of the pollutants toward the mouth of the estuary normal ecological balance is partially restored and plankton growth becomes more in evidence.

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[1] R.A. Olson, H.F. Brust and W.L. Tressler, "Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area", Chesapeake Biol. Lab. Pub. #43:140, November 1941.

It may be concluded then that the unpolluted areas of the estuary demonstrated characteristic plankton stratification and seasonal variation similar to other estuaries of the Chesapeake Bay. However, in the polluted areas, plankton forms were seriously diminished or found wanting, hence this part of the food chain of aquatic organisms has been eliminated.

CHAPTER V

CONCLUSIONS

The conclusions of this study may be summarized as follows:

1. The lowest temperatures occur in January and February at the end of which time temperatures ascend. The maximum temperatures were recorded in July and subsequently began to decline. Stratification was in evidence at all times except during periods of vertical mixing. Atmospheric temperatures appreciably influenced hourly as well as daily variations of temperature of surface waters.

2. Offshore surface and deeper waters were observed to range from pH 2.1 to pH 9.2 and pH 2.0 to pH 9.5 respectively. Shore stations for which only surface concentrations were determined, ranged from pH 2.0 to pH 9.2. The hydrogen-ion concentrations were lower in summer than at any other season of the year in the polluted areas of the estuary. The lowest values were obtained in Curtis Creek for offshore stations, and in Colgate Creek and Humphreys Creek for the shore stations. It was noted that the low concentrations observed in Colgate Creek and Humphreys Creek were consistantly lower throughout the year than in any other region investigated. Lethal values for this factor were found continuously in Colgate and Humphreys Creeks. Unpolluted waters remained, for the most part, characteristically alkaline.

3. The broad variation of salinity in the estuary is a result of the combined effects of tides, convection currents, influx of fresh water from the tributaries, vernal and autumnal circulation and precipitation. The variation of this factor ranged from 0.60 p.p.t. to 6.37 p.p.t. for surface waters and 2.2 p.p.t. to 6.5 p.p.t. for the deeper

waters. The highest values normally occur in fall. Stratification was observed, in general, at all stations.

4. Dissolved oxygen varied from concentrations of 0.43 to 14.25 p.p.m. (surface offshore stations), 0.45 p.p.m. to 9.81 p.p.m. (Bottom offshore stations) and 0.14 p.p.m. to 9.2 p.p.m. (shore stations). Oxygen concentrations and temperature were found to be inversely correlated for surface waters and the former is directly correlated with hydrogen-ion concentrations in the area of copperas pollution. Surface-bottom differences were observed up to 7.5 p.p.m. The tributaries of the estuary are characterized by oxygen-poor waters the year round, however, these low concentrations do not normally extend into the Patapsco River. The upper reaches of the river possess detrimentally low values; the oxygen deficit results from pollutants in the area.

5. The estuary and its tributaries are well supplied with carbon-dioxide. A range of 0.0758 cc./l. to 26.5 cc./l. for surface offshore waters, 0.758 cc./l. to 24.23 cc./l. for deeper offshore waters and 0.510 cc./l. to 25.00 cc./l. for shore surface were noted. The surface-bottom differential ranged from 0.0 cc./l. to 12.74 cc./l. The highest difference occurred in summer. Seasonal variations which are characteristic of other estuarine waters were observed in the Patapsco River.

6. In an upstream direction, the silicate concentrations appear to become higher. For the most part, silicate-silicon values for the surface were higher than those of the deeper waters. The average range for this value was .0485 g./l. to 1154 g./l. for surface offshore waters, .0475 g./l. to .1112 g./l. for deeper offshore waters and .0111 g./l. to .1138 g./l. for shore waters. The surface-bottom difference in concentration varied from 0.0 g./l. to 0.0489 g./l. The absence of this

difference was encountered at the shallower stations or at the period of vertical mixing. The higher surface concentration is indicative of either the influx of fresh water from the tributaries or poor diatom productivity or both. High values for this factor existed more or less at all times of the year. However, stations more proximally located to the mouth of the river demonstrated higher concentrations in the summer with a decline in values in spring and fall. These stations located in the upper reaches appeared to be more concentrated in the spring and decrease in value in the summer.

7. Ferrous iron was found throughout Bear Creek, Colgate Creek, Curtis Creek and Humphreys Creek. No evidence of this pollutant was detected in the mouth waters of the Patapsco River. The range of this factor varied from a trace to 1080.0 p.p.m. depending upon the distance the sample was taken from the source of disposal. High ferrous iron values were directly correlated with low oxygen values. No seasonal variation for this pollutant was evidenced. Flocculation and precipitation of ferrous iron resulting from hydrolysis or oxidation was observed to be serious in all regions where this effluent was disposed.

8. The range of total iron varied from 0.10 p.p.m. to 29.7 p.p.m. for surface offshore stations, from 0.2 p.p.m. to 34.8 p.p.m. for bottom offshore stations and from 1.57 p.p.m. to 36.15 p.p.m. for shore stations. In general, concentrations of surface waters were found to be higher than the lower waters. It was observed that the major part of decomposition occurs in the tributaries of the estuary. This is supported by the fact that dissipation of this factor was found to be rapid in the tributaries and less rapid in the estuary proper.

9. Soluble iron as an indicator of unprecipitated oxidized ferrous

salts, demonstrated characteristically high values in regions more proximally located to the source of disposal. The highest concentrations were found in Colgate Creek and Humphreys Creek. For the most part, surface waters yielded higher values than the waters of the sub-stratum. This is due to the availability of atmospheric oxygen to surface waters. Soluble iron is more or less dissipated before leaving the estuary.

10. Insoluble iron values were observed to be found in higher concentrations in the deeper waters. Higher values for both surface and bottom waters were noted in the tributaries in which the copperas was disposed. Attenuation of this factor was observed to very rapid in the tributaries of the river but much less rapid in the estuary.

11. The nitrate-nitrogen range was wide in the estuarine waters of the Patapsco River. Surface waters were found to be higher in an up-stream direction. The range observed for nitrates was 0.60 p.p.m. to 8.60 p.p.m. (surface offshore stations), 0.80 p.p.m. to 8.40 p.p.m. (bottom offshore stations) and 1.05 p.p.m. to 2.46 p.p.m. (shore stations). The surface-bottom variant ranged from 0.01 p.p.m. to 6.4 p.p.m. A dissipation of more than 0.02 p.p.m. was not encountered. Attenuation of this factor as an index to plankton productivity, justifies the biological results of low plankton populations.

12. The highest values for nitrite-nitrogen were recorded for the shore stations (0.015 p.p.m. to 0.986 p.p.m.). In general, slightly higher values were obtained for subsurface offshore waters than for the surface waters (.003 p.p.m. to .500 p.p.m. and .003 p.p.m. to .552 p.p.m) respectively. The highest concentrations occurred in winter diminishing in spring reaching the lowest concentration in summer. Except at the time of vertical mixing, the surface waters were always exceeded in

value by the bottom waters; the range of difference varied from 0.0 p.p.m. to 5.04 p.p.m. No significant difference was noted relative to this factor between polluted and non-polluted regions of the estuary.

13. The estuary and its tributaries are bountifully supplied with phosphate-phosphorus, ranging from 7.48 p.p.m. to 14.80 p.p.m. (surface offshore waters), 7.91 p.p.m. to 15.93 p.p.m. (bottom offshore waters) and 7.97 p.p.m. to 1106 p.p.m. for shore waters. Head waters were observed to be more concentrated than the downstream waters. Except during the period of vernal and autumnal circulation, surface waters were exceeded by nitrate concentrations of deeper waters. Characteristic seasonal variations were observed.

14. Oil and grease was observed at all shore stations eighty per cent of the time during which this study was conducted. Offshore stations located in the upper reaches of the river were frequently covered with a film of oil. This factor manifested an appreciable effect on the oxygen concentrations of the area. The grease which covered the shores of Bear Creek and which in a coalesced condition was found as far down the Chesapeake Bay as Annapolis, has its origin from the Humphreys Creek into which effluents from the iron and steel mills are emptied.

15. Surface waters do not tend to produce more plankton than subsurface waters. Plankton stratification was not significant in the shallower stations nor at the time of vertical mixing. Seasonal variation of plankton was characterized by increased populations of algae, diatoms, protozoa and copepods in the spring with a decline in numbers in the summer. Rotifers increased in the summer with a maximum number in the fall. The increased populations of the foregoing were coincident with high concentrations of nutrient salts.

16. In the polluted regions of the estuary, a general decrease in the quantitative value of plankters was noted. The protozoa appeared to be most easily and generally affected by low concentrations of oxygen, hydrogen-ion and by ferric hydroxide. Algal forms were less affected by oxygen and favored lowered hydrogen-ion concentrations but were seriously affected by the severe floc of ferric hydroxide. Diatoms were least affected by these factors except in values which because of their concentrations were conditioning.

17. On the basis of the high concentrations of nutrient compounds calculated for the estuarine waters of the Patapsco River, one might conclude that potentially these waters are most fertile if elimination of such pollutants as copperas, oil and grease, vegetable wastes from canneries, etc., could be executed.

SELECTED BIBLIOGRAPHY

1. Allen, Winfred E. *The Importance of Continuity in Marine Plankton Investigations.* La Jolla: Bulletin of Scripps Institution of Oceanography of California, 2051-2055

2. ______. *Methods in Quantitative Research on Marine Microplankton.* La Jolla: Bulletin of Scripps Institution of Oceanography of California, 2: 319-329, 1930.

3. American Public Health Association. *Standard Methods of Water and Sewage Analysis,* New York, Am. Pub. Hea. Assoc., 1936.

4. Atkins, W.R. *The Phosphate Content of Fresh and Salt Water in its Relationship to the Growth of Algal Plankton.* Jour. Mar. Biol. Assoc. 13:119-150, 1923.

5. ______. *The Phosphate Content of Sea Water in Relation to the Growth of Algae Plankton,* Biolo. Association. 14:447-467, 1924.

6. ______. *Seasonal Variations in the Phosphate and Silicate Content of Sea Water During 1926 and 1927 in Relation to Phytoplankton* Crop. Jour. Mar. Biol. 15: 191:205, 1928.

7. ______. and Harris, G.T. *Seasonal Changes in the Water and Heleoplankton of Fresh Water Ponds.* Proc. Royal Dublin Society, 18: 1-21, 1924.

8. ______. and Wilson, E.G. *The Colormetric Estimation of Minute Amounts of Compounds of Silicas, of Phosphorus and of Arsenic.* Biochemical Journal, 20:1223-1228, 1926.

9. ______. *Seasonal Changes in the Silica Content of Natural Waters in Relation to Phytoplankton.* Journal of Marine Biology, 14:89-99, 1926.

10. ______. *Seasonal Variation in the Phosphate and Silicate Content of Sea Water in Relation to the Phytoplankton Corp.*, Journal of Marine Biology, 16:821-852, 1930.

11. Beaven, G. Francis. *Annual Report:* Chesapeake Biological Laboratory, Solomons Island, Maryland, 1942.

12. Brandt, K. *Ueber den Stoffwechsel im Meere Wissensch.* Meeresuntersuch. 18:157-429, 1919.

13. Brust, H.F. and Newcombe, C.L. *Observations on the Alkalinity of Estuarine Waters of the Chesapeake Bay Near Solomons Island,* Maryland. Journal of Marine Research. III, #2, 1940.

14. Carpenter, K. The Lethal Action of Soluble Metalic Salts on Fishes. British Journal Experimental Biology. 4:378-390, 1927.

15. Chamot, E.M. and Pratt, D.S. A Study of the Phenosulfonic Acid Method for the Determination of Nitrates in Water. Jour. Am. Chem. Soc. 31:922, 1909.

16. ______. A Study of the Phenosulfonic Acid Method for the Determination of Nitrates in Water. Jour. Am. Chem. Soc. 32:630-637, 1910.

17. ______, and Redfield, H.W. A Study of the Phenosulfonic Acid Method for the Determination of Nitrates in Water. Jour. Am. Chem. Soc. 33:366-381, 1911.

18. Chandler, D. Limnological Studies of Western Lake Erie. Ohio Journal of Science, XL, #6:291-336, 1939.

19. Clark, H.W. and Adams, G.O. Studies of Fishlife and Water Pollution. Forty-fourth Annual Report of the State Board of Health of Massachusetts, Pub. Doc. #34, Mass. State Bd. of Health, 6:336-345, 1913.

20. Clarke, G. and James, H. Laboratory Analysis of Selective Absorption of Light by Sea Water. Jour. Opt. Soc. Am. 29:43-55, 1939.

21. Coker, R.E. Influence of Temperature on Forms of the Freshwater Copoped, Cyclops vernales Fisher, Reprint - Internationale Revue der gesamten Hydrobiologie and Hydrographie. 30:411-427, 1934.

22. Cowles, R.P. A Biological Study of the Offshore Waters of the Chesapeake Bay. United States Department of Commerce, Bureau of Fisheries Bull. XLVI, #1091:278-381, 1930.

23. Daily, W.A. A Quantitative Study of the Phytoplankton of Lake Michigan Collected in the Vicinity of Evanston, Illinois. Reprint - Butler University Botanical Studies. 4 (6), 1938.

24. Davis, Charles C. Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area. 2 The Effect of Copperas Pollution on Plankton. Chesapeake Biological Laboratory, Solomons Island, 72, 1948.

25. Ellis, M. Detection and Measurement of Stream Pollution. Bull. U.S. Bureau of Fisheries. XLVII:65-437, 1937.

26. Fisher, H. The Problem of Increasing the Production in Fish Ponds by the Use of Chemical Fertilizers. Internat. Rev. Sci. and Prac. Agr. 2:822-830, 1924.

27. Florentin, D. The Determination of Phosphates in Water. Ann. Chim. Anal. Chim. Appl. 3:295, 1921.

28. Gardiner, A.G. The Effect of Aqueous Extracts of Tar on Developing Trout Ova and on Alevins, Ministry of Agriculture and Fisheries, Fishery Investigations. Series I. III (2) :1-14, 1927.

29. Gran, H.H., On the Condition for Production of Plankton in the Sea. Conseil Perm. Internat. Explor. de la Mer, Rapp. et Proc. Verb., 75:37-46, 1931.

30. ______. The Respiration of Puffer Fish, Biological Bulletin, 61, 1931.

31. Hall, F.G. The Influence of Varying Oxygen Tension Upon the Rate of Oxygen Consumption in Marine Fishes. Am. Jour. Physiol., 88: 212-218, 1929.

32. ______. The Ability of the Common Mackerel and Certain Other Marine Fishes to Remove Dissolved Oxygen from Sea Water. Amer. Jour. Physiol. 93:417-421, 1930.

33. Harvey, H.W. Biological Chemistry and Physics of Sea Water, New York, MacMillan Company. 36-39, 1928.

34. ______. Supply of Iron to Diatoms. Marine Biol. Assn. 22:205-219, 1937.

35. ______. Substances Controlling Growth of a Diatom. Jour. Marine Biol. Assn. 23:499-520, 1939.

36. ______. Growth of Phytoplankton. Jour. Marine Biol. Assn. 24: 115-123, 1940.

37. Hiestand, W.A. and Hale, D.M. Respiration Studies with Freshwater Molluscs: II Oxygen Consumption in Relation to Hydrogen-ion Concentration. Reprint - Proceedings Indiana Academy of Science. 47:293-298, 1938.

38. Hutchinson, G.E. Alkali Deficiency and Fish Mortality. Science, 84, #2166, 1936.

39. ______. Chemical Stratification and Lake Morphology. Reprint- Proceedings of the National Academy of Sciences. 24, #2:63-69, 1938.

40. ______. Ecological Aspects of Succession in Natural Populations. The American Naturalist, LXXV:406-418, 1941.

41. Hyman, L.H. On the Action of Certain Substances on Oxygen Consumption: VI. The Action of Acids. Biol. Bull. 49:288-322, 1925.

42. Ilosvay, M.L. Nitrous Acid in the Saliva and in Exhaled Air. Bull. Soc. Chem. 2:388, 1889.

43. Jenken, P.M. Reports on the Percy Sladen Expedition to the Soin Rift Valley Lakes in Kenya in 1929. I Introductory Account of the Biological Survey of Five Fresh Water Alkaline Lakes. Ann. Mag. Nat. Hist., 9:533-553, 1932.

44. Jewel, M. and Brown, H. Studies on Northern Michigan Bog Lakes. Ecology, 10:427-475, 1929.

45. Johnson, M.L. The Control of Respiratory Movements in Crustacea. Jour. Exp. Biol. 13:467-475, 1936.

46. Juday, C. and Birge, E.A. A Second Report on the Phosphorus Content of Wisconsin Lake Waters. Transactions of the Wisconsin Academy of Sciences, Arts and Letters, XXVI: 553-582, 1931.

47. ______. Dissolved Oxygen and Oxygen Consumed in the Lake Waters of Northeastern Wisconsin. Reprint- Transaction of Wisconsin Acad. of Science, Arts and Letters. 27:415-486, 1932.

48. ______. Kemmerer, G.I. and Robinson, R.S. Phosphorus Content of Lake Waters of Northeastern Wisconsin. Reprint- Transactions of the Wisconsin Academy of Sciences, Arts and Letters, XXIII:233-248, 1928.

49. ______, and Meloche, V.W. The Carbon Dioxide and Hydrogen-Ion Content of Lake Waters of Northeastern Wisconsin. Reprint- Trans. of Wisconsin Academy of Sciences, Arts & Letters. 29:1-82, 1935.

50. ______. Chemical Analysis of the Bottom Deposits of Wisconsin Lakes II, Second Report. 1946. Reprint- Transactions of Wisconsin Academy of Sciences, Arts and Letters. 33:94-114, 1946.

51. Kemmerer, G., Bovard, J. and Boorman, W.R. Northwestern Lakes of the U.S.: Biological and Chemical Studies with Reference to Possibilities in Production of Fish. Bull. Bur. of Fisheries, 39: 51-140, 1923.

52. Kessler, L.H. and Nichols, M. Oxygen Utilization by Activated Sludge. Sewage Works Journal, VII, #5, 1935.

53. Kitchling, J.A. The Effects of a Lack of Oxygen and of Low Oxygen on Paramecium. Biol. Bull. LXXVII:339-353, 1939.

54. Lackey, J.B. Oxygen Deficiency and Sewage Protozoa: With Description of Some New Species. Biol. Bull. LXIII, #2:287-295, 1932.

55. Littleford, R. Survival of Four-Spined Stickleback, Apeltes quadracus, in Copperas Dilutions. (Unpublished), 1-8

56. ______. Newcombe, C.L. and Shepherd, B.B. An Experimental Study of Certain Quantitative Plankton Methods. Reprint- Ecology, 21, #3:309-322, 1940.

57. McHargue, J.S. and Peter, A.M. *The Removal of Mineral Plant Food by Natural Drainage Water.* Kentucky Agricultural Experiment Station Bull. 237-362, 1921.

58. Meloche, V.W. Leader, G., Safranski, L. and Juday, C. *The Silica and Diatom Content of Lake Mendota Water.* Reprint- Transactions of the Wisconsin Academy of Sciences, Arts and Letters, XXXI: 363-376, 1938.

59. Morse, D.C. *Some Observations on Seasonal Variations in Plankton Population Patuxent River, Maryland 1943-45.* Publication #65, Chesapeake Biol. Lab., Solomons Island, Maryland. 1947.

60. Nash, C.B. *Environmental Characteristics of a River Estuary.* Chesapeake Biol. Lab., Solomons Island Maryland, Pub. #64:147-174, Dec. 1947.

61. Newcombe, C. *The 1938 Program of the Chesapeake Biological Laboratory.* The Collecting New Vol. XIII, #8, 1938.

62. ______, and Brust, H. *Variations in the Phosphorus Content of the Estuarine Waters of the Chesapeake Bay Near Solomons Island, Md.* Jour. Mar. Research, III, #1:76-88, 1940.

63. ______, and Horne, W. *Oxygen Poor Waters of the Chesapeake Bay.* Science, 88, #2275: 80-81, 1938.

64. ______ and Shepherd, B. *Studies on the Physics and Chemistry of Estuarine Waters in the Chesapeake Bay.* Jour. Mar. Research. II #2-:87-116, 1939.

65. ______, and Lang, A.G. *The Distribution of Phosphates in the Chesapeake Bay. Proceedings of the American Philosophical Soc.* 81, #3:393-420, 1939.

66. Olson, R.A., Brust, H. and Tressler, W. *Studies of the Effects of Industrial Pollution in the Lower Patapsco River Area- Curtis Bay Region 1941.* Chesapeake Biol. Lab. Pub. #43:3-40, 1941.

67. Orr, A.P. *Nitrite Content of Sea Water.* Jour, Mar. Biol. Assn. 14:55-61, 1927.

68. Osburn, R.C. *A Survey of the Bryozoa of Chesapeake Bay.* Ches. Biol. Lab. Pub. #63, 1944.

69. Pearsall, W.H. and Ullyott, P. *Light Penetration into Fresh Water, III. Seasonal Variations in the Light Conditions in Windermere in Relation to Vegetation.* Reprint- Jour. Exp. Biol. XI, #1:89-93, 1934.

70. Rakestraw, N.W. *The Occurrence and Significance of Nitrite in the Sea.* Biol. Bull. 71:133-167, 1936.

71. Rawson, D.S. Physical and Chemical Studies in Lakes of Prince Albert Park, Saskatchewan. Jour. of the Biol. Bd. of Canada, II, #3:227-283, 1936.

72. Richardson, F.W. and Mollinga, F., Tintometric Estimation of Nitrites and Nitrates in Water. Jour. Soc. Chem. Ind. 22:616-6, 1902.

73. Robinson, R. and Wirth, H. Photometric Investigation of the ceruleomolybdate Determination of Phosphate in Water. Ind. Eng. Chem. Anal. Ed. V.7:147-150, 1935.

74. Seiwell, H.R., The Annual Organic Production and Nutrient Phosphorus Requirement in the Tropical Western North Atlantic, Jour. du Conell, Intern. pour L'Explor. de la Mer., X,#1, 20-32, 1935.

75. State of New York Conservation Department. A Biological Survey of the Erie-Niagra System. Supplement to the Eighteenth Annual Report, 1928.

76. ______, A Biological Survey of the Lake Ontario Watershed. Supplement to the Twenty-ninth Annual Report, #16, 1940.

77. Stewart, R. and Greaves, J.E. The Influence of Chlorine upon the Determination of Nitric Nitrogen. Jour. of Am. Chem. Soc. 32: 756-757, 1910.

78. Sverdrup, H. Johnson, M., and Fleming, R. The Oceans. New York: Prentice-Hall Inc. 1946.

79. Thompson, R.H. Fresh Water Dinoflagellates of Maryland. Chesapeake Biol. Lab. Pub. #66, 1947.

80. Thompson, T. and Bremner, R. The Occurrence of Iron in Water of Northeast Pacific Ocean. Conceil Perm. Internat. p. l'Explor. de la Mer. Jour. du Conseil, 10:39-47, 1935.

81. Thompson, T., Bremner, R. and Jamieson, I. Occurrence and Determination of Iron in Sea Water. Industrial and Engineering Chemistry, Analytical Edition, 4:288-290, 1932.

82. Towsand, L.D., Ericksen, A., and Earnest, D. Progress Report on Field Investigations and Research. Washington State Pollution Commission, Dec. 1938.

83. Tressler, W., Tiffany, L. and Spencer, W. Limnological Studies of Buckeye Lake, Ohio. Reprint- Ohio Journal of Science. XL,#5:261-290, 1940.

84. Truitt, R. Annual Report. Chesapeake Biol. Lab., #34, 1939.

85. ______. Annual Report. Ches. Biol. Lab. #40, (Lab. Series), 1940.

86. ______. Annual Report. Ches. Biol. Lab. #47, 1942.

87. Ward, H.B. and Whipple, G.C. Fresh Water Biology, John Wiley & Sons, New York, New York, 1918.

88. Weigelt, C., Saare, O. and Schwele, L. Des chadegung von Frescherei und Fischzuucht durch Industrie and Hans Avevasser. Archev. Fur Hugiene, 3:39-117, 1885.

89. Wells, R.C., Bailey, R.K. and Henderson, E.P. Salinity of the Water of Chesapeake Bay. Department of the Interior, U.S. Geol. Surv., Professional Paper. 154-C:105-152, 1929.

90. ______. Investigations on Plankton Production in Fish Ponds. U.S. Bureau of Fisheries, Document 1082.

91. Wiebe, A. Dissolved Phosphorus and Inorganic Nitrogen in Water of the Mississippi River. Science, 73, #1932-652, 1931.

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