REPORT ON

EFFECT ON DISSOLVED OXYGEN LEVELS

OF DISCHARGING TREATED MIXED EFFLUENTS

INTO RARITAN BAY

BY

DEPARTMENT OF SANITATION, RUTGERS UNIVERSITY

AND

DIVISION OF ENVIRONMENTAL SANITATION

N.J. STATE DEPARTMENT OF HEALTH

A SUPPLEMENT TO REPORT ON

STATUS OF POLLUTION OF THE RARITAN RIVER AND BAY

AND

EFFECT OF DISCHARGING INTO THE BAY TREATED MIXED EFFLUENTS

JANUARY, 1951

NOVEMBER, 1952

Introduction

The results of an extensive sanitary survey of Raritan Bay were given in the 1951 Rudolfs-Fletcher report on the status of pollution of Raritan Bay. The survey was made over a period of four weeks from July 24th to August 15th, 1950. Samples of Bay water were taken from a grid of sixteen sampling stations which covered the entire head area of the bay out to the 3-mile line. Samples were taken on eight different days, two days each week, with one set each week taken at high tide and the other at low tide. On the bay alone 1280 samples were taken and 2816 separate analyses made.

During the survey period dry weather prevailed, and the flow in the Raritan River was uniform and low, averaging an estimated 225 mgd at Perth Amboy. Because of the favorable weather conditions a steady state condition existed in the Raritan River and the headwaters of Raritan Bay. Analyses of the waters were remarkably uniform for the same tidal condition, and it was thus possible to arrive at definite conclusions regarding various factors of sanitary significance, such as the degree of pollution, the movement of water within the bay area, the relative concentrations of fresh and salt waters, and other related phenomena.

The reliability of the data also favored the accuracy of conclusions made concerning the effect on the bay waters of the discharge of effluent into the bay from the proposed chemical treatment plant of the Middlesex County Sewerage Authority.

The purpose of this supplemental report is to amplify the findings and conclusions of the original report concerning the effect of the discharge of treated effluent on the dissolved oxygen content of the bay waters, particularly those waters in the head area out to the 3-mile point.

The following are the conclusions reached in the original report which are pertinent to the problem of dissolved oxygen concentration in the bay waters:

1. The organic pollution in the bay presents no problem, because of dilution and self-purification forces at work. (Page 21)

2. The dissolved oxygen condition in the bay can be considered non-critical. The average minimum for the entire bay was 64 per cent saturation, while the minimum for any sampling station at any given time during the survey was 50 per cent. Stabilization of the pollution load is brought about without seriously affecting the dissolved oxygen content of the water, because of oxygen supplied by the incoming salt water and surface reaeration. (Page 59)

3. The dissolved oxygen concentration in the bay is sufficiently high to prevent the fish population to be affected by a deficiency in oxygen. (Page 59)

4. As indicated by dissolved oxygen content and coliform density conditions in the bay were poorest during low tide and best during high tide. (Page 59)

5. Higher dissolved oxygen saturation values are present near the surface of the bay than near the bottom, pointing toward the greater influence of surface reaeration as compared with oxidation of pollutional material. (Page 59)

Since it was evident from the results that dissolved oxygen levels in the bay would not be an important problem, no attempt was made in the Rudolfs-Fletcher report to calculate reaeration rates of the bay waters and make predictions as to the actual dissolved oxygen content after discharge of treated sewage plant effluent. However, sufficient data are available from the survey results given in the report and listed in the tables therein to make such calculations and predictions.

Basic Considerations

In making the necessary calculations for such predictions certain estimates must be used concerning the volume and strength of the treated effluent discharged, the concentration of the effluent in the bay, the time the effluent remains in the bay area concerned, and the oxidation rate of the effluent. The estimates of these factors used for the calculation of dissolved oxygen levels are all the most conservative that can be used consistent with the data available. Thus, the dissolved oxygen levels calculated are minimum and show the maximum expected effect on the bay waters. The following are the most important basic figures and considerations used in the calculations: ? assumed

1. The original survey was made during the warmest period of the summer when deoxygenation rates were a maximum and dissolved oxygen levels a minimum. Thus, the survey covers the most critical period of the year from the standpoint of dissolved oxygen concentration.

2. The volume of effluent discharged is estimated to be 125 million gallons per day. This is 11% greater than the expected average daily discharge of 112 mgd for the year 2000 which was estimated

for the original trunk sewer proposal. (Reference 1)

3. The maximum 5-day B.O.D. of the chemically treated mixed wastes is 150 ppm. (Reference 2)

4. The maximum expected effluent concentration in the bay waters is 3.7%.

5. A maximum oxidation rate of the effluent is used which is twice the observed oxidation rate. What effect? Any? have to use ultimate BOD?

Summary and Conclusions

The following are the summarized results and conclusions from a detailed study of reaeration and deoxygenation of the waters in the head area of Raritan Bay: (The supporting calculations and technical considerations are given in the Technical Considerations section of this report.)

1. The total reaeration of the waters in Raritan Bay is considerable, amounting to a minimum of 70% of the dissolved oxygen deficiency per day.

2. The waters in the head area of the bay (between the 1-and 3-mile points) will have a minimum average dissolved oxygen content of 75% of saturation when treated sewage plant effluent is discharged two miles out into the bay. (Based on maximum expected biochemical oxygen demand of the effluent, maximum effluent concentration of the bay water, maximum bay water temperatures, and minimum reaeration rates)

3. An average dissolved oxygen level in the bay waters out to the 3-mile point of 85% saturation will provide sufficient reaeration to supply all of the daily B.O.D. requirements of the treated effluent discharged into the head area of the bay.

4. The dissolved oxygen content of the waters adjacent to the shores of Perth Amboy will increase from the present average of 62% saturation to approximately 85% saturation when the pollution is removed from the river and the treated effluent discharged two miles out into the bay. Since the waters adjacent to Perth Amboy show the lowest average dissolved oxygen content, they will be most benefited by the removal of pollution from the river.

5. The minimum dissolved oxygen levels will occur just over the proposed outfall discharge points. At the maximum effluent concentration conceivable the minimum dissolved oxygen content of the water will be 67% of saturation.

6. The maximum possible average dissolved oxygen content of the bay waters is 90% saturation. This represents the average dissolved oxygen content of the sea water entering Raritan Bay from the Atlantic Ocean.

Respectfully submitted,

(s) Harold E. Orford

(s) H. Heukelekian

Department of Sanitation
Rutgers University

(s) Alfred H. Fletcher
Director, Division of
Environmental Sanitation,
N.J. State Department of
Health

TECHNICAL CONSIDERATIONS

Pertaining to
Reaeration and Deoxygenation of Raritan Bay Waters

The most reliable method of predicting the effect of discharging treated sewage plant effluent on the dissolved oxygen levels in Raritan Bay is to consider the combined simultaneous effects of reaeration and deoxygenation. The rate of deoxygenation of the effluent can be determined experimentally in the laboratory and the deoxygenation effect on the bay waters calculated. The rate of reaeration cannot be determined experimentally and must be calculated from dissolved oxygen and B.O.D. information obtained over an extended period from a large area of the bay.

Pertinent Information Concerning the B.O.D., Dissolved Oxygen Content and the Reaeration of Raritan Bay (Summarized from Rudolfs-Fletcher Report, January 1951)

Average	Dissolved Oxygen in Bay	77.5% of Saturation
"	Chlorides of Bay Water	14,650 ppm
"	Temperature	22.9°C.
"	Dissolved Oxygen at Saturation	7.4 ppm
"	Dissolved Oxygen Level	5.7 ppm
"	Dissolved Oxygen Depletion	1.7 ppm
"	5-Day B.O.D.	2.15 ppm
Average	Flow in Raritan River during the Study	225 mgd

Reaeration

Before estimates can be made of the effect of the effluent three days

on dissolved oxygen levels in the bay, it is necessary to determine reaeration rates. The above summarized data was used to determine average reaeration rates in the head end of the bay (out to three miles). The data presented are average values for high and low tide conditions over a period of four weeks.

Assuming that the water stayed in the area for three days*, the 3-day or total oxygen demand was 1.6 ppm ($k = 0.1$ - assumed for bay water). Since equilibrium conditions had been reached, the deoxygenation rate was therefore $\frac{1.6}{3} = 0.53$ ppm/day which is also equal to the reaeration rate.

check with Ayers report

$$\text{The reaeration rate, } k_2 = \frac{0.53}{1.7} = 0.31$$

For the area in the bay around the proposed outfall (Stations 13 to 20, Rudolfs-Fletcher report), the average D.O. was 80.5% of saturation and the B.O.D. 2.05 ppm. The 3-day B.O.D. was 1.5 ppm, and the deoxygenation rate was $\frac{1.5}{3} = 0.5$ ppm/day which equals the reaeration rate. The average D.O. deficit was $7.4 \times .195 = 1.44$ ppm. Therefore,

$$\text{The reaeration rate, } k_2 = \frac{0.5}{1.43} = 0.35.$$

The above are considered as minimum reaeration rate constants. No allowance was made in the reaeration calculations for the dissolved oxygen deficit of the water entering the bay from the Raritan River. The average dissolved oxygen concentration at the Victory Bridge was 4.0 ppm, and the water leaving the bay area concerned had a D.O. of $0.8 \times 7.4 = 6.0$ ppm. There was therefore an increase of 2.0 ppm D.O. in three days or 0.67 ppm/day.

---

*From page 24, Woods Hole Oceanographic Institution Report (Reference 3)

If this is added to the deoxygenation per day, the total re-aeration is 0.53 + 0.67 = 1.20 ppm D.O. per day and the reaeration rate constant $k_2 = \frac{1.2}{1.7} = 0.7$. A reaeration rate of 0.7 simply means that the amount of oxygen entering the water per day is 70% of the oxygen under-saturation. Since the rate was calculated from observed conditions, it is an overall rate which includes oxygen sources other than that from surface diffusion of oxygen into the water. Overall reaeration rates in the bay are high which should be expected because;

1. There is a good algae growth in the bay which increases oxygenation. In some portions oxygen saturation is over 175%. what portion?

2. Wind and wave action promote rapid reaeration of the water.

3. The water discharged from the river into the bay on the ebb tide flows out into the bay for a distance of at least 4 miles on one tide. This promotes mixing over a much wider area than is generally realized, and brings extra oxygen-rich sea water back into the area to supply extra oxygen. ???

Effluent Distribution in the Bay

The Tidal Excursion at the proposed outfall is conservatively estimated to be approximately two miles, as estimated from:

1. Float studies by Udell show tidal excursion from the proposed 2-mile discharge point of 2 to 3 miles. (Reference 4)

2. Woods Hole Oceanographic Institution report of October, 1950 on circulation patterns shows an excursion of 2.1 miles. (Reference 5)

3. Calculations made for the Rudolfs-Fletcher report show an average seaward velocity in the vicinity of the outfall on ebb tide of

3,000 ft/hr. x 6 hours = 18,000 ft. or 3.4 miles.

For purposes of estimating maximum average effluent concentrations in the bay, a segment two miles long is used. (Woods Hole Oceanographic Institution used three miles.) This 2-mile distance was used because:

1. It is a conservative value for the tidal excursion at the outfall.

2. The seaward fresh water drift at this point was calculated to be 3,300 ft./day. Using Woods Hole Oceanographic Institution estimates of six tidal cycles to clear the area, the seaward drift would be $\frac{6}{2} \times 3,300 = 10,000$ ft. or approximately 2 miles.

<u>Effluent Concentrations over the Area Considered</u>

The width of Raritan Bay at the outfall point is 2.4 miles. Therefore, the area to be considered is 2 x 2.4 = 4.8 sq. miles. The average depth over this area is 10 ft. and the volume of water in this prism is 1,340 million cu. ft.

Assuming the effluent flow to be 125 mgd. (16.5 m cu.ft./day), there would be discharged 50 mcf in three days. This would give a maximum average effluent concentration of 3.7%.

<u>B.O.D. Concentrations over the Area Considered</u>

For purposes of B.O.D. estimation the 5-day B.O.D. of the effluent is taken at 150 ppm (Rutgers University reports) and the 3-day B.O.D. as 100 ppm (Maximum effluent B.O.D. values - Rutgers University Reports - Reference 2).

If the effluent concentration is 3.7%, the 3-day B.O.D. of the bay water in the area would be .037 x 100 = 3.7 ppm. Therefore, the average daily oxygen demand will be $\frac{3.7}{3} = 1.23$, say 1.2 ppm per day.

Dissolved Oxygen Levels in the Area Considered

In addition to the B.O.D. requirements of the effluent, there is an additional oxygen requirement caused by the discharge of effluent with zero dissolved oxygen content. Since the effluent concentration will be 3.7% in three days, the daily effluent concentration will be $\frac{3.7}{3} =$ 1.23, say 1.2%. This will tend to reduce the dissolved oxygen level of the water 1.2% (.012 x 7.4 ppm D.O. = .09 ppm D.O.) or approximately 0.1 ppm D.O. per day.

The total average oxygen requirement is therefore 1.2 + 0.1 = 1.3 ppm D.O. per day. With a reaeration rate $k_2 = 0.7$ the dissolved oxygen deficit will be $\frac{1.3}{0.7} = 1.85$ ppm D.O. Since the D.O. saturation value is 7.4 ppm, the expected D.O. level will be $\frac{7.4 - 1.85}{7.4} = 75\%$ of saturation. In other words, a dissolved oxygen level of 75% of saturation will supply oxygen to the water at the same rate as the oxygen demand.

The estimated dissolved oxygen level in the 4.8 sq. mile area at the effluent discharge point is considered to be a conservative figure for the following reasons:

1. No allowance has been made for any excess oxygen carried into the area by Raritan River water discharged into the Bay.

2. No allowance has been made for any excess oxygen carried into the area by bay water as it moves from the Perth Amboy section seaward.

3. No allowance has been made for any reaeration outside the area concerned.

In evaluating the dissolved oxygen levels in the area at the head of the bay, the oxygen levels over the entire area should be considered:

1. The Raritan River discharges on ebb tide out into the bay a distance of about 4 miles. This will bring a considerable amount of dilution water with a high oxygen content into the effluent discharge area 2 miles out in the bay.

2. Reaeration taking place in the bay waters inside the 2-mile effluent discharge point will supply oxygen which will eventually become available to satisfy effluent oxygen demands as this water moves seaward.

In order to estimate the effect of this possible reaeration, the entire head area of the bay out to the 3-mile point is considered as a single unit. This is an area of approximately 9 sq. miles. The water averages about 10 ft. deep at low tide giving a total volume of 18,800 m.g. of water.

For this volume 1 ppm of dissolved oxygen amounts to 156,000 lbs. of oxygen.

The total 3-day oxygen demand of the effluent is 104,000 lbs. oxygen per day (for 125 mg/day flow and 100 ppm 3-day B.O.D.).

If the reaeration rate constant, k_2, is 0.7 for the entire area, then an average dissolved oxygen deficit of 1.0 ppm D.O. would provide reaeration of 109,000 lbs. of dissolved oxygen per day (156,000 x 0.7 = 109,000). This is enough to equal the daily B.O.D. load introduced by the effluent.

The dissolved oxygen deficit would be only 0.2 ppm greater than the normal expected dissolved oxygen deficit of the sea water which amounts to 0.8 ppm (estimated by Woods Hole Oceanographic Institution, page 29, Reference 3), and the water would have a D.O. saturation of approximately 85%.

Thus, when the entire bay head area is considered, sufficient reaeration would occur to supply the expected effluent oxygen demand at 85% dissolved oxygen saturation of the water. Since the normal expected saturation of the sea water is only about 90%, the effluent will have a negligible effect on the dissolved oxygen content, when the waters in the head of the bay are considered as a whole.

The estimation of dissolved oxygen levels in the immediate area around the effluent discharge point is difficult. The discharge point will be located where the tidal movements seaward afford the greatest degree of dilution. Also, the rate of biological oxidation of the effluent is low, about one-third that of domestic sewage. In addition, biological oxidation of the effluent exhibits a definite lag period. The combination of these three factors will tend to reduce the rate of deoxygenation in the waters adjacent to the discharge point.

The maximum effluent concentration, and therefore minimum dissolved oxygen levels, will occur immediately over the effluent discharge points. It is estimated that the maximum effluent concentration at these points will be 10% (Woods Hole Oceanographic Institution Report, page 35, Reference 3). Assuming 75% oxygen saturation for the waters surrounding the outfall area, the minimum dissolved oxygen level at the outfall point will be 5.0 ppm D.O. ($\frac{0.1 \times 0 + 0.9 \times 7.4 \times .75}{1}$ = 5.0 ppm D.O.) The minimum expected dissolved oxygen saturation at the outfall point is therefore $\frac{5.0}{7.4} \times 100 = 67.5\%$.

REFERENCES

1. Summary Report to the Middlesex County Sewerage Authority upon Abatement of Water Pollution in the Raritan River, Its Tributaries, and Raritan Bay - Metcalf & Eddy and Elson T. Killam, March 1951.

2. First and Second Reports on the Characteristics and Behavior of Mixture of Wastes Produced in the Raritan River Valley - Willem Rudolfs.

3. Report to Middlesex County Planning Board on Hydrographic Considerations Relative to the Location of Sewer Outfalls in Raritan Bay - Woods Hole Oceanographic Institution, May 1949.

4. Bacterial Pollution of Raritan and Lower Bays and Its Relation to Shellfish - H. Udell, Thesis, Rutgers University, May 1952.

5. Circulation Patterns in Raritan Bay - Woods Hole Oceanographic Institution, October 1950.