Hydrography and Hydrodynamics of Virginia Estuaries: Dye Tracer Study and Elizabeth River System

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HYDROGRAPHY AND HYDRODYNAMICS
OF VIRGINIA ESTUARIES

IV. Dye Tracer Study at Elizabeth River System

by

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Director

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ACKNOWLEDGEMENTS

The authors wish to thank Dr. Bruce Neilson and Mr. William Athearn for their direction of the field study. We are indebted to Mr. William Matthews for his supervision of the technical personnel from Physical Oceanography and Ecology-Pollution Departments to whom we also extend our thanks.

Funding of this project was provided in part by the Virginia State Water Control Board. The cooperation of the Hampton Roads Sanitation District, both in funding and help during this study is greatly appreciated.
INTRODUCTION

Purpose

During the inclusive dates of April 10 to April 14, the Virginia Institute of Marine Science Department of Physical Oceanography and Hydraulics in conjunction with the Ecology-Pollution group conducted a fluorescent dye study on the Elizabeth River in Virginia. The objective of this study was to provide a physical picture of the typical distribution of the Lambert Point sewage treatment plant effluent in the Elizabeth River complex.

Study Area

A tributary of the mouth of the James River, the Elizabeth River runs through densely populated areas of Norfolk and Portsmouth, and falls into the James at Hampton Roads, adjacent to the Chesapeake Bay.

The area under study included Elizabeth River channels in the Norfolk Harbor Reach from Sewells Point to Tanner Point; Craney Island Reach, Lambert Bend, Port Norfolk Reach and Town Point Reach. Branches studied were the Lafayette River to the first fixed bridge; the Western branch, to the Churchland Bridge; the Eastern Branch and Southern Branch to just beyond their respective mouths. In short, the river complex between 36°50' to 58' latitude and 76°17' to 20' longitude, excluding the Willoughby Bay, was studied. The Elizabeth River has a drainage area of 216.77 square miles and a total water area of 21.18 square miles. The drainage area of the Lafayette River is 14.14 square miles, and its total water area, in square miles is 2.57.
There are a total of five (5) major sewer outfalls in the above stated vicinity of which, the treatment plant at Lambert Point is the largest. VIMS did this study at the request of the Hampton Roads Sanitation District of Virginia.

Approach

The theory of the dye study was to treat the dye in such a way that it was representative of the substance in question, e.g. effluent. By tracing the dye, which is immeasurably easier to follow than the sewage effluent, principle areas of concentration and dispersion in the system could be determined. Also, a hydrographic survey, determining the distribution of temperature, salinity and dissolved oxygen, (plus general weather and sea state observations) was executed during the same period.

DYE AND HYDROGRAPHIC SURVEY

Project Plan

As stated above it was necessary to treat the dye so that when traced, it would be a reliable parameter for following the sewage effluent. Therefore the dye was released in the Lambert Point effluent and, through series of samplings, over several tidal cycles, was traced in its mixing and dispersion travels through the Elizabeth River complex.

Field Study

The dye used in this study was a 20% solution of Rhodamine WT, sold by the E. I. DuPont Company. The constant rate injection of 20 gallons of this dye was accomplished by means
of a Cole-Palmer variable-rate metering pump, which was gauged to pump 1/2 gallon of dye per hour into effluent going directly to the river.

Dye release was started at slack water before flood (approximately 0100 hours) on April 11, and continued for about 40 hours.

Sampling was accomplished by two methods. First, sampling was started on each anchor station 12 hours after the initial dye release and consisted of hourly samples from one meter below the surface, approximate mid-depth, and one meter above the bottom (figure 1). This routine was followed on stations 1, 2, 3, 4, 5A, 5, 6A and 6 during daylight hours (0600 to 1800). The second procedure was accomplished during slack water periods. Stations 3A, 7, 8 and 10 were sampled by station boats, and a boat followed slack water, sampling stations S1 through S8. Therefore the resultant graphs of river profiles, on hours of slack water, will have eight (8) additional data points.

Conjunction of the dye study with hydrographic conditions was done by having in situ temperatures from each depth and samples for salinity and dissolved oxygen each taken hourly. On April 12, samples were also taken to be analyzed in nutrient studies.

Five boats, each with a crew of two were used during the study. This necessitated each boat having to collect samples on two or more stations, and the slack water boat sampling 8 stations during each run.
Acquisition

A G. K. Turner Associates Model 111 filter fluorometer equipped with a high sensitivity cuvette holder, Model 110-880A was used to monitor dye travels and concentrations. Due to a lack of equipment, the samples had to be bottled and brought back to the lab for analysis, rather than using a fluorometer in the field for continuous flow-through monitoring.

The filter combination used in the fluorometer was a Turner-supplied Kodak filter #61 for the primary or excitation filter, and a Corning #3-66 (orange) in combination with a Corning #4-97 (blue-green) for the secondary filter. As an excitation source, white-phosphor coated general purpose U.O. lamps were used. The primary filter isolates the narrow band of green light from the lamp peaking at 546 nm. This excites the main absorption band of the Rhodamine WT, which peaks at 558 nm. The secondary filter, peaking at 590 nm, isolates the Rhodamine fluorescence which peaks at 582 nm.

The fluorometer was calibrated before, after and during use with standard dye dilutions in distilled water. The calibration curves were then used to reduce the reading of each sample to useable values, e.g. parts per billion dye.

No corrections were needed due to suspended sediment variables (found by testing prepared samples), or for temperature variables, since all samples were stored at room temperature for at least 24 hours prior to analysis.

Salinity samples were analyzed at the laboratory using a Beckman RS-78 salinometer, and dissolved oxygen determinations
were made by the azide modification of the Winkler method. Temperatures were measured in situ using Applied Research Austin thermistors and ARA model ET100M readouts.

Plotted curves for salinity values are contained in this report, along with dye concentration curves for stations, hour by hour, and river profile, per hour.

RESULTS

Figures 1 through 5 show the salinity distributions at different depths through eight (8) miles of the Elizabeth River. The eight (8) stations (S1 through S8) were sampled only during slack water periods for every parameter before, during, and after the dye study.

In figures 6 through 13, average dye concentrations in individual water columns are shown with respect to tidal changes at each particular sampling station. High and low slack water periods are so indicated in addition to the location of each station.

Figure 14 shows the average dye concentration (in P.P.B.) over water columns versus river miles at slack water periods on April 12, 13 and 14, 1972.

Figures 15 through 24 show changes in average dye concentration over the Elizabeth and Lafayette Rivers profile on a two, three or four hour basis. From these graphs one can readily see dye concentration fluctuations over particular sections of a tidal cycle.

The first day of the study (April 11) is shown over only one-half of a tidal cycle because the dye was still being
pumped into the river and sufficient time for complete mixing of the dye in water columns had not elapsed.

Dye concentration patterns for the continuous release are presented in figures 25 through 47. Values of the contours are in parts per billion dye, and represent dye concentration after correction for background fluorescence.

The contours on these maps were predicted from average values obtained over the vertical depth of mid-channel. Contour shape was estimated from first hand observation in the field and model results from CBM in Vicksburg, Mississippi.

From figures 25 to 29 and 33 through 47 we can see that higher concentration dye patterns have advanced up the Lafayette River channel, leaving higher dye concentration water to this branch, rather than flushing it out through the Elizabeth River mouth into Hampton Roads.

From these results we can logically surmise that in the Lafayette River the water moves only back and forth with poor flushing action, therefore acting as a source and sink for, in this case, dye.

This same "source and sink" characteristic is demonstrated (though not to such a great degree) in the Western Branch (figures 25 through 27 and 35 through 41) and in the Eastern Branch (figures 25 through 27, 35 through 40, and 43 through 46).

In general, dissolved oxygen remained over saturation throughout the study area, with the average value being about 10 mg/l. It is felt that this over saturation was due to seasonal changes, in this case, low water temperature and a high influx of fresh water.
Water temperature also remained essentially constant in the area throughout the study period. (A chart of general weather conditions can be found in Table 1).

RECOMMENDATIONS

The Elizabeth River is an integral part of the Norfolk-Portsmouth metropolitan area, receiving primary treated sewage from HRSD treatment plants, waste from the many ships in the harbor, and effluent from the many industries in the area.

For these reasons, and from results obtained in this study, it is recommended that a detailed study be undertaken to determine; tidal flushing rate, nutrient levels, present and future; and the finer intricacies of tidal movement in the river complex. These studies would then be coupled to differing seasonal weather conditions in the hope that methods be found to improve water quality and increase the efficiency of waste disposal for all concerns in the Norfolk-Portsmouth area.
<table>
<thead>
<tr>
<th>Date</th>
<th>Air Temperature Max. °C</th>
<th>Air Temperature Min. °C</th>
<th>Average Water Temperature °C</th>
<th>Average Wind Speed (knots)</th>
<th>Wind Direction</th>
<th>Visibility</th>
<th>Seas</th>
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<td>April 10</td>
<td>18.5</td>
<td>3.5</td>
<td></td>
<td>12</td>
<td>SW</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>22.0</td>
<td>13.5</td>
<td>9.8</td>
<td>10</td>
<td>NE</td>
<td>good</td>
<td>low</td>
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<tr>
<td>12</td>
<td>15.0</td>
<td>10.0</td>
<td>10.3</td>
<td>11</td>
<td>SW</td>
<td>poor</td>
<td>calm</td>
</tr>
<tr>
<td>13</td>
<td>27.0</td>
<td>11.0</td>
<td>11.0</td>
<td>12</td>
<td>SW</td>
<td>poor</td>
<td>rough</td>
</tr>
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</table>
Figures 1 - 5. Salinity distributions along the Elizabeth River, Virginia during slack water.

Figure 1. Low water slack - April 11, 1972 1300 hrs.
Figure 2. High water slack - April 12, 1972 0700 hrs.
Figure 3. Low water slack - April 12, 1972 1500 hrs.
Figure 4. Low water slack - April 13, 1972 1500 hrs.
Figure 5. High water slack - April 14, 1972 0900 hrs.
LOW WATER SLACK
APRIL II, 1972 1500 HRS.
△ Surface
▽ Middle
□ Bottom

Figure 1:
HIGH WATER SLACK
APRIL 12, 1972 0700 HRS.
△ Surface
▼ Middle
□ Bottom

SALINITY (P.P.T.)

Miles 1 2 3 4 5 6 7 8

SEWELLS PT. CRANEY I. EFFLUENT TOWN PT.

Figure 2
LOW WATER SLACK
APRIL 12, 1972 1500 HRS.

△ Surface
▽ Middle
□ Bottom

Figure 3.
LOW WATER SLACK
APRIL 13, 1972 1500 HRS.

Surface
Middle
Bottom

Figure 4
HIGH WATER SLACK
APRIL 14, 1972 0900 HRS.

\( \triangle \) Surface
\( \triangledown \) Middle
\( \square \) Bottom

Figure 5.
Figure 2.

HIGH WATER SLACK
APRIL 12, 1972 0700 HRS.

Δ Surface
▽ Middle
□ Bottom
Figure 3.

SALINITY (P.P.T.)

LOW WATER SLACK APRIL 12, 1972 1500 HRS.

APRON 12, 1972 1500 HRS.

△ Surface
vio Bottom
LOW WATER SLACK
APRIL 13, 1972 1500 HRS.
△ Surface
◇ Middle
□ Bottom

Figure 4.
Figure 5.

HIGH WATER SLACK
APRIL 14, 1972, 0900 HRS.

△ Surface
▼ Middle
□ Bottom

SEWELLS PT.

CRANEY I. EFFLUENT

Miles

21
20
19
18
17
16
15

SALINITY (PPT)
Figures 6 - 13. Time variation of dye concentration (in parts per billion) averaged over water column.

Figure 6. Station 001 - 3.5 miles downstream from outfall via Norfolk Harbor Reach.

Figure 7. Station 002 - 1.6 miles downstream from outfall via Norfolk Harbor Reach.

Figure 8. Station 003 - 1.3 miles downstream from outfall via Lafayette River channel, in mouth of same.

Figure 9. Station 004 - 750 yds. adjacent to outfall in Craney Island Reach.

Figure 10. Station 05A - 1.0 miles upstream from outfall around Lambert's Point via Lambert Bend.

Figure 11. Station 005 - 1.5 miles upstream from outfall in mouth of Western Branch.

Figure 12. Station 06A - 1.6 miles upstream from outfall via Lambert Bend.

Figure 13. Station 006 - 2.5 miles upstream from outfall via Port Norfolk Reach and Lambert Bend.
Figure 6. Dye Concentration (ppb)

- Low Slack
- High Slack

STATION 001

APRIL 11, 1972

TIME OF DAY (24-HOUR CLOCK)

06 08 10 12 14 16 18
APRIL 12

06 08 10 12 14 16 18
APRIL 13

06 08 10 12 14 16 18
APRIL 11, 1972

DYE CONCENTRATION (PPB)
Figure 12.
Figure 14. River profiles during slack periods of dye concentrations (in p.p.b.) averaged over the water column.

Figure 15. April 11, 1972 - 1300 through 1600
Figure 16. April 11, 1972 - 1600 through 1800
Figure 17. April 12, 1972 - 0600 through 0800
Figure 18. April 12, 1972 - 0900 through 1300
Figure 19. April 12, 1972 - 1400 through 1700
Figure 20. April 12, 1972 - 1700 through 1800
Figure 21. April 13, 1972 - 0600 through 0900
Figure 22. April 13, 1972 - 0900 through 1200
Figure 23. April 13, 1972 - 1200 through 1500
Figure 24. April 13, 1972 - 1500 through 1800
Figure 15.
APRIL 12, 1972

- O 1400 Low Slack
- • 1500
- □ 1600
- △ 1700 Max. Flood

DYE CONCENTRATION (P.P.B.)

SEWELLS PT.

ELIZABETH RIVER MILES

LAFAYETTE RIVER MILES

sewage outfall

mouth

Figure 19.
Figure 21:

APRIL 13, 1972

- 0600 Max. Flood
- 0700
- 0800
- 0900 High Slack

DYE CONCENTRATION (P.P.B.)

LAFAYETTE RIVER MILES

SEWELLS PT.

ELIZABETH RIVER MILES

TOWN PT.
Figure 22.
Figure 23.
APRIL 13, 1972

- O 1500 Low Slack
- ● 1600
- □ 1700
- △ 1800 Max. Flood

DYE CONCENTRATION (P.P.B.)

ELIZABETH RIVER MILES

SEWELLS PT.

TOWN PT.

Figure 24.

Figure 25. 0700 - April 12 - High slack
Figure 26. 0800 - April 12 - Early ebb
Figure 27. 0900 - April 12 - Pre-maximum ebb
Figure 28. 1000 - April 12 - Maximum ebb
Figure 29. 1200 - April 12 - Post-maximum ebb
Figure 30. 1300 - April 12 - Late ebb
Figure 31. 1400 - April 12 - Low slack
Figure 32. 1500 - April 12 - Early flood
Figure 33. 1600 - April 12 - Pre-maximum flood
Figure 34. 1700 - April 12 - Maximum flood
Figure 35. 1800 - April 12 - Post-maximum flood
Figure 36. 0700 - April 13 - Post-maximum flood
Figure 37. 0800 - April 13 - Late flood
Figure 38. 0900 - April 13 - High slack
Figure 39. 1000 - April 13 - Early ebb
Figure 40. 1100 - April 13 - Pre-maximum ebb
Figure 41. 1200 - April 13 - Maximum ebb
Figure 42. 1300 - April 13 - Post-maximum ebb
Figure 43. 1400 - April 13 - Late ebb
Figure 44. 1500 - April 13 - Low slack
Figure 45. 1600 - April 13 - Early flood
Figure 46. 1700 - April 13 - Pre-maximum flood
Figure 47. 1800 - April 13 - Maximum flood
Figure 25.
Figure 26.
Figure 27.
Figure 28.
Figure 30.
Figure 31.
Figure 34.
Figure 35.
Figure 39.
Figure 40.
Figure 41.
Figure 42.
EARLY FLOOD 1600 APRIL 13 (P.P.B.)

.01 - .09
.10 - .19
.20 - .29
.30 - .39
.40 - .49
.50 +

OUTFALL

LAFFAYETTE RIVER

CRANEY ISLAND

ELIZABETH RIVER

LAMBERT POINT

WESTERN BRANCH

Figure 45.

57
Figure 46.
Figure 47.