THE VERTICAL DISTRIBUTION OF DISSOLVED OXYGEN AND THE PRECIPITATION BY SALT WATER IN CERTAIN TIDAL AREAS.*

BY

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BIRGE and Juday[1] have shown that dissolved oxygen is deficient in the lower layers of water of 129 inland lakes of Wisconsin, due to thermal stratification of the water and subsequent depletion of the oxygen in the colder layers by the process of respiration of plants and animals, by the direct oxidation of dead organic matter, and by the decomposition which results from the action of bacteria.

Data obtained by the Water Laboratory of this Bureau show that less dissolved oxygen is present in the water near the bottom of the Potomac Estuary and of portions of the Chesapeake Bay than in the surface water, apparently due to the under-run of salt water present in those waters and the subsequent depletion of the oxygen in the lower layers as indicated by Birge and Juday.

Other data obtained show that maximum turbidity of two tidal rivers is attained in the regions where salt water first appears.

The two phenomena of depleted dissolved oxygen content and of maximum turbidity at the junction of fresh and salt water are related in that the sedimentation caused by the salt water is a contributing factor in the depletion of the oxygen of the lower layers of water.

These data are of particular interest at this time because of the possible relation which the dissolved oxygen content bears to the mortality of fish and shellfish, reported as occurring at the mouth of the Potomac and of other rivers flowing into Chesapeake Bay and in other tidal waters. It is thought that the dissolved oxygen content of those waters may have a profound influence on fish life, particularly on the migration of fish in those regions.

Helland-Hansen[2] noted a deficiency of oxygen in the lower

* Contribution from the Water Laboratory, Bureau of Chemistry, U. S. Department of Agriculture. Communicated by Doctor Skinner.

water of some oyster ponds situated in Norwegian fjords. These ponds were connected with the main bodies of water in the fjords only during unusually high tides. The deficiency of dissolved oxygen threatened the destruction of the oysters.

The content of chlorin, turbidity, and dissolved oxygen of about 275 surface and deep samples collected from the lower Potomac River, Maryland, the Maurice River, New Jersey, the

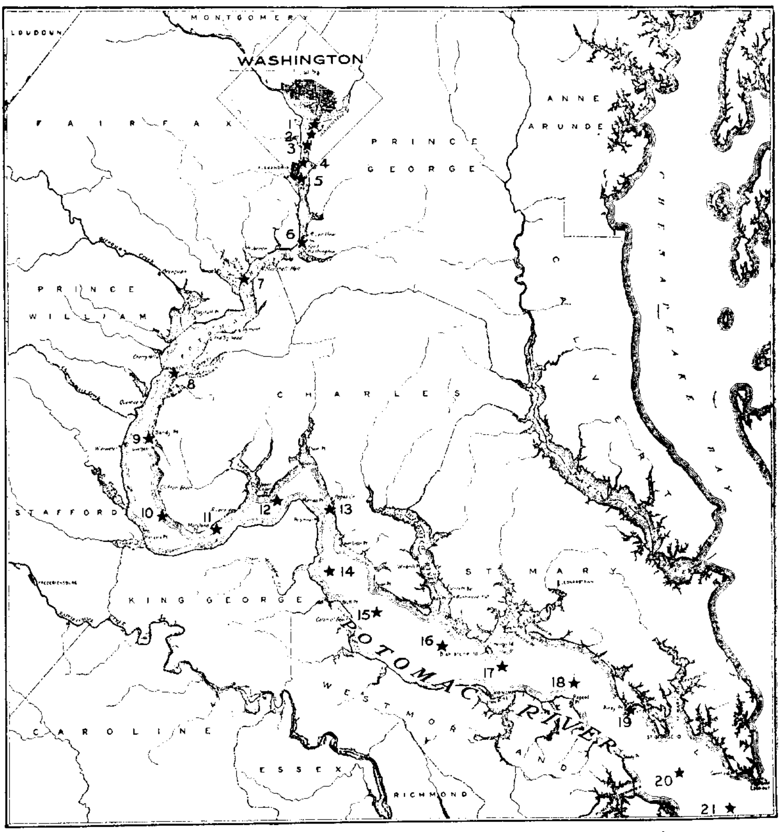

FIG. 1.—Map of Potomac Estuary, showing location of sampling stations.

Approximate depth in feet at Sampling Stations in lower Potomac River:

No. 1, 27;	No. 2, 33;	No. 3, 27;	No. 4, 31;	No. 5, 33;
No. 6, 20;	No. 7, 34;	No. 8, 33;	No. 9, 30;	No. 10, 27;
No. 11, 24;	No. 12, 45;	No. 13, 32;	No. 14, 34;	No. 15, 27;
No. 16, 43;	No. 17, 27;	No. 18, 30;	No. 19, 75;	No. 20, 75;
No. 21, 75.				

Chesapeake and the Delaware Bays have been plotted for purposes of comparison, the mutual relations being shown clearly in the accompanying curves. Seasonal temperature and chlorin curves for the lower Potomac River are contained in Figs. 8

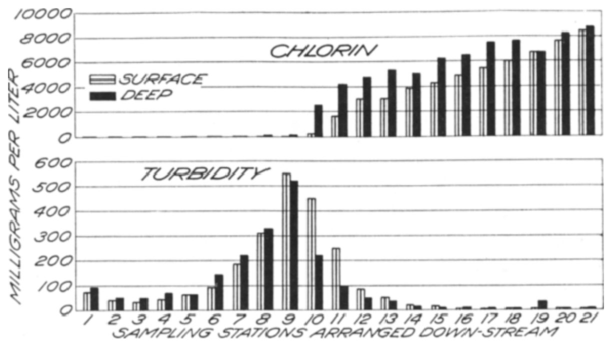

FIG. 2.—Lower Potomac River, Washington, D. C., to Point Lookout, March 11–13, 1912.

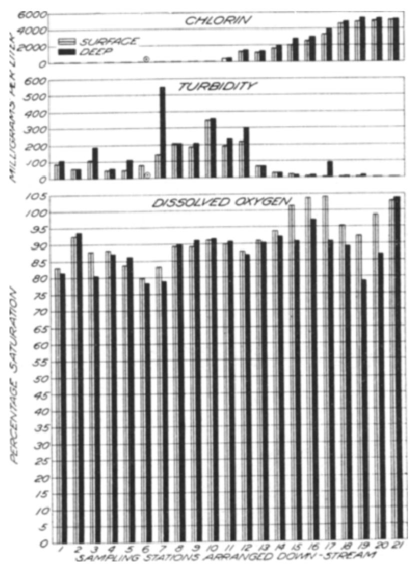

FIG. 3.—Lower Potomac River, Washington, D. C., to Point Lookout, April 29–May 9, 1912.

and 9. All curves have been arranged to extend down stream or down the bay. The locations of the sampling stations in the lower Potomac River are shown on the map, Fig. 1. The so-called surface samples were collected about one foot below the surface and the deep samples about three feet from the bottom. The methods of examination used were those recommended by the A. O. A. C., published in the *Journal of the A. O. A. C.*, vol. 2, No. 4.

The under-run of salt water in the Potomac Estuary and Chesapeake Bay is shown by a comparison of the chlorin curves for the surface and deep samples (Figs. 2, 3, 4, 5, 6, 7 and 10). It will be noted that the two layers of water of different specific gravity are quite distinct in the salt-water section of the river. In the Maurice River the under-run of salt water, while present,

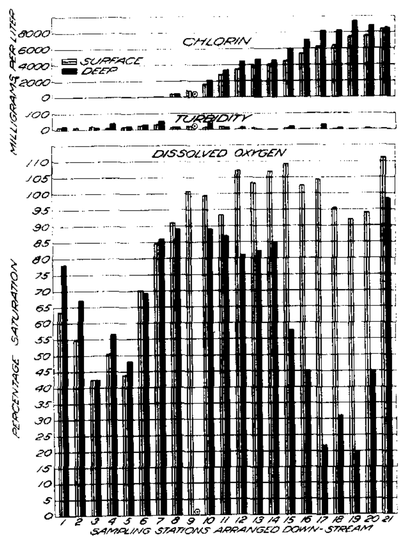

FIG. 4.—Lower Potomac River, Washington, D. C., to Point Lookout, September 21, 22, 1912.

is not so noticeable, the mixing of the water in that locality being fairly complete when samples were collected in November, 1912 (see chlorin curves, Fig. 11).

A comparison of the turbidity curves with the chlorin curves for both the Potomac and Maurice Rivers shows that, with two exceptions, which are evidently abnormal (Figs. 3 and 5), maximum turbidity is attained at the station where the content of chlorin begins to increase (Figs. 2, 4, 6, 7, 11). This relation is most evident when the fresh water of the rivers is quite turbid (Figs. 2, 3, 7), and indicates a precipitation of matter which had been dissolved in the fresh river water. A noticeable feature of the turbidity curves is that the rise to a maximum and the fall take place within a few sampling stations above and below the rise in salinity.

Cummings[3] has stated that the area from Indian Head to Maryland Point in the lower Potomac River is a great natural basin in which sedimentation is caused by the irregularity in velocity and direction of current and by the admixture of enormous volumes of sea-water, with its inability to carry large proportions of suspended matter.

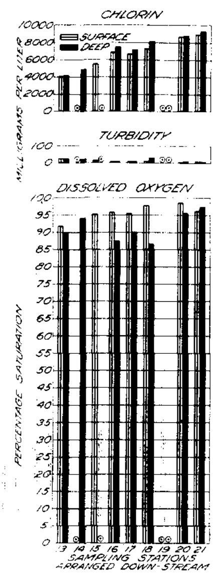

FIG. 5.—Lower Potomac River, off Pope's Creek, Maryland, to Point Lookout, October 24, 25, 1912.

These conclusions are confirmed by the data expressed in graphic form in Figs. 2, 3, 4, 6, 7.

An inspection of Chart No. 559 of the United States Coast and Geodetic Survey for the section of the lower Potomac River extending from lower Cedar Point to Mattawoman Creek shows an extensive series of flats between Maryland and Sandy Points, which it is believed have been formed by the precipitating and coalescing action of the salt water and subsequent sedimentation of the suspended matter. The channel of the river for a considerable distance opposite these flats is very narrow. For instance, off Douglass Point the river is about 2.7 miles wide, while the channel of the river is only about one-tenth of this distance, or 0.27 mile.

A study of the relations of the dissolved oxygen curves to the chlorin curves shows that when an under-run of salt water is present the dissolved oxygen curves for the deep samples are considerably lower than the curves for the surface samples, showing less dissolved oxygen in the deep samples than in the surface samples. When an under-run of salt water is absent (that is, when the water is practically uniform in composition),

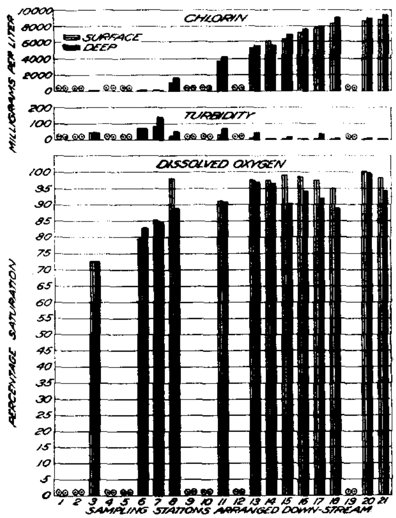

FIG. 6.—Lower Potomac River, vicinity of sewage outlet, to Point Lookout, December 3, 4, 1912.

the dissolved oxygen curves are closer together, or the deep samples may contain even more dissolved oxygen than the surface samples. For example, in September, 1912 (Fig. 4), the curves for surface and deep samples are relatively close together in that area of the lower Potomac River extending from Stations 1 to 7, while from Stations 8 to 21 they are widely separated. The chlorin curves show that above Station 7 the water was uniform in composition, while below Station 7 there was a marked under-run of salt water.

It is probable that the under-run of salt water in the Potomac Estuary and in Chesapeake Bay interferes with the distribution of oxygen by reason of its greater specific gravity, which keeps the denser water persistently on the bottom, thus hindering the mechanical mixing of the water by tides, winds, etc.

This stratification, due to concentration, is very persistent in the Potomac Estuary. It was present without exception each time samples were collected from that area under widely varying conditions of the weather. For example, on October 24, 1912, the wind was very high and the water of the estuary was very rough. For several days prior to this date a strong northwest wind had lowered the level of the water appreciably. Nevertheless, this

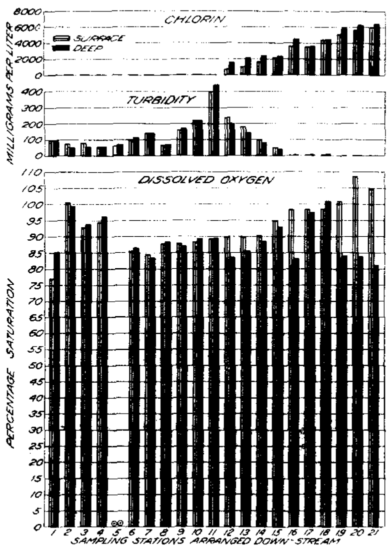

FIG. 7.—Lower Potomac River, Washington, D. C., to Point Lookout, April 15-17, 1913.

extreme agitation of the water of the estuary did not effect a uniform mixing (Fig. 5). Also, a few days prior to April 15, 1913, heavy rains occurred, following a rather dry season of about a month. The flood at this time pushed back the incoming salt water to Station 11, between Maryland Point and Riverside, some thirty miles below Station 7, off Whitestone Point, which was the upper limit of the salt water in September and December, 1912 (Figs. 4, 6, and 7). It will be noted that the under-run of salt water, together with the depleted oxygen content in the lower layer of water, persisted under these conditions.

The dissolved oxygen content has been expressed in percentage saturation. The lower curves for dissolved oxygen in the deep samples, therefore, represent an actual consumption of oxygen.

Since dissolved oxygen is consumed chiefly by the decomposi-

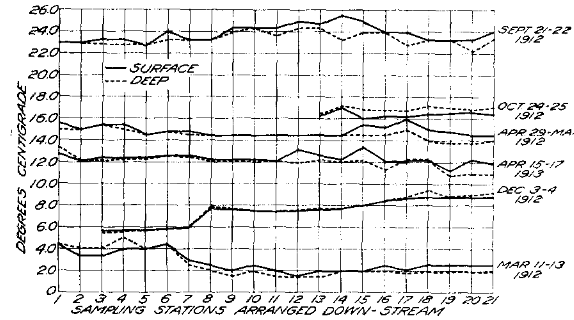

FIG. 8.—Lower Potomac River, Washington, D. C., to Point Lookout. Seasonal variations in temperature.

tion of inanimate organic matter, the stratum of water nearest to the decaying organic matter would suffer the greatest depletion of oxygen. The decomposable organic matter may be obtained from several sources. During high water in the river, a portion of the material which has been deposited by the process of salt-

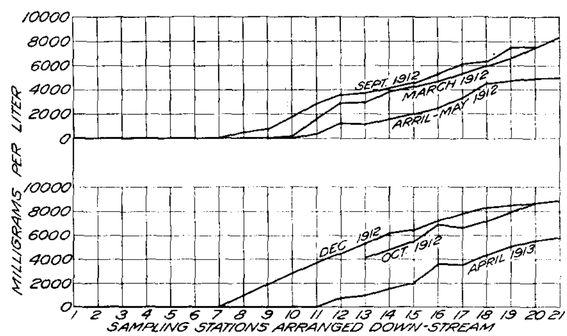

FIG. 9.—Potomac River chlorin curves, March, April, September, October, December, 1912, and April, 1913. (Surface samples.)

water precipitation referred to above, and by sedimentation in a rather restricted area, is stirred up and swept down stream with the current, to again gradually settle out over a larger area of bottom or to be collected in other portions of the river, favored because of the contour of the bottom or by the currents. Another source of decomposable matter is plankton forms, which die, settle to the bottom, and decompose. Purdy [4] has shown that the volume of plankton in the Potomac River in the vicinity of Point Lookout is greater than in any other portion of the lower river.

Broken-down, submerged plants, leaves, elutriated soil, and other débris which are carried into the estuary and bay by

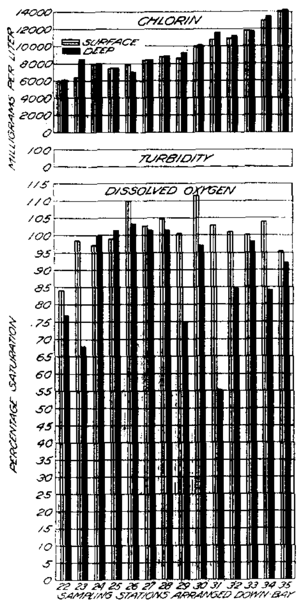

FIG. 10.—Chesapeake Bay, Annapolis to Fortress Monroe, September 20 and October 3, 1912.

Sampling Station, No.	Date collected	Depth, feet	Location
22	10–3–12	50	Off Annapolis.
23	10–3–12	50	One mile south Kent Island Light.
24	10–3–12	50	Off mouth Great Choptank River.
25	10–3–12	40	About two miles above Cove Point.
26	10–3–12	30	Off mouth Patuxent River.
27	10–3–12	30	Just above Point No Point Light.
28	10–3–12	24	Off Point Lookout.
29	9–20–12	60	4¼ miles off Smith Point Light.
30	9–20–12	30	9 miles off mouth Great Wicomico River.
31	9–20–12	40	10 miles off mouth Rappahannock River.
32	9–20–12	35	6 miles off shore, south of Piankatank River.
33	9–20–12	35	4 miles off Mobjack Bay.
34	9–20–12	30	13 miles off mouth of York River.
35	9–20–12	30	8 miles off Buckroe Beach.

numerous tributaries also furnish their quota of decomposable matter.

A certain amount of dissolved oxygen is consumed in the life-processes of marine organisms.

The dissolved oxygen, therefore, in the dense bottom layer of water is depleted chiefly by the decomposition of dead vegetable

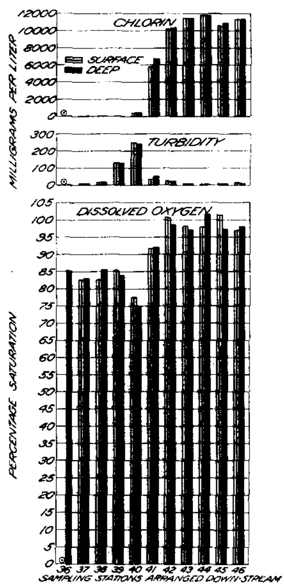

FIG. 11.—Maurice River and Delaware Bay, Millville to Egg Island Light, November 19, 20, 1912.

Sampling Station, No.	Date collected	Depth, feet	Location
36	11–19–12	12	Maurice River, at Millville.
37	11–19–12	12	Maurice River, at Kees Landing.
38	11–19–12	24	Maurice River, off Buckshuten.
39	11–19–12	26	Maurice River, at Morristown Bridge.
40	11–19–12	33	Maurice River, ¼ mile below Menhaden.
41	11–19–12	14	Maurice River, at mouth.
42	11–20–12	11	Delaware Bay, 5 miles S. by E. of East Point Light.
43	11–20–12	12	Delaware Bay, 5 miles S. of East Point Light.
44	11–20–12	13	Delaware Bay, 1½ miles S. W. Egg Island Light.
45	11–20–12	18	Delaware Bay, just outside False Egg Island.
46	11–20–12	9	Delaware Bay, about ⅓ mile off Egg Island Light.

and animal matter gathered from various sources, while the stratification of the water due to difference in specific gravity prevents a restoration of the supply from the saturated or supersaturated upper layers of water by hindering the mechanical mixing of the water by the tides, winds, etc.

The maximum reduction of dissolved oxygen in the Potomac Estuary and Chesapeake Bay was found in September and represents late summer conditions. At Stations 15 to 20 on this trip the dissolved oxygen was reduced to 57.5, 45.1, 21.6, 30.8, 19.7, and 45.1 percentage saturation. The actual volumes of oxygen (0° C. and 760 mm.), corresponding to the above figures for percentage saturation, are 3.2 c.c., 2.5 c.c., 1.2 c.c., 1.7 c.c., 1.1 c.c., 2.5 c.c., respectively (see Fig. 4).

It is to be expected that the maximum reduction in the dissolved oxygen content of the denser bottom layer of water would occur at this season of the year, since the supply of decomposable organic matter from plankton form, vegetation, etc., is greater during the summer months, and bacteria which assist in the breaking down of the organic matter are most active at this season, because of the higher temperature. It will be noted, from an inspection of the curves for seasonal variation in temperature (Fig. 8), that the water was about 23° C. at this time. In October the temperature had fallen to about 17° C., and in March was about 2° C., the lowest temperature noted.

Lebedinzeff [5] reported diminished dissolved oxygen content at depths of 183 to 200 metres in the Black Sea, and it is of interest to note that no life was found below 183 metres. As in the Potomac Estuary and Chesapeake Bay, vertical circulation was cut off in the Black Sea by stratification due to increase in concentration with increased depth.

It appears that thermal stratification may exist to a slight extent in the Potomac Estuary (Fig. 8). However, the variation in temperature of the surface and deep samples is generally of the order of 1° C. or less. This body of water may be regarded, therefore, as homothermous.

The chlorin and dissolved oxygen curves for May, 1912, and for April, 1913, are very similar, and their comparison is of interest, as showing the annual recurrence of seasonal conditions (Figs. 3 and 7).

SUMMARY.

It has been shown that the lower layers of certain tidal waters under investigation contain less dissolved oxygen than the upper layers. Evidence has been presented to show that this phenomenon is caused by the stratification of the water due to the specific gravity of the under-run of sea-water, which cuts off vertical circulation, and to the subsequent depletion of the oxygen in the lower layers by natural agencies. The depletion of oxygen was found to be greatest in September. The precipitation and sedimentation of matter in tidal areas by sea-water have been presented in graphic form. These data are considered to be of particular interest from the viewpoint of fish and shellfish life.

WASHINGTON, D. C., June, 1917.

REFERENCES.

[1] Birge and Juday, Wis. Geo. and Nat. Hist. Sur., 1911, Bul. 22.

[2] Helland-Hansen, "Meddelelser om Oesteraylen," III, pp. 1-109 (1907); abstract, Wis. Geol. and Nat. Hist. Sur., 1911, Bul. 22, p. 63.

[3] Cummings, Bul. 104, Hyg. Lab., Wash., pp. 224, 229.

[4] Purdy, Hyg. Lab., Wash., Bul. 104, pp. 152, 190.

[5] Lebedinzeff, "Aus. der Fischzuchtanstalt Nikolsk," No. 9, pp. 113-136 (1904); abstract, Wis. Geol. and Nat. Hist. Sur., 1911, Bul. 22, p. 60.

Heating Houses With Gas. E. D. MILENER. (*American Gas Engineering Journal,* vol. cvii, No. 18, p. 393, November 3, 1917.)—As a producer of heat units on the generous scale requisite for such service as house heating, manufactured city gas has not in the past been able to compete with coal, and the householder has had to accept the inconveniences of the latter fuel. There are, of course, other economies than those of fuel cost gained by the use of gas, and latterly, in Baltimore, the Consolidated Gas, Electric Light and Power Company has demonstrated that fuel-gas house heating is possible by the maintenance of a house-heating service supplying 500 dwellings.

An efficient furnace is a prerequisite to success with gas fuel. Even with gas at 35 cents a thousand cubic feet and coal at $8.50 a ton, the average fuel cost of heating an entire house with gas will be at least 25 per cent. more than with coal, and to keep this difference from being greater it is necessary that the best equipment only be used and proper attention given to its operation. A three-story cottage equipped with a gas-fired steam-heating system consumed, during the eight months from October to May, 465,800 cubic feet of gas. The lowest monthly consumption, during October, was 23,700 cubic feet, and the highest, during February, was 88,700 cubic feet.