FDA, DIVISION OF COOPERATIVE PROGRAMS
IN COLLABORATION WITH THE
MAINE DEPARTMENT OF MARINE RESOURSES

CONDUCTED AUGUST 3 - 9, 2001

COASTAL HYDROGRAPHY OF ELLSWORTH, MAINE WASTEWATER DISCHARGE

TABLE OF CONTENTS

DATA AND ILLUSTRATION SECTIONS

ABBREVIATIONS

CFS Cubic feet per second

CFSAN Center for Food Safety and Applied Nutrition (FDA)

CHS Computerized Hydrography System

CTD Conductivity, Temperature, Depth Probe

DCP – FDA Division of Cooperative Programs - US Food and Drug Administration

DGPS Global Positioning System with Differential Beacon Receiver (DBR)

DMR Maine Department of Marine Resources

FC Fecal coliform

MGD Million gallons per day

MPH Miles per hour

MPN Most probable number

mS Milli-second

NM Nautical mile

NOAA National Oceanographic and Atmospheric Administration

NSSP National Shellfish Sanitation Program

PPB Parts per billion

PSU Practical Salinity Units

USPHS United States Public Health Service

V DC Volts, direct current

WWTP Wastewater Treatment Plant

ACKNOWLEDGMENTS

This report is written with sincere appreciation of all the Maine Department of Marine Resources (DMR) and other Maine state personnel for their assistance with this project. Mercuria Cumbo, John Fendl, and Robert Goodwin were the key DMR personnel conducting and reporting the study, while Harold Boynton was also key to conducting the successful data acquisition. Amy Fitzpatrick and Cassandra Perkins not only supported this project to success, but also, as did Jan Barter, collaborated on the data acquisition fieldwork onboard the DMR study vessel. The DMR personnel were highly cooperative and pleasurable to work with, and in addition, exceptionally enthusiastic and intelligent about understanding how to conduct hydrographic studies.

The DMR study vessel was among the best FDA staff have had access to, for assembling and operating the FDA computerized hydrography system. The covered cabin was valuable to protect expensive electronics from sunlight and potentially destructive rain and spray, allowing the study to continue during wet weather. The captains and crew of the DMR vessel provided safe operation and great patience for the tedious tracer dye monitoring over a seven-day period. DMR was also exceptional in the lab and office facilities provided to FDA. In short, this longest tracer dye study FDA has undertaken was a success only with the much-appreciated collaboration of Maine DMR personnel

Also key in his support of this project was Martin Dowgert, a FDA Regional Shellfish Specialist located in Stoneham, MA. Virgil Carr from FDA provided an important part of the technical assistance in this project, including his planning and conducting the continuous tracer dye injection at the Ellsworth, ME wastewater treatment plant (WWTP). Along with the injection data, he provided the average dye concentration in the effluent. He also helped provide FDA instruction that was part of this project. Mr. Carr commendably conducted a three-day long tracer dye injection that he checked on around the clock.

Thanks also to the Ellsworth, ME WWTP personnel who made possible the tracer dye injection for this study. The facility supervisor, Ray Robidoux, was the main contact at the WWTP for this study. WWTP personnel were quite cooperative considering that the tracer dye injection was conducted for three days with monitoring around the clock.

Background

This report assists the Maine Department of Marine Resources (DMR) with shellfish growing area management. The report may also assist others with an interest in the hydrography of effluent from the Ellsworth, ME Wastewater Treatment Plant (WWTP) after discharged into Union River. The Food and Drug Administration's (FDA) Division of Cooperative Programs (DCP) provides technical assistance to state programs as part of FDA's National Shellfish Sanitation Program (NSSP). Two DCP staff members traveled to Maine DMR for this project.

For this project, FDA and DMR collaborated on an 8/3-9/01 hydrographic study that simultaneously measured dye concentration, salinity, temperature, and instrument depth, as well as location and time. These data were logged every six seconds onboard a DMR study vessel, with a computerized hydrography system configured by FDA (see pages D1-4). DMR also provided laboratory and office space at Lamoine, ME (see page D6), and several DMR personnel (see pages D2-5). A continuous tracer dye injection into the WWTP effluent was conducted 8/3-6/01 by FDA. Instruction on conducting hydrographic studies and reporting the results was provided to the DMR within FDA's 8/1-14/01 time in Maine with DMR. DMR contributions to the report included the CORMIX model analyses, spreadsheet tables of data that are presented in this report, as well as an improved process of creating these spreadsheets.

Reference to any specific commercial product, service, or company in this report does not constitute an endorsement or recommendation by FDA or its representatives. Please email correspondence about this report to: Peter Pirillo, ppirillo@cfsan.fda.gov (telephone 301-436-2145), (FDA/CFSAN/HFS-625, 5100 Paint Branch Parkway, Room 2C009, College Park, MD 20740-3835).

Note that the Table of Contents, Data and Illustration Sections pages at the beginning of this report show the tab and page numbers for all the figures in the report.

Objectives

An interest for this project was to examine potential growing area water quality effects from long-term as well as short-term periods of un-disinfected WWTP discharge. Objectives for this study included the below.

A. Conduct a collaborative hydrographic study of the Ellsworth, ME WWTP effluent in Union River and Union River Bay. Include a tracer dye study of travel time, dispersion, and dilution, using a continuous dye injection into the WWTP discharge. Study travel time at the beginning of the tracer dye injection, during the first ebb tide.

B. Conduct the tracer dye study after building up the dye to concentrations approaching steady state. Compare the tracer dye study results for the first ebb tide with the results after the tracer dye build up.

C. Provide hands-on instruction of fluorometric study preparations, computerized data acquisition, and computerized reporting, using a computerized hydrography system.

D. Explore if CORMIX for Windows or Visual Plumes models can be adapted to be useful for this estuary.

2. *METHOD*

Study Site

The Food and Drug Administration (FDA) and the Maine Department of Marine Resources (DMR) collaborated on an 8/3-9/01 hydrographic study of Ellsworth, ME wastewater discharged into Union River, which flows into Union River Bay. Page A1 includes these features of the study site as well as the surrounding area and the convenient location of the reference tide station. In the direction towards the Atlantic Ocean, Union River Bay adjoins Blue Hill Bay, which is west of Mt. Desert Island. The study site was situated in about the middle of Maine's extensive coastline between New Hampshire and Canada, at the southern end of Maine's Downeast Acadia region.

Page A2 is a closer view of the portion of the study site showing sample stations identified for this study, for hydrographic measurements. The WWTP outfall in Union River is shown at the south end of Ellsworth, ME. The outfall was located about one-third the short distance across the river from the WWTP situated along the eastern shoreline. The 12-inch outfall pipe was not believed to have a diffuser at its end near the river bottom. The depth of the outfall was about 4 feet at low water and 12 feet at high water.

A hydroelectric dam is situated about 0.6 NM north of the outfall, as can be seen on page A2. In August the average flow through the dam is typically about 105 cfs. This flow rate represents the source of the Union River above the WWTP. The relatively narrow and shallow Union River flows from the outfall to the south for 2.25 nautical miles (NM) to where it begins to widen, at the location of station 4. Similarly, the distance is 3.48 NM from the outfall to Weymouth Point, where the river mixes with the much deeper Union River Bay. Depths in the river and bay can be seen on page A2 as well as similar graphics throughout the report that are based on electronic NOAA nautical charts. Patten Bay, seen on the left of pages A1-2, was also studied because the dyed effluent was expected to travel into Patten Bay and the DMR was interested in this area.

Tides

The predicted tides used for planning and conducting this study are shown on page A3. Page A1 shows the close location of the Blue Hill Bay, Union River tide station used for the page A3 tide predictions. To superimpose this study on page A3, the tracer dye injection began at 12:03 on 8-3-2001 (Friday) and ended at 17:37 on 8/6/2001 (Monday). The hydrographic study, including the tracer dye study, continued until 12:49 on 8/9/01 (Thursday). The tracer injection was planned to first appear at the WWTP outfall at about the same time as the 11:37 high water. Data acquisition continued throughout that first ebb tide on 8/3/01. As much as possible, the rest of the data acquisition was conducted around the times of low and high water during daylight hours, as seen on page A3. Page A3 also shows the daily times of sunset (SS), sunrise (SR) and tidal heights. Page A3 was created with ChartView Pro software, which contains Tides and Currents software, both sold now by NobleTec Software.

Dye Standard Preparation and Fluorometer Calibration

The tracer dye purchased from Keystone Aniline Corporation, with the product name of Rhodamine WT (generic name of Acid Red 338), had approximately 1.2 specific gravity and was approximately 20 % standard. A 10 ppb and other standards were prepared from the stock solution of Rhodamine WT dye and distilled water. Ten (10) standards were created by serial dilution, ranging from 100,000 ppm to 0.1 ppb.

The Turner Designs 10-AU digital fluorometer was calibrated using a 10 ppb standard solution. Prior to calibrating the fluorometer, the basic operating level was set using the sensitivity adjustment knobs and a 10 ppb standard at medium scale.

The field fluorometer was flushed and blanked during calibration with tap water flow followed by distilled water flushes. The calibration was conducted according to the procedure in the fluorometer user's manual, using a 10 ppb standard. Linear operation of the fluorometer was checked using 100, 10, 1, and 0.1 ppb standard solutions. The blank used for calibration was distilled water. For the "Subtract Blank" option, "Yes" was selected.

Tracer Injection

As pictured on page A4, a Masterflex model 7553-20 variable speed peristaltic pump (Cole-Palmer Instrument Co.) was used to withdraw the tracer dye solution from a calibrated translucent plastic container, using Masterflex Tygon tubing, to continuously feed the dye into the WWTP effluent. A pump head size 7014 was used with the Masterflex pump. The tracer dye was dripped out of the tubing into the effluent just after it flowed over the V-notch weir and just before the 18-inch diameter effluent pipe that exited the WWTP. The injection was located after the WWTP's dechlorination. Travel time from the injection location at the WWTP to the outfall in the river was negligible because the corresponding distance was only about 100 feet.

This injection was planned to appear at the outfall in Union River at the time of high water on 8/3/01, which was predicted to occur at 11:37, so that travel time could be studied during the first ebb tide. This tracer injection starting time was also planned so that buildup of the tracer dye in the estuary could occur over the weekend when data acquisition would be conducted from stations accessed by land. The more extensive data acquisition was planned to resume on Monday 8/6/01 with the DMR study vessel. Using an average expected WWTP flow of 0.56 MGD, and a target tracer dye concentration of 1000 ppb in the effluent outfall pipe, an estimated 2.9 gallons per day was needed. For an estimated three-day injection, 8.7 gallons of stock tracer dye liquid would be diluted 1:3 with unchlorinated water to provide efficient pumping for the tracer injection.

Computerized Hydrography System

This project utilized a previously developed FDA computerized hydrography system (CHS). The CHS included a Turner Designs 10-AU digital fluorometer, DGPS, notebook PC, ChartView Pro software by Nobeltec, NOAA electronic nautical charts, dual serial PCMCIA card (ruggedized model by Socket), twelve-volt batteries, and electrical and mechanical apparatus. A photograph of a CHS similar to the configuration on board the DMR study vessel is shown on page D1. The CHS as configured on the DMR study vessel is shown on page D2.

Page D3 shows the CTD (salinity, temperature, depth) sensor utilized as the underwater part of the CHS. Applied Microsystems Ltd. made the CTD probe; their CTD smart sensor model. The CTD was 13.6" long and 2.75" diameter, and in water it was essentially weightless. The CTD smart sensor was powered externally from 12V DC, for its 55 mA sampling current.

The CTD was mounted onto the "V-Fin" towed vehicle also shown on page D3. The V-Fin towed vehicle made by Endeco/YSI was their model Type 166. The towed vehicle alone weighed 17 pounds in water, without the custom stainless steel CTD protective cage. It was 24" long, 13.75" high, and 28.5" wide.

Page D4 shows the DMR rigging for the towed V-Fin with CTD sensor and the green hose that carried the seawater from the pump under the V-Fin to the fluorometer onboard the vessel. Also shown are the two electrical lines and the towing line that were connected to the CTD and the yellow V-Fin. The combined weight of the V-Fin with the CTD mounted below it was supported by the orange mooring buoy.

The CHS recorded data from the scientific instruments simultaneously with time and position (latitude and longitude). These data were seen for any point along the vessel track real-time with ChartView Pro's "Track Console," and later with two options. These data were seen later by pointing and clicking along the vessel track plotted onto the nautical chart (e.g., Section F of this report), and as a table of all the data (e.g., Section G) recorded every six seconds. The vessel tracks on nautical charts and the related data tables were viewed within ChartView Pro, but can also be viewed with other software. Whether within ChartView Pro or after exporting, the vessel tracks and data can be enhanced and color printed. ChartView Pro software was used in this report for color prints of the vessel tracks and the related analyses (e.g., Sections B and C). Note that vessel tracks like those shown in Section F type charts were overlaid with latitude and longitude grid lines. These grids may assist matching data with its vessel track, based on the position data contained in data tables like those in Section G.

ChartView Pro was used to record separate data files for vessel "tracks" rather than recording continuously. Three computer files were created for each data acquisition track. One file stored the proprietary information to plot the vessel track on the nautical chart, and to display the data in a table within ChartView Pro. The other two files were ASCII files from the two instruments (CTD sensor and fluorometer). A custom spreadsheet application was developed to match these two data files into one file for analyses and reporting, as can be seen in Section G.

A Furuno GP-35 DGPS unit was used for this project. A DGPS functioning in differential correction mode consistently outputs latitude and longitude position information to computer software with the maximum available accuracy of $\pm$ 0.001 minutes (about 2 meters). This study considered negligible any location uncertainty that might have occurred due to the brief lag time from the submersed sampling pump to the onboard fluorometer. The materials used for the fluorescence sampling apparatus did not contribute to the fluorescence concentration readings.

A serial PCMCIA card or serial multiplexer is needed when the number of instruments connected to the PC is greater than the number of PC serial ports. A PC with a built-in pointing device is needed so that the serial port can be used for a scientific instrument or a multiplexer, rather than a mouse. With two serial ports, for example, a multiplexer could be avoided if only one scientific instrument is being used in addition to a GPS. Even if a notebook PC has only one serial port, a second serial port can be added if the notebook will accept a PCMCIA card. Page D1 illustrates a CHS used by FDA and how a dual serial PCMCIA card leaves the PC's serial port available for connection to a third scientific instrument. Avoiding the use of a serial multiplexer simplifies the electrical apparatus involved in the CHS, therefore reducing the chance of malfunction of the portable system in the marine environment on a survey vessel that is likely to create some forceful movements and seawater spray. However, use of a serial multiplexer allows the integration of more than three instruments into a CHS.

The mechanical apparatus of the CHS was primarily the custom apparatus assembled to provide a flow of seawater through the field fluorometer on board the survey vessel from various depths. Using an opaque polyethylene garden hose, seawater was impelled from a submersible pump through the fluorometer cell, and discharged overboard. Either AC or DC centrifugal pumps could be used, but DC pumps were used in this study. The submersed pump was prevented from surfacing during trolling by attaching it to the rear of the CTD cage. The nylon line to the pump served as a backup line, in case the cable connected to the towed vehicle came loose. The nylon line also supported the pump's electrical cord, which was taped to it at measured intervals. The pump's electrical cord was constructed with a power switch and fuse near the battery end of the cord.

3. RESULTS

The Vessel's Data Acquisition Tracks

The computerized hydrography system (CHS) recorded data from the scientific instruments (fluorometer and CTD) simultaneously with time and position (latitude and longitude from a GPS). The study vessel's data acquisition tracks were color plotted onto nautical charts and grouped by day in sections/tabs of this report, for example in Section F for 8/3/01. Each vessel track was shown as an orange line made from dots representing each data point recorded at six-second intervals. A label of the start or end was added to the figures to indicate the direction of the vessel's track.

Tables of all the data for each vessel track are included in the report immediately following the section containing the corresponding tracks, as seen in Section G. All columns in these tables contain data computer recorded real-time onboard the study vessel, except the "Dilution" column that was calculated using the recorded dye concentrations and the average dye concentration in the outfall pipe. Note that these dilutions are shown for convenience of data analyses that followed and not for presentation of any data analyses. Though Sections F and G were referenced above as examples (from 8/3/01), Sections H through O contain the vessel tracks and data tables for data acquisition conducted 8/6-9/01. Data acquisition on Saturday – Sunday 8/4-5/01 was conducted by collecting water samples at stations accessed by land and measuring tracer dye concentration with the same fluorometer but manually in the DMR laboratory rather than computerized on the DMR study vessel.

Weather Conditions

Coastal Maine weather conditions are generally dry in late summer. River flows drop back to a minimum and runoff is often non-existent. Sunlight is a factor in bacterial dye off and thus more prominent in summer months when the sun is at a higher angle in the sky. In this study the tracer dye was initially found to be traveling at a low to middle depth down river until it surfaced before the mouth. As the study continued, the dyed effluent mixed more uniformly throughout the water column in both the river and bay. On the last morning of data acquisition a light rain was encountered (0.06" at adjacent Acadia Park) that would not significantly impact dispersion of the dyed effluent.

In the area of this study site in Maine's Downeast Acadia region, winds predominantly come out of the west-southwest. Initially on 8/3/01 the dye was found along the eastern shore of the river and bay and this may have been related to the northwest wind that afternoon. On subsequent days, the tracer dye spread toward the west and the winds were generally southwest. This suggests that the currents carried the dye in the opposite direction of the surface winds. Therefore, the winds encountered in this study did not appear to prevent the dyed effluent from spreading west across the bay.

The below weather conditions were estimated by DMR marine resources personnel:

Date	Time	Weather
8/3/01	12:15	5-10 mph winds from the North
8/3/01	14:30	0-5 mph winds from the Northwest
8/6/01	07:30	10 mph wind from the South
8/6/01	13:30	20-25 mph winds from the South-Southwest, sunny
8/7/01	07:30	5-10 mph winds from the Southwest, sunny
8/7/01	13:40	10-15 mph winds from the West-Northwest, sunny
8/8/01	14:30	15 mph winds from the South, sunny
8/9/01	09:00	0-5 mph winds from the South, light rain encountered

Chronology

The hydrographic study is chronologically outlined below together with the tracer injection and 8/3/01 tide predictions. Except for the travel time data collected throughout the ebb tide at the start of the study on 8/3/01, all other data were collected as near as possible to the times of high and low water during daylight hours.

- 8/3/01, 09:55: Started background fluorescence checks with CHS and DMR vessel.
- 8/3/01, 11:37: Predicted high water, based on the Union River tide station.
- 8/3/01, 12:03: Started the tracer dye injection at the Ellsworth, ME WWTP.
- 8/3/01: Tracer dye arrived at the outfall in Union River moments after 12:03.
- 8/3/01, 12:34: Started logging hydrographic data with the CHS and DMR vessel.
- 8/3/01, 17:28: Predicted low water.
- 8/4-5/01: Collected water samples at stations accessed by land for limited data.
- 8/6/01, 06:52: Resumed hydrographic data acquisition with CHS and DMR vessel.
- 8/6/01, 17:37: Ended the tracer dye injection at the WWTP, after data acquisition.
- 8/9/01, 12:49: Ended the last data acquisition track onboard the DMR study vessel.

Tracer Injection

The tracer dye injection at the Ellsworth, ME WWTP was started at 12:03, 8/3/01 (Friday) and ended at 17:37 on 8/6/01 (Monday). The injection was continuous for a total of 3 days, 5 hours and 34 minutes. 34 Liters of tracer dye were injected during the study. The dye was mixed with 68 liters of distilled and unchlorinated tap water. Therefore a total of 102 liters of tracer dye solution (1:3 dye dilution) was injected. This volume provided for efficient pumping of the tracer dye solution. Three different mixings were needed during the injection because the containers were too small for the total volume.

The effluent flows varied because of the cycling of WWTP pumps. Hourly flows were estimated as the midpoint of these cyclic flows. The average WWTP effluent flow rate during the injection was 0.54 MGD. According to data recorded at the WWTP, 1,748,078 gallons of treated wastewater flowed out the effluent pipe during the injection period. An average tracer dye concentration in the effluent outfall pipe was 1171 ppb, remarkably close to the target 1000 ppb target.

8/3/01 Hydrography

8/3/01 Travel time

Travel time could only be studied during the first ebb tide of this long-term study, when the first appearance of the tracer's leading edge could be monitored as it traveled seaward. Therefore, the tracer dye injection was planned to appear at the WWTP outfall at high water. Page A3 shows that this 8-3-01 high water was predicted to occur at 11:37 for the tidal station near the mouth of Union River (located on page A1). The injection began at 12:03 on 8/3/01 and reached the outfall moments later, since the WWTP was located along the shoreline of the narrow Union River. The tracer dye was curiously not visible in the shallow water near the outfall for most of the entire three-day injection and was therefore difficult to measure near the outfall. This indicated the dyed effluent was traveling well below the surface of the river near the outfall.

Page B1 shows that leading edge data was not obtained until the effluent had traveled past the Spindle Road station 5 set up for this study. In addition to leading edge location and time, page B1 shows the travel time after the tracer injection began at the WWTP, and the distance the dyed effluent traveled from the WWTP outfall. Station 6, "Closson's store" was the approximate location of the second leading edge data collected, with a travel time of 3 hours 52 minutes at a distance of 2. 78 NM (see pages A2 and B1/Track T11). Similarly, the farthest south leading edge located on the first ebb tide was about 0.2 NM south of the "Mill Cove" Station 7, as shown on page B1. This Track T16 data was collected at 18:16, after the 17:28 low water predicted on page A3. This farthest south leading edge identified during the first ebb tide was located 4.42 NM from the outfall, 6 hours and 15 minutes after injection began, giving an average current velocity of 1.19 ft/sec. Since the page B1 Track 15 leading edge was located at 17:37, about the same time as the

17:28 predicted low water, the average current velocity of (1.10 ft/sec) was similarly calculated.

The leading edge data closest to the Spindle Road Station 5 was Track T10 on page B1. This leading edge was located 2.72 NM from the outfall, 3 hours and 38 minutes after injection began, giving an average current velocity of 1.26 ft/sec. Using this velocity, the travel time to the Spindle would have been about 3 hours 17 minutes. This is the closest data to compare to an 8/7/1991 drogue study by DMR. This 1991 study found travel time of about 4.75 hours to Spindle Road and an average current velocity of 0.875 ft/sec. The 1991 study was conducted during 0-5 mph southwest winds for the first half and 5-10 mph southwest winds for the second half of the data collection. The 8/3/2001 FDA - DMR tracer dye study was conducted during 5-10 mph north winds. The north winds appeared to be a factor for the shorter travel times identified with the 8/3/2001 study. This difference was probably compounded by wind impact upon the drogue floats. However, the tide dropped approximately the same height for both of these ebb tide studies. Because the wind was with the tracer dye but against the drogues, the difference in methodology and results will not be further commented on in this report.

8/3/01 Dispersion

Page B2 illustrates 8/3/01 longitudinal and lateral dispersion identified during the first / ebb tide, when data acquisition began. The dyed effluent was shown as dispersed laterally across Union River because the narrow river was not much wider than the navigation channel. Most of the tracer dye appeared to follow the channel near the WWTP outfall. This was indicated by the west edge of the dyed effluent identified near the end of the vessel Track 4 shown on page F2 (see Section G for the tracer concentrations). Lateral dispersion across the river, especially farther south, is supported by uniform vertical mixing identified for most of Profile 9 shown on page F4. Profile 9 and the other profiles are discussed below.

Page B2 shows that, as the river widens into Union River Bay, Tracks 13 and 16 identified the west edge of lateral dispersion. Therefore the dyed effluent traveled along the eastern shore of Union River Bay during the first ebb tide. The longitudinal dispersion was further identified with the most southern edge located, during Track 16 at 18:16. Page B2 shows that this most southern excursion of dyed effluent located on 8/3/01 was 4.43 NM from the WWTP outfall.

8/3/01 Dilution compared to 8/4-9/01

Misleadingly more dilution would be reported using the tracer dye concentration data recorded on 8/3/01 rather than using the highest tracer concentrations recorded during the entire data acquisition period. Most of the 8/3/01 tracer concentration data were much lower than the concentrations recorded during the rest of the study. Therefore a discussion of the tracer dye study results for the first ebb tide compared with the results after the tracer dye build up is provided here. This was one objective of the study.

Page B3 summarizes tracer dye concentration data at the stations set up for this study, by date, tide, and access from land or water (DMR study vessel). Hydrographic measurements at the page A2 stations did not fully commence until 8/4/01, but 8/3/01 data were available for several stations. Page B3 shows tracer concentrations at three stations on 8/3/01. Additionally, Track 14 recorded the tracer as high as 0.13 ppb near station 6. This station 6 data point along with the highest tracer concentrations at stations 1 and 3 from page B3 are graphed on page B4, for both 8/3/01 and 8/6/01. Stations 1, 3, and 6 span the length of Union River studied but do not extend into Union River Bay. Page B3 shows that the effluent tracer data recorded on 8/6/01 were higher than on any other day of the study at all stations except for station 7. And the 8/6/01 concentrations were higher at the time of low water than at high water.

Page B4 illustrates graphically the comparison of the effluent tracer dye concentrations recorded during the 8/3/01 first tide compared to the 8/6/01 date of highest build up. The page B4 graph of effluent tracer concentration and distance from the outfall indicates a relatively linear dilution on both 8/3/01 and 8/6/01, remarkably so on 8/3/01. Effluent tracer concentrations at these stations were almost an order of magnitude higher on 8/6/01 compared to 8/3/01. Likewise, the dilution of the dyed effluent at stations 1, 3, and 6 in Union River differed by almost an order of magnitude between the first ebb tide compared to when the tracer dye was most built up on 8/6/01.

Page B5 is a graph of effluent tracer concentrations recorded at low water and at one location (station 5 near the mouth of the river) over the entire 8/3-9/01 period of the study. Page B5 shows a continual build up in tracer concentration during the tracer injection period, and a continual dissipation after the tracer injection was ended on 8/6/01. However, build up to a perfect steady state is not indicated by this graph because the tracer dye did not remain near a maximum concentration for two consecutive data acquisition periods.

8/3/01 Hydrographic profiles

Though the 8/3/01 tracer dye was not built up to the concentrations of 8/6/01, the 8/3/01 hydrographic profiles provided important information. Page F1 summarizes profile data by locations across the page and depths going down the page. Profile data included temperature, salinity, and tracer dye concentration.

The first profile recorded with tracer concentration highest near the surface was located 1.31 NM from the WWTP outfall (Profile 9). Profile 9 is shown on the page F4 nautical chart. Page F1 indicates that, at the location of Profile 9, the dyed effluent had mixed almost uniformly in the water column to a depth of at least 10 feet. Temperature dropped only about 3 degrees Centigrade with depth. There was a salinity gradient throughout the water column at station 9, from 3.9 psu at the surface to 28 psu at 15 feet deep.

The remaining profiles were located close to each other and at the following short distances from the outfall: Profile 8, 0.49 NM; Profile 7, 0.25 NM; and Profile 5, 0.13 NM. These three profiles are shown on the page F3 nautical chart. The temperature profile at these three stations was about the same as recorded at station 9. The salinity at the surface was higher at station 9 compared to all these three stations. Salinity at the surface increased as distance south of the outfall increased, towards the bay.

Unexpectedly, the dyed effluent was not most concentrated near the surface of these three profile locations. Rather, the highest tracer concentrations were located at the following depths that increased with distance away from the outfall: Profile 5, 5 ft; Profile 7, 8 ft; and Profile 8, 10 ft. These profiles were conducted because the effluent tracer was unexpectedly hard to locate around the outfall, even thought the river was only about 10 ft deep near the outfall. Similarly, Tracks 3 and 4 shown on page F2 conducted near the water surface recorded tracer concentrations only as high as 0.11 ppb, during Track 3 (0.07 ppb during Track 4). These three profiles were an attempt to find the dyed effluent and it was found to be traveling mainly near the bottom of the river after discharged from the WWTP outfall, and dispersing deeper with distance in the area of these three profiles. The most concentrated dyed effluent inverted from near the bottom to the surface between Profiles 8 and 9 (closest stations were stations 1 and 3).

Also unexpected was that the highest tracer concentration south of Profile 9 was recorded on the most southern and last track conducted on 8/3/01. This 0.30 ppb concentration was recorded in Union River Bay at the beginning of vessel Track 16. This 18:07 data point was recorded after the 17:28 low water was predicted to have occurred. The next highest tracer concentration recorded south of Profile 9 was located in mid-Track 15. Both Track 15 and 16 are computer plotted on the page F7 nautical chart, with the corresponding data presented in Section G.

8/4-9/01 Hydrography

8/4-9/01 Dispersion

Page C1 illustrates the furthest longitudinal and lateral dispersion identified during the entire study period. Also shown for the entire study period are all the south edges located near the time of low water. These south edges at low water moved further south into Union River Bay with time, as shown for 8/3/01, 8/6/01, 8/7/01 and 8/9/01. The furthest south excursion of dyed effluent located during this study was identified with vessel Track 7 on 8/9/01, 7.8 NM from the WWTP outfall, as shown on page C1.

Data acquisition was conducted 8/4-5/01 only at stations 1-7, which were accessed from land. When the study resumed on board the DMR vessel on 8/6/01 the dyed effluent was found to have dispersed laterally across Union River Bay, during Track 6 shown on page H3, south of Mill Cove. Page C1 also shows the location of Track 13 near the mouth of

Union River, where the tracer dye was still most concentrated along the eastern shore on 8/6/01. Page C2 shows the location of the highest tracer concentrations for these lateral Tracks 6 and 13. By 8/6/01 the dyed effluent was most concentrated a little west of the middle of Union River Bay. Similarly, page C2 shows that the highest tracer concentration for lateral Track 6 conducted on 8/8/01 was located in the middle of the mouth of Union River. By 8/9/01 lateral Track 8 indicated that the dyed effluent was most concentrated on the western shore of Union River Bay, as shown of page C2. Although the highest concentration of the dyed effluent appeared to cross from the eastern to western side of Union River Bay as it traveled south, and perhaps because of this finding, it is practical to assume the same dilution could occur at any point across the bay, for a given position along the bay.

Page C1 also illustrates a comparison of the tracer dye study results for the first (8/3/01) ebb tide overlaid with the results after the tracer dye build up. This was one objective of the study. The west edge of the 8/3/01 dye field can be seen along the eastern shoreline near the mouth of Union River. The furthest excursion or south edge located on both 8/3/01 and 8/9/01 are shown. Even more graphic than the page B4 graph of concentrations at stations, page C1 is a compelling illustration of the important difference in results from a study for one tide excursion compared to a study building up the tracer dye. The differences in this case included longitudinal dispersion at least 3.37 NM farther south in the bay, and lateral dispersion across the river's mouth and across Patten Bay, as well as the lower dilution in Union River indicated by pages B3-4.

The dyed effluent had traveled across Patten Bay to its western end by Monday 8/6/01 when data acquisition on board the DMR vessel resumed. Since page C1 shows the 8/3/01 dyed effluent (shown also on page B2) did not flow directly into Patten Bay on the first ebb tide, but later was dispersed throughout Patten Bay, the dyed effluent was transported into Patten Bay with the reversal of subsequent flood tides. Since Page C2 shows a Track 9 data point from 8/6/01 at the west end of Patten Bay, this study did not find when during 8/3-6/01 the dyed effluent first entered or crossed Patten Bay. A higher tracer concentration recorded at that location on 8/9/01 during the last day of data acquisition indicates that the dyed effluent was built up at the west end throughout the study period.

8/6-9/01 Hydrographic profiles

What changed most in the 8/6-9/01 compared to 8/3/01 profiles were the profiles of tracer dye concentration. 8/6/01 was the date the tracer dye injection was ended and the date the tracer dye was most built up in the study area. The injection ended shortly after the 8/6/01 data acquisition. Page H1 summarizes the 8/6/01 profiles. Page H1 summarizes profile data by location going across the page and by depth going down the page. Profile data included temperature, salinity, and tracer dye concentration. This same profile summary page layout is utilized and placed at the beginning of each section containing the vessel tracks printed on nautical charts (see tabs J, L, and N). This places the summary page close to prints of the profile locations also on nautical charts, for profiles not located at a study station.

Page H1 indicates how the dyed effluent had mixed into the water column of Union River on 8/6/01. At station 1 the dyed effluent was most concentrated (19.8 ppb) at a depth of 3 feet, similarly concentrated near the bottom (5 feet), yet only 2.00 ppb near the surface (1 foot). At the location of station 3 (over half way down the river) the most concentrated dyed effluent was found near the surface and a gradient of more dilution with depth was also evident. Profile 2 at the WWTP outfall includes the highest grab sample collected, thus is not based on the same data collection method. The remaining profile 8 conducted before high water, in the middle of north Union River Bay, showed that the dyed effluent was found only in the top 3 feet of the water column. Closer to the time of high water, the dyed effluent was most concentrated near the surface yet mixed throughout the water column at stations 2 and 4, while uniformly mixed to a depth of 9 feet and absent near the bottom at the mouth of Union River (profile 14). The most concentrated dyed effluent inverted from bottom to top between stations 1 and 4 on 8/6/01.

Page J1 summarizes the 8/7/01 profiles and indicates how the dyed effluent had mixed into Union River on that date. At station 3 the dyed effluent was uniformly mixed but more concentrated near the bottom. Conversely, at station 4 the dyed effluent was uniformly mixed but more concentrated near the surface. At station 6 the dyed effluent was uniformly mixed down to 4 feet and not found below 5 feet. Profiles 6 and 10 were conducted after low water and in similar locations in north Union River Bay. These two locations also showed similar profiles of uniformly mixed dyed effluent down to 3 feet and not present below 4 feet. The most concentrated dyed effluent inverted from bottom to top between stations 3 and 4 on 8/7/01.

Page L1 summarizes the 8/8/01 profiles and indicates how the dyed effluent had mixed into Union River on that date. Data at the time of low water indicated the dyed effluent was uniformly mixed at all stations examined (1,2,4,7), though stations 1 and 2 had less concentration near the water surface. Therefore, the most concentrated dyed effluent inverted from bottom to top between stations 2 and 4. Data at the time of high water show more clearly the inversion of the most concentrated dyed effluent, between stations 1 and 4. At station 1 the most concentration was between 9-14 feet, but at station 4 the most concentration was near the surface. At high water on 8/8/01 date the dyed effluent was otherwise relatively uniform and, like for most dates, the dyed effluent did not extend to the bottom in the bay (see profile 5).

Page N1 summarizes the 8/9/01 profiles and indicates how the dyed effluent had mixed into Union River on that date. On this seventh and last day of data acquisition, the dyed effluent was still much more concentrated near the bottom than near the surface (1-3 feet deep) at station 1 near the outfall. The dyed effluent was uniformly mixed at stations 2, 3, and 4, with higher concentration near the bottom at station 2 and near the surface at station 4. The dyed effluent was diluted on a gradient with depth at stations 6, 7 and Profile 7, and again there was an absence of dyed effluent near the bottom at the profiles in the bay (station 7 and Profile 7).

For all the profiles conducted 8/6-9/01, the most concentrated dyed effluent in the water column inverted from near the bottom or mid depth, to near the water surface by the time it reached station 4 (the narrow part of the river just above the mouth of Union River. Another trend was that the dyed effluent mixed throughout the water column in the river but not down to the bottom in Union River Bay.

8/4-9/01 Dilution

Page C2 shows the results of searching through and analyzing all of the data collected for this study. The data are presented mainly in the numerous computer recorded tables of data presented within sections/tabs of this report, but page B3 summarizes some additional data, mainly the 8/4-5/01 tracer concentrations manually measured from grab samples. Page C2 presents the highest tracer dye concentrations for the corresponding locations, which are marked by a black "x" or point on the red line shown. The analyses presented on Page C2 identified the highest effluent tracer concentrations and the farthest distance these concentrations were found to have traveled away from the Ellsworth, ME WWTP outfall. With only a few exceptions for informational purposes, the high data shown on page C2 appear to dilute with distance away from the outfall into Union River and into both Union River Bay and Patten Bay. By including distance from the outfall to these highest concentrations located throughout the study site, a graph of concentration with distance can be created that would enable calculation of dilution at any distance along an estimated line of travel. The page C2 red line of dyed effluent travel was estimated by connecting the most possible page C2 data points along a possible line of most concentrated flow. Also shown on page C2 are the source of these highest data points identified, whether from a station or a data acquisition track, and the date and distance from the WWTP outfall.

The distances along the page C2 estimated line of most concentrated flow were used to create the page C3 graph of distances and highest effluent tracer concentrations (see dashed line). The resulting page C3 dashed line is expected to be a linear dilution, even if the study vessel could not always be in the right place to record the highest data. Therefore a linear best-fit line is shown on page C3, starting after near field dilution nearest the WWTP outfall. This best-fit line enables calculation of dilution at any distance seaward along the projected line of effluent travel through Union River and most of Union River Bay. If Patten Bay is a resource to be similarly examined, a similar graph to determine dilutions could be attempted using the Track 6, 0.35 ppb data point as intermediary between Station 6 and the Track 10, 0.12 ppb data point shown on page C2.

Page C4 represents dilutions determined by the best-fit line on page C3. Concentrations reflected in the page C4 graph of distance and dilution represent the page C3 best-fit line rather than the concentrations shown on page C2. Since page C4 is a graph of dilution for the entire study area, dilutions are shown at data locations not available on page C2 (nor in the datatables in this report that show dilutions used for but not resulting from data analyses). Therefore dilution can be determined with page C4 at any distance away from the outfall into Union River and Union River Bay. This study suggests that, for any distance from the outfall, the least dilution represented on page C4 could occur at any position laterally across the river or bay.

Page C5 illustrates dilutions expected, along with distances from the outfall, at the intervals shown throughout the study area. Though "Haynes Point" is covered by the 58,550:1 label on page C5, this dilution may be expected at that location 7.75 NM from the WWTP outfall, near the furthest excursion of dyed effluent that was located. Similarly, dilutions of 5400:1 near Smiths Ledge and 2200:1 near Mill Cove result from the analyses described above.

The page C5 dilutions shown in Patten Bay are simply derived using the critical data points with highest tracer dye concentrations, after analyzing all the data collected for this report. Dilution between these two points might be approximated similar to the procedure described above. The fluorometry indicates that dilution as low as 9758:1 may be expected near the west end of Patten Bay.

Page C5 includes examples of how the page C4 graph can be used to determine dilution at any distance south of the WWTP outfall where the dyed effluent was located. For example, Weymouth Point is 3.48 NM from the outfall and page C4 indicates a corresponding dilution of 1200:1, as illustrated on page C5. Similarly, the 120:1 dilution shown for Station 2 on page C5 was derived from page C4, rather than the data shown on page C2 that did not appear to be the highest concentration at that location. Provided in this report then is a tool that can be used to determine dilution at points of interest in Union River and Union River Bay. When dilution is combined with a die-off factor for the fecal coliform indicator, a total reduction factor can be applied to different scenarios of fecal coliform densities released at the WWTP outfall, to predict fecal coliform densities expected throughout the study area under those scenarios.

CORMIX Model Analysis

One objective of this project was to explore if the CORMIX model can be adapted to be useful for this estuary. A number of attempts were made to model this estuary using CORMIX software developed by Dr. Robert Doneker. However, CORMIX is primarily a near field, steady state mixing model and is not reliable for the hydrodynamic conditions that occurred in the far field mixing. Since CORMIX assumes a steady state, it does not allow input of the environmental changes, such as fluctuations in river velocity and buildup of dye or bacteria during subsequent 12-foot tidal cycles, or increasing pycnocline level as the river approaches the open ocean. Dr. Doneker was consulted about the applicability of his software in a continually changing tidal estuary and he suggested that under these conditions, a tracer dye study would be more accurate in determining far field mixing. His suggestion was verified by this study and CORMIX analyses.

Several CORMIX scenarios were run, each slightly changing the parameters of ambient water density, ambient water velocity, and density increase with pycnocline depth. Each scenario gave slightly different results in the near field mixing output but nearly identical results in far field mixing. In each case the near field ended less than 20 meters from the WWTP outfall with a stratified layer of effluent at the depth of the pycnocline. In most cases for the far field, simulation indicated the effluent traveled downstream in a layer no more than 0.6 meters thick and spreading from bank to bank.

The CORMIX results supported the findings of the 8/3/01 tracer dye study from the WWTP outfall to a point before Profile 9 (see page F4) located 2400 meters from the outfall. The Page E1 CORMIX near field profile shows a "wake attachment" of the effluent to the river bottom for a distance of approximately 11 meters, at which point jet buoyancy brings the plume up to the pycnocline depth of 1.8 meters (6 feet). The CORMIX analysis output discusses this near field mixing on page E3. The complete CORMIX analysis output can be found in section E, pages 3 through 15.

Page F1 field readings show that the effluent tracer was evenly mixed throughout the water column at the location of Profile 9 shown on page F4. However, the CORMIX model predicts a constant thickness and depth (on the pycnocline) for the plume at the location of Profile 9 and farther downstream from the WWTP outfall, as shown on page E2. CORMIX modeling of the effluent mixing into the estuary appeared to be similar although not identical to the 8/3/01 tracer dye study results for the near field and for a short distance beyond, into the far field of the Union River. This similarity did not continue for the entire length of the river or into the bay.

The CORMIX model analysis indicates that the CORMIX model does not take the place of a tracer dye study in the far field. Yet CORMIX results were closer to the tracer dye study results than expected. In the near field, the amount of data collected did not allow the determination of whether CORMIX could take the place of a tracer dye study. However, near field analysis is less important than far field analysis for NSSP studies. CORMIX appears to be a useful tool for planning NSSP hydrographic studies.