A Water-Quality Simulation Model for Well Mixed Estuaries and Coastal Seas:
Vol. V, Jamaica Bay Rainstorms

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THE NEW YORK CITY RAND INSTITUTE

Rand
PREFACE

This report summarizes the results of water-quality simulations of Jamaica Bay, New York, here applied to the effects of rainstorm runoff discharged through combined sewer overflows on the water quality of the bay. The model has been operant at Rand for several years; progress reports have been published previously.*

The present model study was made in conjunction with a current program of the City of New York to provide a quantitative assessment of the water quality and to develop scientific parameters for the control of pollutants in the bay. The objective is that the water quality of Jamaica Bay be effectively and economically improved (through the judicious construction of new auxiliary water-pollution control facilities and through upgrading of existing water-pollution control facilities) to meet the state water-quality standards.

The research program is part of Rand’s effort in the development of quantitative assessment of environmental problems, to be used in management of water quality. The research draws heavily upon new advances in computer sciences and, in broader context, is part of Rand’s research program in the area of urban environmental and urban management problems.

A summary of the tests described here was presented to the Commissioner of Water Resources of the Environmental Protection Administration of the City of New York, his staff, and his advisors on October 30, 1971, along with the results of a series of test simulations designed to verify the accuracy of the flow computations in this model, which are described in a companion report, R-109-9-NYC.

* See RM-6239-RC, R-708-NYC, and R-709-NYC.
SUMMARY

A mathematical model of Jamaica Bay, New York, is employed to simulate the effects of combined sewer overflows on the water quality of the bay. In dry weather, the water-pollution control facilities discharge a treated and chlorinated effluent. But during and after a storm, the runoff so increases the load to the combined storm-drain and sewer system and the treatment facilities that the overflows discharge untreated water directly into the bay. These discharges are then carried through the various channels of the bay by tidal currents, increasing the coliform bacteria densities throughout a large portion of the bay to levels which exceed the water-quality standards.

New York City has recently built a new auxiliary water-pollution control facility for combined sewer overflow in the Spring Creek drainage basin. This report describes the results of simulations using Rand's Jamaica Bay model to predict the effects of the storm runoff on the coliform-bacteria densities in the bay with and without the new Spring Creek facility in operation.

A 1.08-inch rainfall, coinciding with high water in the bay, and a 0.75-inch rainfall, coinciding with low water, were used to provide inputs to the model for two locally typical storms. Each simulation was run twice, once with the Spring Creek facility in operation, and once without. For each storm, time-varying inputs from other drainage basins were kept identical in the simulations with and without the Spring Creek facility operating. Results are shown in computer-generated maps and histories of coliform-bacteria levels.

From these tests it is concluded that:

1. The combined sewer overflow at Spring Creek has the greatest effect of all overflows on the densities of coliform bacteria in the bay.
2. Operation of the new Spring Creek Auxiliary Water Pollution Control Facility will significantly reduce densities of coliform-bacteria in the northwest part of the bay introduced after rainstorms. For example, near Canarsie Pier the reduction is about an order of magnitude.
3. For several days after rainstorms the water-quality standard for coliform
bacteria in Jamaica Bay of 24 MPN/ml cannot be reached with operation of the Spring Creek facility alone.

4. The densities of coliform bacteria throughout the bay resulting from the discharges of combined sewer overflows are highly dependent on the stage of the tide when the storm occurs.
ACKNOWLEDGMENTS

The author would like to thank Mr. Martin Lang, Commissioner of Water Resources for the City of New York, and his staff for their support of the research program on which this study is based. The cooperation of Mr. David Liu of Engineering Science Incorporated in assisting with the preparation of input data necessary for this study is gratefully acknowledged. Computing assistance was obtained from the Health Sciences Computing Facility, UCLA, sponsored by NIH special research resources grant RR-3.
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I. INTRODUCTION

Water-quality requirements have undergone continuous evaluation with time. Past concepts of conveying all liquid wastes and sewage to the nearest point of discharge are no longer valid. However, as sewage treatment was instituted by the City of New York for the purpose of improving the water quality of the receiving waters, the existing combined storm-drain and sewer systems were retained for economic reasons. When it rains these systems carry more waste water than can be treated by the existing water-pollution control plants, and the excess is discharged.* untreated.

Jamaica Bay is an area of roughly 20 square miles, partly marsh, at the southwestern end of Long Island, bordered by Brooklyn on the west and Kennedy International Airport on the northeast. On the spit that almost entirely separates the bay from the Atlantic Ocean is Rockaway. Jamaica Bay drains sixty or seventy square miles of rain runoff and the sewage of a medium-to-heavy-density population of a million and a half people.

To improve the situation in Jamaica Bay, the city has begun a program of construction of auxiliary control plants to provide treatment for the discharge from the CSOs. The first of these plants is the Spring Creek AWPCF (Auxiliary Water-Pollution Control Facility). During dry periods, the flow is treated entirely by the existing 26th Ward Plant. As rainstorms occur, the excess outflow consisting of sewage and urban runoff will be diverted to the Spring Creek basins, where it will be stored and discharged to the 26th Ward Plant after the storm. If the storm is of sufficient intensity to cause a runoff exceeding the capacity of the Spring Creek treatment basins, an overflow into Jamaica Bay will occur. However, this overflow will be treated so that its coliform-bacteria content will be below the values set for the bay.

The results of the simulation described in this report give a quantitative indication of the decrease in coliform-bacteria concentration that will occur throughout Jamaica Bay with the activation of the Spring Creek plant.

The effect of fluid waste discharges on an estuary involves complicated relation-

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* The outfalls where this discharge occurs are here referred to as "CSOs," or combined sewer overflows.
ships, such as those between the waste load, the location of discharges, and degree of treatment, the geometry of the estuary, the flow in the estuary, and the various chemical and biological interactions that occur among waste constituents transported in its waters. Today, high-speed computers make it possible to solve numerically the mathematical equations of fluid flow and constituent transport that describe these physical, chemical, and biological interactions.

The Water Quality Simulation Model developed by Rand and used in these studies is described in detail in Refs. 1-3. The model is based on the numerical solution of the two-dimensional vertically integrated equations of motion and continuity for a fluid and the numerical solution of a transport equation describing the transport of waste constituents within the fluid medium. Because of the extreme complexity and variability of the phenomena modeled, the results of these simulations are here presented in charts and graphs produced by automated computer-graphic systems. For convenient review these have been reduced for display in this report. For analysis at Rand, an 11- by 14-inch copy is used.
II. SIMULATION INPUT DATA

The successful prediction of water quality at various points throughout Jamaica Bay requires that the simulation model be adjusted to present conditions. This has been accomplished by checking through the computational procedures and determining critical unknown parameters by comparing the computational results with observed water velocity and tide stages furnished by the U.S. Army Corps of Engineers. This procedure is detailed in Ref. 4. The final adjusted input tide used in these computations was determined by the methods explained in Ref. 4. It is shown in Fig. 1 for the three-day period considered in these simulations. This period is considered to present a typical tide condition.

The area modeled in this simulation of Jamaica Bay and the locations of CSO outfalls are shown in Fig. 2. Figure 3 is a printout of the computer model of the bay; it shows the locations of the stations where time histories of the coliform-bacteria concentrations are computed.

The simulations presented in this report are based on two rainstorms differing in intensity and duration. The first is a 1.08-inch rainstorm that occurs at high tide, varies in intensity, and lasts for about an hour and a half. The storm-water excess, along with the concentration of coliform bacteria in the flow, discharged into the bay from each of the CSOs is shown in Fig. 4. The upper graphs in Fig. 4b give the discharge conditions from the Spring Creek East and Spring Creek West drainage basins without the treatment basin. The lower graph shows the conditions for the basin outflow with the Spring Creek plant operating. Time \( t = 0 \) on these curves corresponds to 1 hour 10 minutes after high tide at the Rockaway Water-Pollution Control Facility. These time-varying discharges and concentrations are input into the simulation model using the procedures described in Ref. 2. For all of these simulations, the coliform decay coefficient is assumed to be \( 2.65 \times 10^5 \) per second (an exponential decay of 0.1 per day).

The second rainstorm is a hypothetical 0.75-inch, isolated storm that hits the general area at low tide and lasts about an hour. The discharge rates and corresponding concentrations of coliform bacteria from each outfall for this storm are shown in Fig. 5. Time \( t = 0 \) corresponds to 24 minutes after low tide in the north channel of the bay. The lower graphs in Fig. 5b show Spring Creek East and West drainage basins combined without treatment and with treatment.
Fig. 1—Input tide for rainstorm simulations

The hydrograph and pollutograph data for these two rainstorms were obtained from studies made by H. F. Ludwig and Associates for New York City; they are based on current rainstorm data and estimates of future conditions. It was felt that rainstorms of this type occur with sufficient frequency in the Jamaica Bay area that prospects of getting subsequent field verification of predicted concentrations of coliform bacteria are quite favorable.

In both of these rainstorm simulations, it was assumed that the outflow from the three major water-pollution control facilities, Jamaica, Rockaway, and 26th Ward, was so treated that it would cause no increase in the coliform bacteria in the bay. The input conditions for these facilities are shown in Table 1.
Table 1

<table>
<thead>
<tr>
<th>WPCF</th>
<th>Flow Rate (ft³/sec)</th>
<th>Total Coliform Bacteria (MPN/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamaica</td>
<td>119.8</td>
<td>0</td>
</tr>
<tr>
<td>Rockaway</td>
<td>22.6</td>
<td>0</td>
</tr>
<tr>
<td>26th Ward</td>
<td>95.3</td>
<td>0</td>
</tr>
</tbody>
</table>

* For the locations of the water-pollution control facilities (WPCF) see Fig. 2.

Fig. 2—Jamaica Bay area showing locations of combined sewer overflow (CSO) outfalls and water-pollution control facilities (WPCF)
Fig. 3—Computer version of Jamaica Bay showing stations at which time history data were computed.
Fig. 4a—Time-varying inputs of overflow discharge and coliform-bacteria concentrations from six outfalls for the 1.08-in. storm at high tide.
Fig. 4b—Time-varying inputs of overflow discharge and coliform-bacteria concentrations from three outfalls for the 1.08-in. storm at high tide.
Fig. 5a—Time-varying inputs of overflow discharge and coliform-bacteria concentration from four outfalls for the 0.75-in. storm at low tide
Fig. 5b—Time-varying inputs of overflow discharge and coliform-bacteria concentrations from four outfalls for the 0.75-in. storm at low tide.
III. RAINSTORM SIMULATIONS

1.08-INCH RAINSTORM AT HIGH TIDE

Two quantities were computed for the bay water in the 1.08-inch rainstorm simulation: degree of salinity and coliform-bacteria concentrations from the CSOs. Two runs were made, one with and one without the Spring Creek AWPCF operating. A comparison of the concentration profiles for each of these two cases is shown in Fig. 6. These charts are presented at intervals of 2 hours and 4 minutes over the period of the simulation, approximately two days from the beginning of this storm. The grid interval for these simulations is 500 ft; the time step is one minute; and the velocity-vector grid size shown in the charts (e.g., near the inlet in Fig. 6a) is 1 ft/sec. The coliform isocontour lines are at 25, 100, 250, 10³, 2.5 × 10³, 10⁴, and 5 × 10⁴ MPN/ml*. The lowest contour line shown on these charts, the 25 MPN/ml line surrounding the shaded area is approximately the water quality standard set for the bay. It can be seen in Fig. 6b that the concentration of coliform bacteria in parts of the bay is still above 25 MPN/ml, and thus that the effect of this storm lasts somewhat longer than the 2 days shown.

The first two charts of Fig. 6a, time step 372 (6 hours, 12 minutes after the start of the computation), show the conditions just before the beginning of the storm. The increase of flow due to the storm begins to affect the bay at time step 420 (7 hours after the start of the computation), and the second two charts of Fig. 6a, time step 496, show conditions 1 hour 16 minutes after the storm water begins discharging. Since the storm occurs at high tide, some of the runoff is held back in the overflow basins, and the full effect of the storm is not seen immediately. This is apparent by the small area affected by the Rockaway overflow and by the considerable time before the effect of Paerdegat Basin is visible.

If the charts are compared for the cases before and after the Spring Creek AWPCF is in operation, it is apparent that the Spring Creek outfall has more effect on the bay’s coliform-bacteria concentrations than any other outfall. Note the much larger area covered by the 25 MPN/ml contour in the northern area of the bay for the case before operation of Spring Creek in comparison with the case after opera-

* Mean probable number (of coliform bacteria) per milliliter.
Fig. 6a—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative (left) and operative (right): steps 372, 496, and 620.
Fig. 6b—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative and operative: steps 744, 868, and 992
Fig. 6c—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative and operative: steps 1116, 1240, and 1364
Fig. 6d—Computed coliform-bacteria concentrations for the 10-in. storm with Spring Creek inoperative and operative: steps 1488, 1612, and 1736
Fig. 6c—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative and operative steps 1860, 1984, and 2108.
Fig. 6f—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative and operative: steps 2232, 2356, and 2480
Fig. 6g—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative and operative: steps 2604, 2728, and 2852
Fig. 6h—Computed coliform-bacteria concentrations for the 1.08-in. storm with Spring Creek inoperative and operative: step 2976

tion of the Spring Creek plant (see for example, time steps 868, 992 and after). It is also interesting to note that, before operation of Spring Creek, high concentrations of bacteria are carried down through Pumpkin Patch Channel on the first flood tide after the beginning of the storm. This causes larger areas of central Jamaica Bay to become affected in a shorter time, and storage of coliform bacteria on the tidal flats becomes important. With Spring Creek operating, a large portion of the central area of the bay never has a high coliform level (greater than 25 MPN/ml). In addition, the increase in coliform concentrations in the bay that is due to rainstorm discharge lasts longer before the Spring Creek plant is in operation than afterward. This can clearly be seen in Fig. 6h, which shows the concentration profiles in the bay for the last computational time step of the simulation.

Another matter of interest is the rapid decrease in coliform-bacteria concentration near the Rockaway outfall. By time step 992 (approximately 9 hours 32 minutes after the first storm-water discharge) the discharge from the Rockaway overflow no longer affects the concentrations in the bay.

Two-day histories of the coliform-bacteria concentration at certain stations indicated in Fig. 3 are shown in Fig. 7. The results are presented for all stations that show a coliform concentration above 24 MPN/ml at some time during the rainstorm. Results for stations 2, 3, and 5 are also presented—for later comparison with the 0.75-inch rainstorm results. The dashed line indicates the concentration levels for the simulation without the Spring Creek plant in operation, whereas the solid line gives the history with the plant in operation.

The upgrading in water quality that occurs with the activation of the Spring Creek plant is clearly shown by these histories of coliform-bacteria levels, especially
in the northern channel of the bay (stations 7–11). The periodic nature of the bacteria-level history, as shown for example in Fig. 7b for station 9, is due to the oscillation introduced into the channels of the bay by the tide. The importance of correctly adjusting the tide computations by using accurate field measurements is readily seen as the tide’s influence on the concentration profiles and histories becomes apparent.

0.75-INCH RAINSTORM AT LOW TIDE

For the 0.75-inch rainstorm simulation, two runs again were made, with and without Spring Creek operating. The overflow-discharge histories shown in Fig. 5 were used as inputs.

The coliform-bacteria concentration profiles from the calculation comparing the cases with and without the Spring Creek plant operating are shown in Fig. 8. The duration of this simulation is approximately three days. The first two charts of Fig. 8, time step 744, show the conditions just before the beginning of the storm. The storm begins to discharge water and coliform bacteria into the bay at time step 768, and the second two maps of Fig. 8, time step 868, show conditions 1 hour 40 minutes after the first discharge.

The first few charts show one effect of the storm hitting the area at low tide. The low tide allows effluent from the Rockaway overflow to be discharged into the bay immediately (see time steps 868, 992, and 1116). This concentrated patch of pollutants is then carried toward the back of the bay on the incoming flood tide. A much larger area of the bay is thus affected by the Rockaway discharge when the rainstorm hits at low tide, even though it is smaller in size than the first storm, which began at high tide. Also, it takes much longer for the water quality of the bay to recover from the influence of the Rockaway discharge. Even at time step 2356 (26 hours and 28 minutes after the start of the storm) a large area of the southern part of the bay is still covered by the 25 MPN/ml contour due to the Rockaway discharge (see Fig. 8e). This is in contrast to the very rapid decay of the pollution source from the Rockaway plant for the 1.08-inch rainstorm.

A comparison of the concentration profiles for the cases with and without the Spring Creek plant operating show that its operation markedly influences the upgrading of the water quality of the bay. A much larger area of the bay is covered by the 25 MPN/ml contour for the case without the Spring Creek plant operating.

Histories of the coliform-bacteria concentrations over the three-day simulation period are shown in Fig. 9. The effect of the Rockaway overflow is evident at stations 2, 3, and 5 in Fig. 9a. If the results at these stations are compared with those obtained for the 1.08-inch rainstorm (Fig. 7a), it is found that the coliform-bacteria level is substantially higher for the 0.75-inch rainstorm at low tide. The decrease in bacteria concentration with the activation of the Spring Creek plant is clearly shown in the histories of the stations in the northern channel of the bay.
Fig. 7a—Histories of coliform-bacteria concentrations for the 1.08-in. storm at high tide: stations 2, 3, and 5
Fig. 7b—Histories of coliform-bacteria concentrations for the 1.08-in. storm at high tide: stations 7, 8, and 9
Fig. 7c—Histories of coliform-bacteria concentrations for the 1.08-in. storm at high tide: stations 10, 11, and 12
Fig. 8a—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 744, 868, and 992
Fig. 8b—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 1116, 1240, and 1364
Fig. 8c—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 1488, 1612, and 1736.
Fig. 8d—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 1860, 1984, and 2108.
Fig. 8e—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 2232, 2356, and 2480
Fig. 8f—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 2604, 2728, and 2852.
Fig. 8g—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 2976, 3100, and 3224
Fig. 8h—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 3348, 3472, and 3596
Fig. 8i—Computed coliform-bacteria concentrations for the 0.75-in. storm with
Spring Creek inoperative and operative: steps 3720, 3844, and 3968
Fig. 8j—Computed coliform-bacteria concentrations for the 0.75-in. storm with Spring Creek inoperative and operative: steps 4092 and 4216
Fig. 9a—Histories of coliform-bacteria concentrations for the 0.75-in. storm at low tide: stations 2, 3, and 5
Fig. 9b—Histories of coliform-bacteria concentrations for the 0.75-in. storm at low-tide: stations 7, 8, and 9
Fig. 9c—Histories of coliform-bacteria concentrations for the 0.75-in. storm at low tide: stations 10, 11, and 12.
DISCUSSION

The response of the bay's water quality to the stage of the tide at which the storm occurs should be carefully noted. Two effects are observed in relation to the two types of CSO outfall. At Rockaway, the CSO discharges directly into the bay. Consequently, the 1.08-inch rainstorm, which occurs at high tide, causes a smaller increase in the coliform bacteria levels in the southern portion of the bay than does the 0.75-inch storm at low tide. This occurs because the higher tide holds back some of the storm runoff in the Rockaway sewer system, and the discharge is then both gradual and subject to treatment by the Rockaway WPCF. When the storm hits at low tide, a very intense discharge occurs at the Rockaway CSO, as is evident in Fig. 5b; and the incoming flood tide carries this discharge immediately toward the back of the bay.

The CSOs in the northern part of the bay—Paerdegat, Fresh Creek, Hendrix Basin, Spring Creek, and Bergen Basin—discharge into channels and basins of various lengths and capacities, rather than directly into the bay. Therefore it takes some time—several hours—for the effluent from these CSOs to flow and diffuse down to the mouths of their channels, which empty into the bay. For the storm at high tide, this effluent is carried out of the basins with the first ebb tide, and is dispersed over a wide area very quickly because of the transport that occurs during the next flood tide (see time steps 744–1240 in Figs. 6b, 6c). In contrast, the discharge from the storm that occurs at low tide is held back in the channels by the rising flood tide and does not get carried out into the bay until the next ebb tide. This coincidence of low tide with the start of the rainstorm, and consequent storage in the channels, leads to an increase in coliform-bacteria concentrations over a larger area of the bay for a longer duration than with the storm at high tide.
IV. CONCLUSIONS

From these tests it is concluded:

1. That the combined sewer overflow at Spring Creek has the greatest effect of all overflows on the coliform-bacteria densities in Jamaica Bay;
2. That operation of the new Spring Creek Auxiliary Water-Pollution Control Facility will significantly reduce the densities of coliform bacteria in the northwest part of the bay introduced after rainstorms. For example, near Canarsie Pier, the reduction is about an order of magnitude over a period of several days;
3. That for several days after rainstorms, the water-quality standard for coliform bacteria in Jamaica Bay (24 MPN/ml) cannot be reached with operation of the Spring Creek facility alone;
4. That the densities of coliform bacteria throughout the bay resulting from the discharges of combined sewer overflows are highly dependent upon the stage of the tide when the storm strikes. For example, the increase of coliform bacteria in the southern part of the bay due to discharges from the Rockaway CSO is found to be much greater for a storm occurring at low tide than for one at high tide.
REFERENCES


