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Reprinted from Estuarine and Coastal Modeling Proceedings
WW Div/ASCE, Newport, R.I., November 15-17, 1989

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CSO Induced Circulation in Marine Tributaries

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ABSTRACT

Pulses of freshwater flow to estuarine tributaries from combined sewer overflows create short duration intense salinity stratification in the tributaries. An accurate assessment of the flux of pollutants out of the tributary and into the major receiving water body can only be developed through an understanding of the interaction between the low density CSO water and the higher density salt water. This paper summarizes the application of a three-dimensional hydrodynamic, mathematical model to this short term intense stratification situation. An overview of the model, its level of calibration, and the results of its application are given.

INTRODUCTION

Jamaica Bay is a circular shaped marine water body which is located within the geographical confines of the City of New York. Except for a small opening to the Atlantic Ocean, the bay is surrounded on all sides by densely populated areas. A series of 12 (one mile long, 300 feet wide, 10 feet deep) canals receive fresh water inflow from combined sewers, storm sewers, and waste water treatment plants. Both bathing and shellfishing are prohibited in Jamaica Bay and the 12 tributary creeks because of fecal contamination.

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SDMS DocID 499062

Previous studies (Cataldo, et al 1987) have shown that the CSOs to the head ends of the tributaries can reach flow rates of over 1,000 cfs for a few hours during intense rainfall. These studies have also shown that this water is considerably less dense than the marine water in the tributaries. Density differences between the storm water and marine water cause the storm water to ride over the salt water resident in the tributaries. Indications are that the storm water is confined to the top 2-3 feet of the water column in the tributaries. This density stratification results in the storm water being transported into Jamaica Bay more quickly than if the entire volume of the tributary were available to assimilate the storm water.

This study focuses on 3 creeks to Jamaica Bay, known as the 26th Ward Tributaries (Fresh, Hendrix, and Old Mill Creeks, Figure 1) and examines the hydrodynamic response to freshwater pulses. By understanding the movements of storm water through the 26th Ward Tributaries, it will be possible to more accurately calculate the flux of bacteria and other pollutants into Jamaica Bay from CSOs into the tributaries.

OBSERVATIONAL PROGRAM

A four month water quality sampling program was conducted during the summer, 1988, to provide data on the impacts of combined sewer overflow (CSO) on the water quality of Jamaica Bay and the 26th Ward Tributaries. Water samples were typically collected from four locations along the length of each tributary (Figure 1) at depths of 1 ft. below the surface and 1 ft. above the bottom. Samples were generally collected every 3-4 days throughout the summer during both wet and dry weather periods. During and after CSO events, samples were taken every 3-4 hours during daylight for 5 days. The samples were analyzed for a wide range of parameters including dissolved oxygen, salinity/conductivity, temperature, and secchi depth measurements. Laboratory analyses included biological oxygen demand, total and volatile suspended solids, total and fecal coliform and a full complement of chemical constituents.

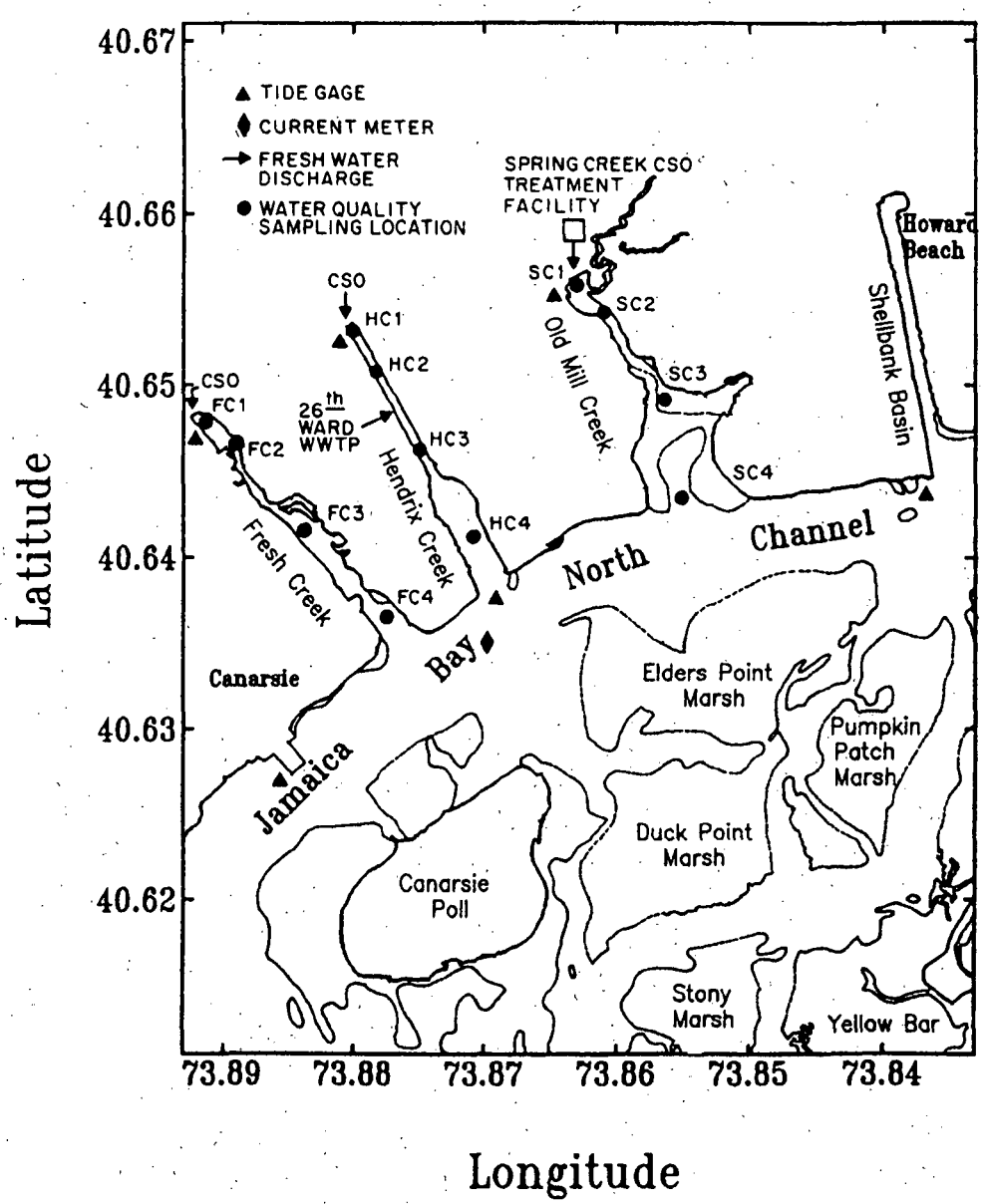

Figure 1. The study area and location of sampling stations

The water quality sampling program was complimented by a hydrodynamic sampling program. Tide gages located in the 26th Ward Tributaries were placed at the heads of the tributaries, and at 3 locations in the North Channel (Figure 1) and remained installed for a period of 2 1/2 months. In addition, 5 current meters were deployed throughout Jamaica Bay, one of which was located in the North Channel (Figure 1) for a period of 30 days while the tide gages were in place. The current meter in the North Channel was located about 20 ft. below the surface in water of 35 ft. depth. Dye studies were also conducted in the 26th Ward Tributaries to provide information on the longitudinal and vertical mixing in the tributaries.

MODEL PHYSICS

The model used for this study is the time-dependent, three-dimensional estuarine, coastal and ocean model (ECOM-3D) developed by Blumberg and Mellor (1987). This model has been used in numerous previous studies; among them are Blumberg and Mellor (1983) on the South Atlantic Bight, Oey et al. (1985) on the Hudson-Raritan estuary, Galperin and Mellor (1989) on Delaware Bay, Blumberg and Goodrich (1990) on Chesapeake Bay and Blumberg and Galperin (1990) on the New York Bight.

The model is three-dimensional and responds to surface wind stress, heat and salinity fluxes, fresh water discharges and to the specifications of tidal forcing. Because non-linear terms in the equation of motion are incorporated by ECOM-3D, this model is, therefore, well suited also to the modeling of tidally induced mean flow. Spatial discretization on the vertical and horizontal dimensions are addressed by spatially variable coordinate systems, a topographically conformal and an orthogonal curvilinear, respectively. The reader is referred to the above referenced articles for a detailed description of the governing equations and numerical techniques.

MODEL CALIBRATION

The model domain is essentially the region shown on Figure 1. Included in the model domain is the North Channel region of Jamaica Bay and the three 26th Ward Tributaries. The grid spacing in the bay is 500 ft. in both the east-west and north-south directions. The tributaries are laterally averaged with segments of 500 ft. along the tributary axis and their actual width. There are three sigma levels in the vertical. This resolution is only marginally sufficient to investigate the physics of the circulation induced during a CSO event. It does not resolve any small-scale eddy activity which may be occurring. In this study, constant horizontal and vertical diffusivities for momentum and salt are used. These values as determined through calibration are 3 m^2s^{-1} and 2 cm^2s^{-1}, respectively. Typically, advective processes dominate the vertical mixing during CSO events, therefore, any dependence of the vertical diffusivities on vertical shear and buoyancy is not critical so long as small values of the diffusivity are used. The bottom roughness is 0.2 cm as suggested by Oey et al (1985).

Elevation and velocity simulations, from July and August, 1988, were combined with the salinity profiles calculated for August, September and October, 1988, to evaluate the calibration of the hydrodynamic model. Examples of the comparison of model calculations with observed data are presented in Figure 2. The upper portion of the figure shows velocity predictions during July, 1988. The model appears to match the data very well. The discrepancies towards the end of the period can be attributed to biofouling of the instrument which by July 15th rendered the data of little use. The remaining part of the figure shows spatial and temporal salinity profiles calculated and observed both in Fresh Creek and Hendrix Creek during September 1988. The limited mixing between the fresh and saline water is observed in both the data and the calculations. The

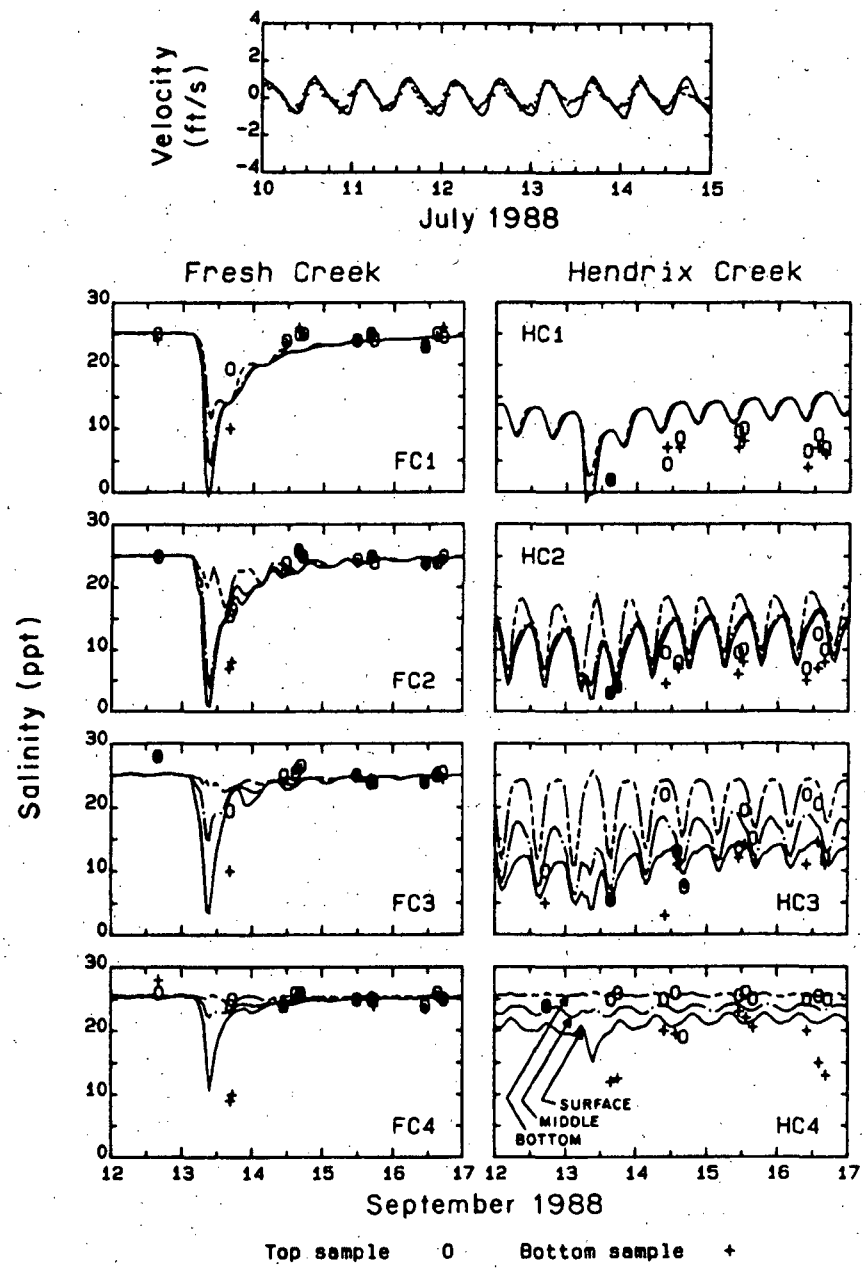

Figure 2. Comparison of model simulated currents and salinities with observations. Stations locations are denoted on Figure 1.

reason that Hendrix Creek experiences large tidal oscillations in salinity is due to the continuous discharge of fresh water from the 26th Ward WWTP (Figure 1). Fresh Creek does not experience these oscillations because discharges to Fresh Creek are limited to CSOs. It is readily apparent from the model result/data comparisons afforded by use of Figure 2 that the model is calibrated and simulates the essential physical behavior of the region. The model calibrations will be further refined in future efforts by incorporating improved estimates of the CSO predictions and salinity boundary conditions.

PHYSICAL RESPONSE TO CSO EVENT

The salinity distributions shown in Figure 2 illustrate the dramatic changes in the tributaries due to a CSO event which occurred on September 13, 1988 at 5 AM and lasted for approximately 5 hours. To demonstrate details of the system's response to a freshwater pulse, a sequence of vertical profiles of currents and salinities from Fresh Creek will be used here.

Initially pulse waters force surface salinities downstream and out into Jamaica Bay proper while bottom salinities remain somewhat constant (Figure 3). This produces a highly, vertically stratified situation with a greatly increased longitudinal salinity gradient. The second stage of reaction to the pulse is the response of the density induced circulation. As the pulse decreases beginning at about 8 AM, there is a net transport of salt back up the tributary to a position beyond its prepulse location due to the large, up-tributary directed currents in the lower portions of the water column. These large currents are forced by the enhanced longitudinal pressure gradient. The final stage is one where vertical advection and mixing between surface and bottom waters and longitudinal advection result in a salinity structure similar to that viewed before the event occurred. The time for complete recovery is quite short, about 8-10 hours for these tributaries. A more global view of this response is shown in Figure 4 which illustrates surface and bottom currents at a time when

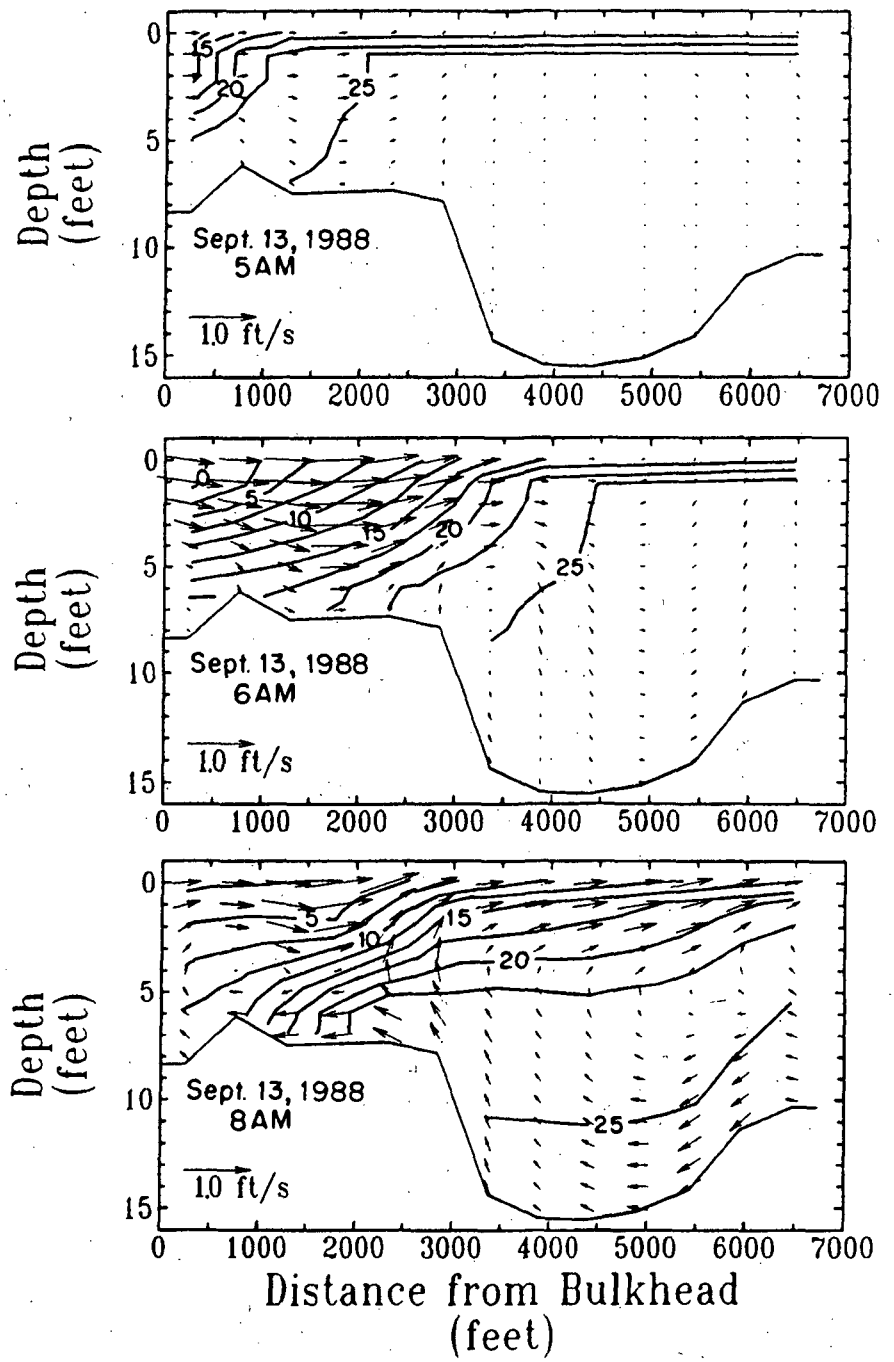

Figure 3. Time sequence of vertical distributions of currents and salinities in Fresh Creek through the CSO event.

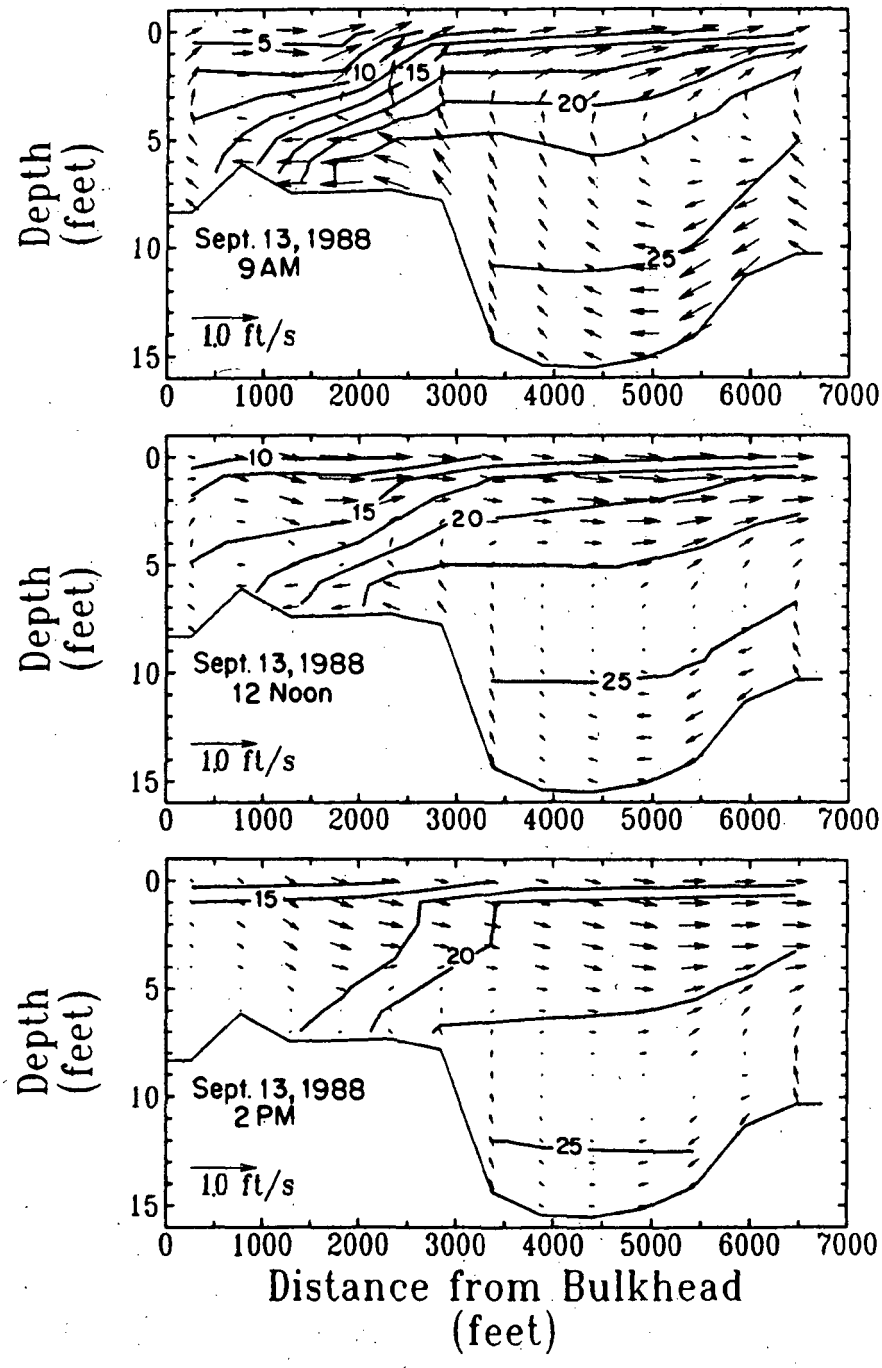

Figure 3. Continued

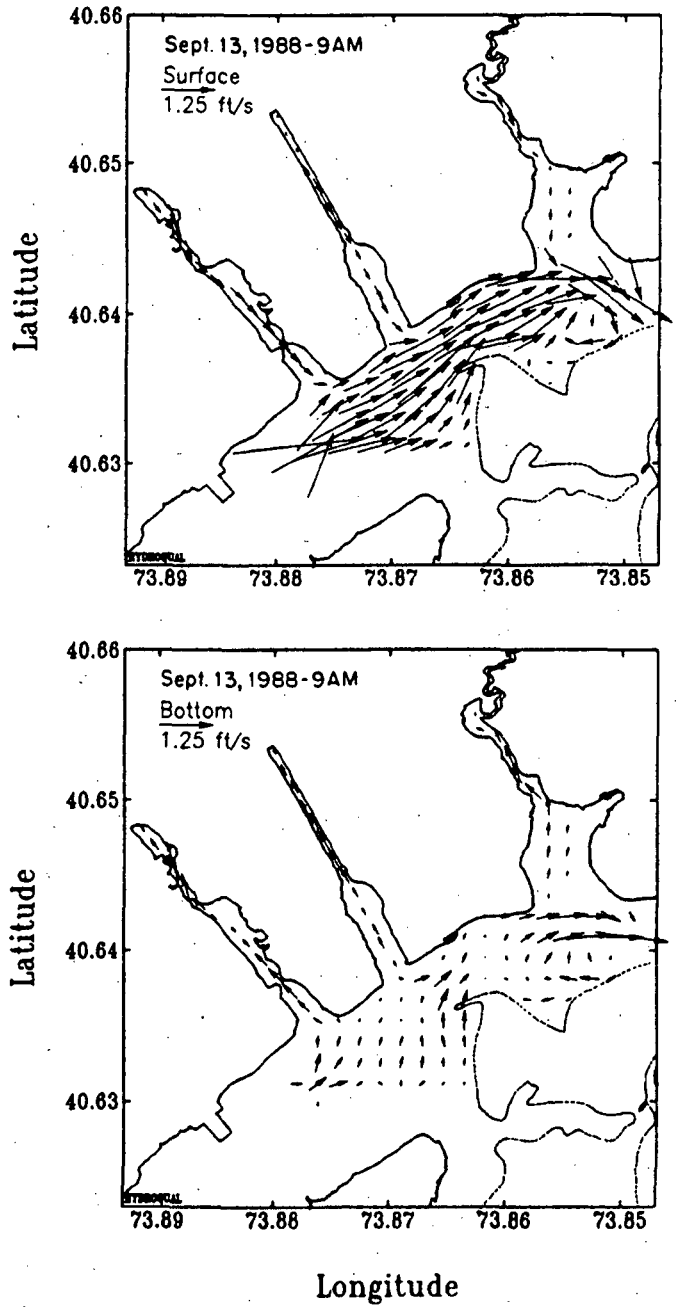

Figure 4. Surface and bottom currents at the time of maximum event-induced two-layered circulation.

the system is responsing most strongly to the event. Surface currents in the tributaries are strong and bayward while the bottom currents are equally strong but directed oppositely.

CONCLUSIONS

A joint program of field observations and three-dimensional hydrodynamic modeling has been undertaken in the 26th Ward Tributaries to acquire an understanding of how marine tributaries respond to freshwater (CSO) events. Comparisons of the model results with observations indicate that the circulation can be simulated although some refinements to the boundary forcing data are probably in order. The present results re-affirm much of what is known about physical responses to CSO events and provide further evidence of the complexity of the response. Subsequent efforts will go towards developing a coupled hydrodynamic-water quality model which will address the significant variations in water quality which occur during and subsequent to the events.

ACKNOWLEDGEMENT

This study was sponsored by the New York City Department of Environmental Protection, CSO Abatement Division. Appreciation is expressed to John P. St. John for his guidance and to Boris Galperin, University of South Florida, for his technical assistance.

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