Ocean outfall dye study peer review

Massachusetts Water Resources Authority

Environmental Quality Department

Report ms-065

Citation:

CDM. 2000. Ocean outfall dye study peer review. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-065. 30 p

Contents

Table of Contents
Executive Summary 1

Section 1 Introduction 3

Section 2 Permit Requirements 5

Section 3 Overview of MWRA's Dye Study 9
3.1 Dye Addition 9

3.2 Field Programs 9
3.2.1 Background Surveys 10
3.2.2 ZID Surveys 10
3.2.3 Nearfield Surveys 11
3.2.4 Farfield Survey 11

3.3 Shakedown Exercise 11

3.4 Summary 11

Section 4 Overview of Other Dye Studies 13
4.1 Dye Addition 13

4.2 Field Dye Monitoring 14
4.2.1 Fluorometric Data 14
4.2.2 Hydrographic Data 15

Section 5 Review of MWRA's Dye Study 16
5.1 Adequacy of Data 16

5.2 Other Suggested Improvements/Comments 17

5.3 Comparison to Other Dye Studies 18

Section 6 Summary of Comments and Recommendations 19

Section 7 Bibliographies 21

Appendices
Appendix A Independent reviews by Dr. P. Roberts and Dr. B. Jones

Executive Summary

As a part of the MWRA's 1999 NPDES permit, a dilution study is to be conducted to evaluate the new outfall's minimum dilution ratio. The protocols outlining the study are described in detail in the MWRA's "Combined work / quality assurance project plan (CW / QAPP) for plume tracking: 1999-2000". CDM has reviewed this study plan to evaluate the ability of the study to address the adequacy of the study plan's technical approach and the plan's ability to efficiently and effectively evaluate both the nearfield and farfield dilution ratios. Dr. P. Roberts (Georgia Institute of Technology) and Dr. B. Jones (University of Southern California) have also independently reviewed the study plan in this same manner. All of the comments submitted are summarized in this report. Dr. Roberts and Dr. Jones' reviews are attached as Appendix A.

The following comments and recommendations regarding the MWRA's plume tracking study plan are offered:

- Although the winter survey (non-stratified water column) will provide information concerning the extent of the surfacing of the effluent plume, it is not necessary to respond to the requirements of the permit.

- ADCP data should be collected during the entirety of the study. In addition, the spatial variability in currents throughout the dye study area should be evaluated in the shakedown cruise to decide whether more fixed current meters should be deployed.

- The location of the ZID survey track should be reevaluated based on the specific field conditions (effluent flow rate, stratifications, and currents) found on the day of the dye study.

- In lieu of the diffuser centerline survey tracks, transects down current of the diffuser should be conducted to evaluate the change in effluent dilution as a function of distance.

- Although it is important to keep dye concentrations as low as possible, the targeted initial dye concentration should be reevaluated to ensure that background dye concentrations do not limit the range of measurable dilution ratios, i.e., nearfield and farfield dilution ratios.

- The chlorination / dye interaction test outlined in Section 14.3.4 of the dye study plan should be conducted during the shakedown cruise with the dye added as outlined in Section 7.2.1 and the test sample taken after the hypochlorite mixers. If this test shows that chlorine may compromise the accuracy of the study, then the possibility of interrupting chlorination for the duration of the dye study should be investigated or the targeted initial effluent concentration should be increased to compensate for this potential dye loss.

- More information concerning the concentration of cyanobacteria in Massachusetts Bay should be collected and evaluated for possible interference with the Rhodamine WT fluorometry readings.

- Special attention should be placed on the dye injection pump so that it does not clog up.

- If possible, the duration of the farfield survey should be extended and grab samples should be taken and analyzed for dye and coliform concentration.

Overall the protocols outlined in the study plan are very thorough. The level of detail in the study is a high as any of the other dye studies reviewed in this evaluation. There is a considerable amount of data to be collected in this study in a short time frame. Therefore, it should be ensured that the quantity of data collected does not compromise the quality of the data collected.

Section 1
Introduction

As a part of the Massachusetts Water Resources Authority's (MWRA) 2000 National Pollutant Elimination Discharge System (NPDES) permit, a dye dilution study is to be performed on the new ocean outfall for the Deer Island Wastewater Treatment Plant. The outfall is located in Massachusetts Bay off of Deer Island and is comprised of a nine mile discharge pipe with 55 risers spread out over 2000 meters.

The purpose of the study is to evaluate the ability of the outfall to dilute the effluent, which is done by determining the initial dilution characteristics of the outfall and tracking the long-term location and mixing characteristics of the outfall plume. A plume tracking study plan (Battelle 2000) has outlined the proposed protocols to accomplish these goals. In order to track the effluent plume, Rhodamine WT dye will be injected into the finished effluent at the Deer Island WWTP and a field monitoring program will monitor the effluent plume by tracing the injected dye via fluorometry.

CDM has been retained to review this study plan. The main objective is to evaluate the ability of this proposed plume tracking study to efficiently fulfill the goal set forth in the 2000 NPDES permit. In addition to this goal, other objectives were considered, as follows:

- Will the plume tracking study be able to demonstrate the far field dilution of the outfall?
- Are there any recommended improvements to the study plan that would contribute to its success, including:
  - Technical improvements to the study,
  - The elimination of any unnecessary measurements to reduce the study's cost,
- How does this study compare to other similar studies?

At the direction of the MWRA, CDM has also retained Dr. P. Roberts, of the Georgia Institute of Technology and Dr. B. Jones of the University of Southern California to conduct independent reviews. Their work is incorporated into this document, and is attached as Appendix A.

The remainder of this report is organized as follows:

- Section 2 reviews the MWRA's 1999 NPDES Permit requirements and how the requirements were established.
- Section 3 presents the specific details of the MWRA plume tracking study plan.
- Section 4 gives a brief overview of various other dye studies, along with comments concerning problems that happened in these dye studies.

- Section 5 reviews the MWRA's dye study, including any recommended adjustments to the proposed protocols.

- Section 6 will summarize all comments and recommendations for the MWRA's plume tracking study.

- Appendix A will include the independent reviews of the work plan by Dr. P. Roberts and Dr. B. Jones.

Section 2
Permit Requirements

The MWRA's 1999 NPDES permit requires a dye study to "certify whether the outfall's minimum dilution is equal to, or greater than the predicted minimum dilution", which was specified the 1993 report, "Hydraulic Model Study of the Boston Wastewater Outfall, II: Environmental Performance", by Roberts and Snyder (the "1993 Report").

The modeling effort that was presented in the 1993 Report was conducted using a physical model and two mathematical models (ULINE and RSB). The physical model consisted of a density stratified towing tank, a model diffuser and a sampling array. This model was set up to test how varying the number of outfall diffusers (risers), distance between diffusers, and the number of ports per diffuser (8 or 12) would affect the outfall's effectiveness in terms of minimum dilution ratio. These experiments were conducted under various physical conditions, ranging from:

- no water column stratification to a steeply stratified water column
- low wastewater flows to high wastewater flows,
- and no ambient ocean currents to high ocean currents.

The physical model results indicated that an outfall design of 55 diffusers at a spacing of 37.2 meters with 8 ports per diffuser would produce the most economically efficient minimum dilution ratio under the conditions observed in the proposed outfall location in the Massachusetts Bay.

The two mathematical models were then run with final outfall design characteristics so that comparisons can be made between these models and the physical model. The EPA model ULINE calculates effluent mixing based on line-source buoyancy-flux-induced effluent mixing. This model was used to predict dilution ratios and effluent riser heights. The RSB model (Roberts-Snyder-Baumgartner) is a mathematical model based on experiments on multiport diffusers in density stratified currents, which calculates effluent mixing based on buoyancy and momentum fluxes. The RSB model can be used to predict the effects of density stratification and ocean currents on the effectiveness of ocean outfall multiport diffusers, in terms of effluent plume rise height, waste-field thickness, and minimum dilution ratio (Roberts, 1993). The results of this comparison indicated that ULINE did not have the capability to model some of the important characteristics of the ocean outfall, i.e. mulitport diffusers and variable diffuser spacing. The RSB model was more able to address these complexities of the MWRA's ocean outfall.

As stated earlier, all of the models were conducted under various oceanic conditions, in order to identify the conditions under which minimum dilution occurs. Table 2-1 summarizes the results of modeling runs that were conducted using the final design outfall characteristics. As shown in Figures 2-1 and 2-2, the results of the physical model and ULINE model indicate that the late summer stratification (steeply stratified water column) in conjunction with low ambient ocean currents are the most critical conditions under which minimum dilution occurs. Furthermore, Table 2-1 indicates that dilution ratios are found to be a minimum when these two conditions are met with high effluent flow rates. The table also indicates that parallel currents are more constrictive than perpendicular currents. Currents that are perpendicular to the outfall's diffusers typically give dilution ratios that are around twice as large as those dilutions resultant from equivalent parallel currents.

Table 2-1
Summary of Outfall Modeling

Effluent Flow Rate (MGD)	*Ocean Current (cm/s)*	*Current Direction*	*Measured Minimum Dilution Ratio From the Physical Model (S_m)[1]*			*Minimum Dilution Calculated From the ULINE Model (S_m)[1]*		
			Steeply Stratified[2]	*Slightly Stratified*	*Non-Stratified*	*Steeply Stratified*	*Slightly Stratified*	*Non-Stratified*
390	0	--	81	112	180	73	79	161
390	12	Parallel	83	105	210	83	89	184
390	25	Perpendicular	223		561	241		663
390	25	Parallel	125	133	220	101	105	229
620	0	--	70			55		
1270	0	--	56		113	37		73
1270	25	Parallel	63		111	44		93

1 – The flux averaged initial dilution is equal to 1.15 times the measured initial dilution ($S_{fa} = 1.15*S_m$)
2 – The water column is steeply stratified during the late summer, slightly stratified during the early summer and non-stratified during the winter.

In Attachment S to the MWRA's NPDES permit, a flux average minimum dilution of 70:1 (ocean water : effluent) was defined as the nearfield initial dilution ratio. A flux averaged initial dilution ratio is equated to a measured initial dilution ratio using the following equation:

$$S_{fa} = 1.15 * S_m,$$

where S_{fa} is the flux average (or water column averaged) initial dilution ratio and S_m is the lowest measured initial dilution ratio in the water column. A flux averaged minimum dilution ratio of 70:1 would equate to a 61:1 minimum measured initial dilution ratio. This dilution ratio is the benchmark of the effluent plume study, which was predicted to occur under a steeply stratified water column (late summer), a high effluent flow rate, and low to no ambient ocean currents.

Figure 2-1
Physical Model Dilution with Parallel Currents @ 390 MGD

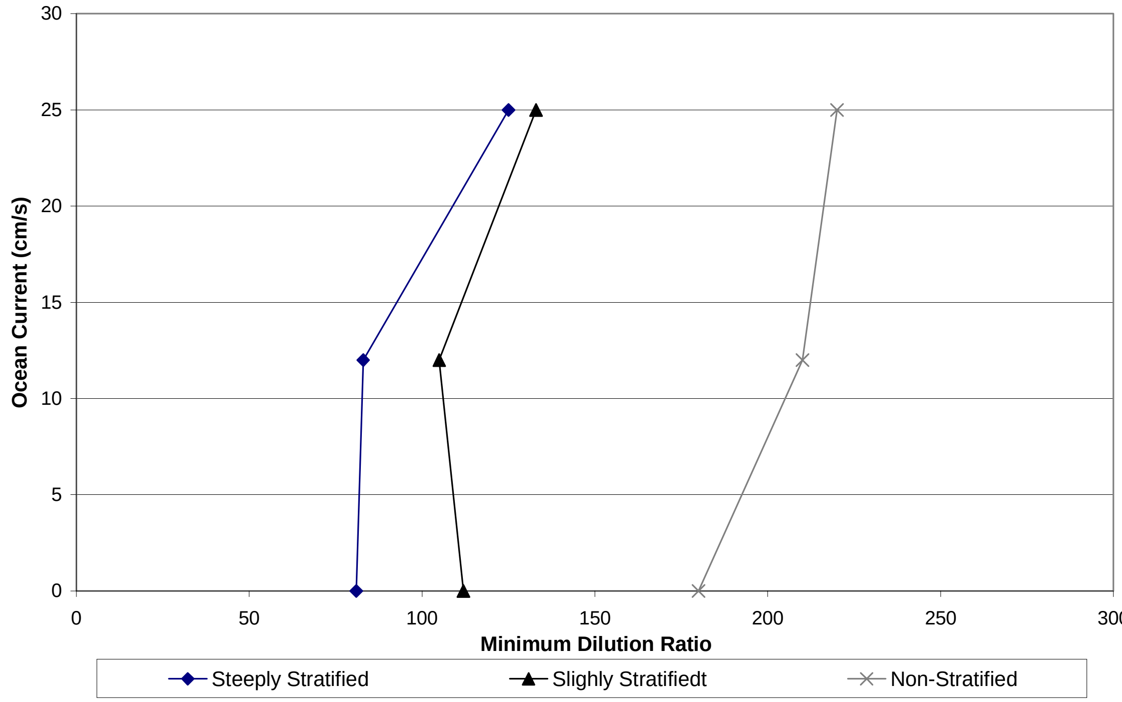
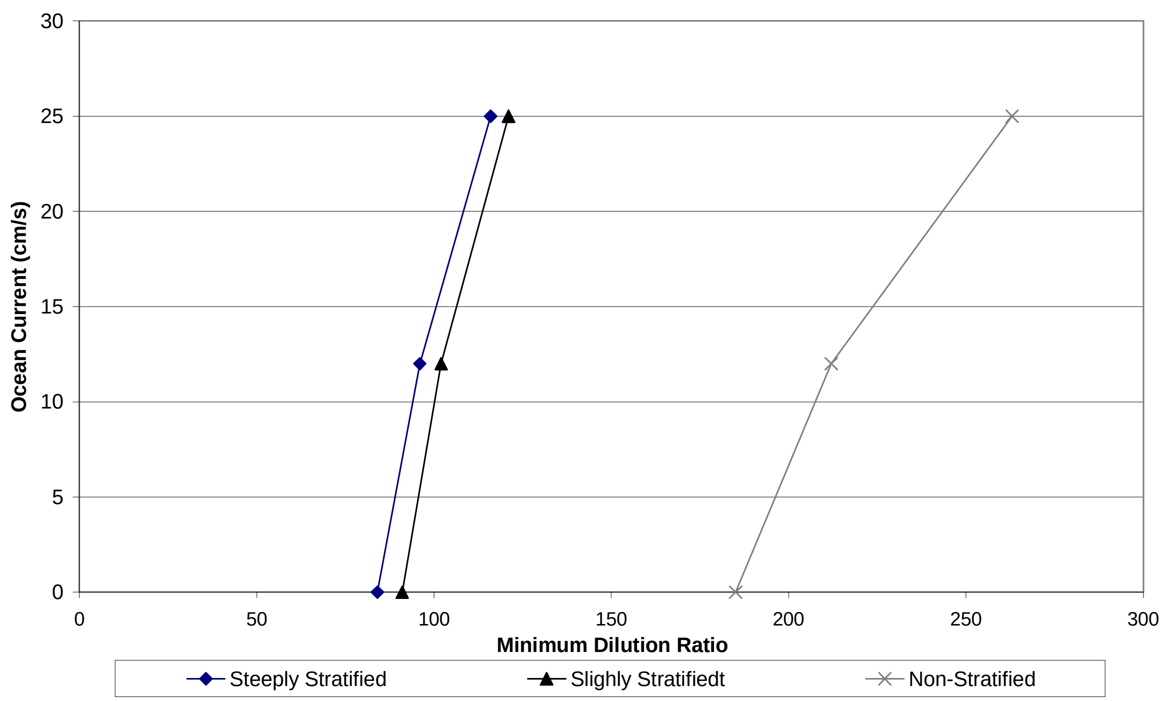


Figure 2-2
ULINE Model Dilution with Parallel Currents @ 390 MGD



The probability of conducting the dye study under these exact conditions is very low; therefore it will be necessary to compare the measured results under the observed conditions to the RSB model run under the same conditions in order for conclusions to be drawn concerning the outfall's minimum dilution ratio. Therefore it will be necessary to collect enough data to ensure that the mathematical models can reproduce the ocean characteristics observed during the dye studies.

Section 3
Overview of MWRA's Dye Study

The proposed plume tracking study has two basic components: the dye addition and the field program. The dye addition component is concerned with ensuring that effluent exiting the outfall has a constant dye concentration and the field program is set up to quantify the spread and dilution of the effluent plume. The proposed plume tracking study includes three separate field exercises, a dye study under a non-stratified water column (winter conditions), a second dye study under a stratified water column (summer conditions) and a shakedown exercise. The purpose of the two dye studies is to quantify the actual dilution under observed conditions under both non-stratified and stratified water columns. The shakedown exercise is conducted to test the overall dye addition system and to practice field logistics.

3.1 Dye Addition

A tracer dye (Rhodamine WT) will be added to the effluent stream at the Deer Island WWTP. The dye will be added just upstream of the sodium hypochlorite dosing lines and the hypochlorite mixers. The dye addition will be normalized by the actual effluent flow rate so that a constant dye concentration of 50 ppb is achieved. For each of the two main dye studies, the dye will be added for 25 hours with the time of dye addition coordinated with the tides and effluent travel time along the diffuser so that the dye will first be emitted at the diffuser at low tide, and continue for 25 hours thereafter. The effluent dye concentration will be monitored by a Turner Design flow through fluorometer downstream of dye addition at the end of the disinfection basin. Temperature and conductivity of the effluent will also be continuously recorded. In addition, discrete effluent samples will be taken throughout the dye addition process and analyzed for Rhodamine WT, TSS, NH_4, PO_4, Ag, Cu, and fecal coliform.

3.2 Field Programs

The two dye studies are to be conducted within one year following the initiation of MWRA's new outfall. The non-stratified water column study is to be conducted in December of 2000, while the stratified water column study is to be conducted in July of 2001. The studies will be conducted over a 25-hour period (two tidal cycles), and will include the following exercises:

- Background Survey
- Zone of Initial Dilution (ZID) Survey
- Near Field Survey
- Far Field Survey

The hydrographic and fluorometry readings will be taken in "Towyo" mode using the Battelle Ocean Sampling System (BOSS), which includes a fluorometer, a conductivity, temperature, and pressure gage (CTD), and a light transmissometer. The BOSS will be attached to a winch that can be lowered and raised at various speeds within the water column. Continuous measurements will be taken while the boat is travelling at a predetermined speed. At various points during the surveys, vertical profiles will be conducted and discrete water samples will be taken. In addition to these data an acoustic Doppler current profiler (ADCP) will be used to take ambient water column current measurements. A summary of data that is to be collected in each survey is listed in Table 3-1.

Table 3-1
Summary of Data to be Collected During Dye Surveys

Survey	*No. of Surveys*	*Fluorometer Profiles Per Survey*	*Meters of Continuous Tow-yo Fluorometer Readings Per Survey*	*Discrete Water Samples per Survey*			*ADCP Data*
				TSS, NH4, PO4 and Chlorophyll	*Bacterial Indicators[1]*	*Silver and Copper*	
Background	1	0	4420 @ 4 knots	4	0	2	Yes
ZID	4	15	4420 @ 4 knots	9	24	2	No
Near Field	4	16	21815 @ 8 knots	0	0	0	Yes
Far Field	1	50	Unknown @ 8 knots	0	0	0	No

1 – Bacterial indicator samples will only be taken on one ZID survey to ensure delivery of samples to laboratory within holding times.

3.2.1 Background Surveys

Prior to each dye study a background survey will be conducted to scan for ambient material in the water that may emit fluorescence, which would interfere with the ability of the fluorometers to detect the dye emitted from the outfall. Background fluorescence readings can range from 0.01 ppb to 0.5 ppb (Seaconsult, 1992, 1994, 1997a and 1997b). The background fluorescence readings will be subtracted from the in-situ fluorescence readings during each of the surveys before the data is evaluated. The ratio between the initial effluent dye concentration and the background fluorescence will define the maximum dilution ratio that can be measured. For example, if background fluorescence is found to be 0.2 ppb and the initial effluent dye concentration is 50 ppb, then the maximum dilution ratio that can be measured is 250:1 (ambient water to effluent wastewater). In addition to fluorometry readings discrete water samples will be collected and analyzed in a laboratory for various constituents (Rhodamine WT, TSS, NH_4, PO_4, Ag, Cu, and Chlorophyll). A coarse net will be dragged along the sea surface in the area of the effluent plume to evaluate the effectiveness of the new treatment plant in the removal of large debris and other floatable materials.

3.2.2 ZID Surveys

The ZID surveys will be conducted to measure the dilution ratio within the zone of initial dilution. The ZID is defined as a zone around the diffuser that is about 2-4 times as wide as the water column is deep. The minimum dilution ratio measured in this survey will be used to test outfall compliance with the 1999 NPDES permit requirements. This will be done by taking fluorometry and CTD measurements along a loop with a radius of 60 meters around the centerline of the outfall diffusers. Continuous measurements will be taken in "Towyo" mode and water column profiles will be taken approximately every 300 meters along the loop. While profiling, discrete water samples will be taken and analyzed for TSS, NH_4, PO_4, Ag, Cu, Chlorophyll and fecal coliform. Each dye study will have four such ZID surveys conducted, one at maximum flood and ebb currents, and one at the minimum flood and ebb currents. During the minimum flood and ebb current surveys, continuous fluorometry readings will also be taken down the centerline of the diffusers. The minimum dilution ratio will be calculated by comparing the maximum fluorescent reading found in the ZID surveys to the initial effluent fluorescent reading. No ADCP data will be collected during these surveys.

3.2.3 Near Field Surveys

Four near field surveys will be conducted in between each of the four ZID surveys. These will be conducted to characterize the effluent plume's near field horizontal and vertical structure and to determine how the plume will be affected by near field ocean currents and water column stratification. Continuous fluorometric, CTD and velocity measurements in "Towyo" mode will be taken along four concentric loops around the centerline of the diffusers at distances of 60, 120, 240 and 480 meters. At four discrete locations along each of the loops, vertical fluorometric and velocity profiles will be taken, in order to map the vertical structure of the effluent plume.

3.2.4 Far Field Surveys

After the ZID and near field surveys are complete and at least 9 hours after the dye addition has ceased, a far field survey will be conducted to map the extent of the effluent plume, down to levels of 0.1 ppb. The far field survey will be conducted for up to 12.5 hours. At least four vertical profiles will be conduct each hour during the far field survey. The fluorometry readings will be conducted in "Towyo" mode. No ADCP data will be collected during this survey.

3.3 Shakedown Exercise

Approximately four weeks prior to the first plume tracking exercise, a shakedown exercise will be conducted. Dye will be added to the finished effluent at the Deer Island WWTP for a total of four hours to create an estimated 50 ppb effluent concentration of Rhodamine WT dye. This exercise will test most or all of the components of the plume tracking exercises, including the die addition and transit time, background survey, ZID survey, near field survey, and if time permits a far field survey. Samples of the WWTP effluent will be taken and analyzed at the Deer Island laboratory for Rhodamine WT, TSS, temperature, salinity, chloride and bacteria. The "Towyo" system will also be tested.

3.4 Summary

The data collected during each survey has a specific use. Table 3-2 summarizes the purpose for the data collected within each survey.

Table 3-2
Summary of Survey Purposes

Survey	*Purpose*
Background	To define background fluorescence levels and to obtain background discrete water samples.
ZID	To measure dilution in the ZID to determine compliance with the requirements of the NPDES permit.

Near Field	To determine plume structure and behavior in the nearfield and its response to ambient ocean currents and water column stratification.
Far Field	To determine plume structure and behavior in the farfield.
Shakedown Exercise	To conduct the background, ZID, nearfield, and possibly the farfield survey to test survey procedure and field logistics.

Section 4
Overview of Other Dye Studies

Several dye studies have been reviewed as a part of this report. Various levels of effort were put forth into each of the studies. For comparison with the MWRA dye study, focus has been placed on the overview of two of the more detailed dye studies. These two studies, Annacis Island and Lulu Island (Seaconsult 1997a and 1997b), were conducted by Seaconsult in Vancouver, British Columbia. Like the MWRA dye study, these two studies can be divided into two parts: dye addition and field dye monitoring. This section will review the level of effort that went into each of these two parts from all of the studies reviewed and then focus in on the two Seaconsult studies. Comments concerning some of the major problems incurred during these dye studies will be highlighted.

4.1 Dye Addition

The level of effort that was put into the dye addition in these dye studies ranged from injecting a constant rate of dye into an outfall pumping station (Seaconsult 1992) to pumping a precise amount of dye, normalized by the effluent flow, into the effluent stream (Seaconsult 1997a and 1997b). The difference between these two levels of effort was obvious in that the normalized dye addition resulted in a constant effluent dye concentration exiting the diffuser, instead of a variable concentration. In the Lulu Island study (Seaconsult, 1997b) it was noted that keeping the effluent dye concentration exiting the outfall constant made the dye dilution study more accurate and the data evaluation more straight forward.

In the two Seaconsult studies (Seaconsult 1997a and 1997b) the dye was added after the chlorination process. In the Annacis Island study (Seaconsult 1997a) the dye was added after the sulfur dioxide dechlorination process. The dye was added in this manner to reduce contact between the Rhodamine WT and free chlorine. When free chlorine is added to wastewater it will ionize any organic material in the waste stream, including the Rhodamine WT dye. This reaction can have an affect on the measurable concentration of the dye exiting the outfall. In order to make sure that the free chlorine in the wastewater does not degrade the Rhodamine WT dye, the dye should be added after the free chlorine has had enough time to come into contact with the suspended solids in the effluent, thus providing a prophylactic type of protection from the chlorine (Ocean Surveys Inc. personal conversation). Most of the chlorine that remains after this point is in the form of residual chlorine, to which Rhodamine Dye is much less reactive (Deaner, 1988).

Due to instrument detection limits and background fluorometry readings, the targeted effluent dye concentration varied in these studies. Table 4-1 lists some of the targeted concentrations of Rhodamine WT dye in the effluent for these studies. The targeted effluent dye concentration was chosen based on the maximum range of dilution that was desired to be measured in the field.

In the Annacis Island dye study (Seaconsult 1997a), a problem occurred with the Rhodamine WT dye feeding pump. After operating for a while the dye filters in the system tended to clog up, reducing the amount of dye that was injected into the system, resulting in a sustained decrease in effluent dye concentration. It was recommended that the dye feeding station be monitored continuously throughout the dye study in order to prevent and monitor for such problems.

Table 4-1
Summary of Effluent Dye Concentrations

Study	*Targeted Effluent Concentration (ppb)*	*Background Dye readings (ppb)*	*Maximum Dilution Ratio*
Seaconsult, 1994	6700	0.15	44667:1
Cavinder, 1992	1200	0.5	2400:1
Seaconsult, 1997a	500-800	0.18	2778:1 to 4444:1
Seaconsult, 1997b	400-600	0.18 to 0.4	1000:1 to 3333:1

4.2 Field Dye Monitoring

The basic components that made up the field monitoring of the dye studies reviewed consisted of fluorometric data and hydrographic data.

4.2.1 Fluorometric Data

The two Seaconsult studies (1997a and 1997b) took fluorometry readings in horizontal transects across the study area and also vertical profiles through the water column. The vertical profiles were focused in on the initial dilution zone, near the diffuser. The field crews were split into two different boats, with one boat taking horizontal transect data and the other boat taking the water column profiles. Because there were two different fluorometers taking field measurements, the two instruments had to be calibrated to each other so that the field readings were internally consistent. The data from the vertical profile data was used to calculate the trapping height of the effluent plume and the minimum dilution ratio, while the transect data was used to map the extent of the effluent plume.

As listed above, background fluorometer readings around the diffusers were measured in all of the studies. These background readings were sometimes significant enough (0.18 to 0.5 ppb) as to have an affect on the maximum dilution ratio measured. In addition, tests were conducted to ensure that the ambient water has no adverse affects on the Rhodamine dye.

One difficulty that occurred in the Annacis Island study (Seaconsult 1997a) had to do with the data from the profiling fluorometer. The instrument that was used to take the profiles was a flow through fluorometer. This instrument required a pump to pump the profile of the water column through the deck-mounted fluorometer. The pump was attached to a pressure gage that recorded the depth from which the sample was taken. The difficulty that was incurred took place in the data analysis when the fluorometry readings had to be correlated to the depth gage readings. It was recommended that an in-situ profiling fluorometer be used to eliminate this problem.

4.2.2 Hydrographic Data

The hydrographic data collected in most of the dye studies reviewed consisted of temperature, conductivity and ambient current measurements. In all of the studies reviewed conductivity and temperature data was collected as a part of the field monitoring. The fluorescence of Rhodamine WT dye is affected by temperature, and therefore temperature data needed to be collected to make the proper corrections to the fluorometric measurements. The conductivity was collected to determine the density structure of the water column.

Ambient ocean currents were also quantified in these studies. In the smaller studies (Seaconsult 1992 and 1994) drogues were used to measure the overall ambient currents in the study area. In the more recent studies (Seaconsult 1997a and 1997b) ADCPs were used to measure the ocean currents. The ADCPs are able to measure the profile of currents in the water column. The data collected from the ADCPs provide much more detail into the ambient ocean currents than that which was taken from the current drogues.

The field monitoring conducted in the Mamala Bay study did not consist of a dye study but various hydrographic instruments were used, including ADCPs and thermistors. Thermistors are in-situ probes that can internally record temperature and dissolved oxygen readings. The data from the thermistors provided detailed temporal information about the water column density structure that was useful in the model runs that followed the field study. Although these instruments proved very helpful, it was recommended that if they were used, it should be ensured that the thermistor chain extended all the way to the surface, so that a complete water column density structure is recorded.

Section 5
Review of MWRA's Dye Study

5.1 Adequacy of Data

The minimum dilution predicted by numerical and physical models occurs under conditions of high wastewater flows, strong water column stratification and no current. One cannot reasonably expect to encounter these conditions during the field surveys. This would require one to defer the deployment until such time as a relatively large storm occurred (which would produce the high flow rate as a result of inflow and combined sewage entering the system) in concert with a steeply stratified receiving water. Therefore, a numerical model will have to be used to calculate the actual minimum dilution ratio of the outfall, after having validated the use of the model for this purpose. In order to validate the model, sufficient data must be collected so that comparisons can be made between the observed dilution (measured in the field) and the predicted model dilution (calculated by the model for the conditions that were observed).

As presented, each of the two cruises can be expected to produce 60 discrete vertical plume profiles during the ZID surveys and 64 during the nearfield surveys. In addition, the operation of the fluorometer will produce a continuous indicator of dilution and plume structure. The shakedown cruise, assuming that it will produce useable data, will produce about one sixth of the data of a full cruise. Collectively, this should provide adequate data to compare the predicted dilutions to the observed conditions.

As discussed in Section 2, both the physical model and the mathematical models calculated the minimum dilution ratio to occur under a stratified water column condition. Although the winter survey (non-stratified water column) will provide information concerning the extent of the surfacing of the effluent plume, it is not necessary to respond to the requirements of the permit.

The field survey protocol is somewhat vague about the extent of ADCP operation. It implies that ADCP data is to be collected only during the nearfield survey. To ensure complete understanding of the ocean currents during the dye study, ADCP data should be collected throughout the entirety of the survey. The complete reliance on the ADCP meter for current data should be evaluated. Consideration should be given to augmenting the data with instrumentation in place, to provide additional data source for comparison. In addition, prior studies (MWRA, 1988) suggested that there can be high spatial variability in ambient current velocity over distances as small as 5 kilometers. The shakedown cruise should be used to evaluate this spatial variability.

The ZID transects may be too close to the diffuser. Both the physical and numerical models estimate dilution at the point where dilution from momentum and buoyancy has ceased, i.e. where near field process end and far field processes take over. In many instances this could be farther from the diffuser than the 60-meter offset planned from the ZID survey. Calculations conducted by Dr. Roberts suggest a high variation in the distance between the diffuser and the end of the near field. Under zero current speed and strongly stratified water column, the nearfield can extend 50 meters from the diffuser and up to 100 meters under a non-stratified water column. For a current of 25 cm/s perpendicular to the diffuser, low effluent flowrate, and a strongly stratified water column, this offset can be about 150 meters and can be as much as 300 meters under a non-stratified water column. Similar problems confounded the interpretation of the results of the St. John's River Studies (Cavinder, 1994) and of the Lulu Island Outfall Studies (Seaconsult, 1997b). If the ZID is to be considered a hydrodynamic mixing zone as opposed to a regulatory mixing zone, then it may be best to leave the actual offset distance of the ZID survey track to be determined in the field, taking into consideration flow rate, stratifications and currents, both tidal and non-tidal. In addition, in lieu of the proposed diffuser centerline survey tracks, transects down current of the diffuser should be conducted to evaluate the change in effluent dilution as a function of distance.

The targeted effluent dye concentration (50 ppb) is much lower than the targeted ranges found in other studies, as shown in Table 4-1. It is important to keep dye concentrations as low as possible to minimize the cost of the dye, but it must be ensured that the targeted initial effluent dye concentration does not limit the range of measurable dilution ratios. With the anticipated measured minimum dilution ratio (S_m) of 61:1, the maximum measurable concentration after initial dilution would be 0.8 ppb. In the Deer Island Plume Tracking Survey Report (Abro, 1994b), all of the fluorometry readings below 0.3 ppb had to be thrown out. If this were the same case as in this study, this would only leave an additional 2.67 measurable dilutions to account for variations in actual measured initial dilution and farfield dilutions. Farfield dilution can account for as much as an additional 10 dilutions (Roberts, 1999). In addition, in the summer, with perpendicular currents, initial dilutions may exceed 250:1 for a portion of the tidal cycle, which would exceed the maximum measurable dilution ratio with this initial effluent concentration and anticipated background fluorescent level. These factors indicate that initial dye concentrations greater than 50 ppb are warranted to ensure proper quantification of the actual dilution and for mapping the farfield extent of the effluent plume.

5.2 Other Suggested Improvements/Comments

In general, dye addition should occur after the effluent is chlorinated and well mixed (Ocean Survey Inc., personal conversation). This reduces the chances of the dye coming into contact with free residual chlorine. Ensuring that only combined residual chlorine is present in the effluent would significantly lessen the chance of the dye being oxidized by the chlorine. If dye addition after chlorination is not possible, then the procedure outlined in Section 14.3.4 should be followed for the full 60-hour period during the shakedown cruise. The dye should be added as outlined in Section 7.2.1 and the test sample should be taken after the hypochlorite mixers. If this shows that chlorine may compromise the accuracy of the study, then the possibility of interrupting chlorination for the duration of the dye study should be investigated or the targeted initial effluent concentration should be increased to compensate for this potential dye loss.

As with phytoplankton and Rhodamine WT dye, cyanobacteria can be measured by fluorescence. Each of these substances absorbs light of a certain wavelength and then instantaneously emits light at a different wavelength. This combination of light absorption and emission is how the fluorometer is able to tell the difference between the substances. For example Rhodamine absorbs green light with a wavelength of 510 nm and emits red light at a wavelength of 650nm. Because the absorption and emission wavelengths of marine cyanobacteria are close to that of Rhodamine WT, there is some potential for interference. Although the concentrations of cyanobacteria in marine environments are usually low and that these interferences will be detected in the background survey, Dr. Jones suggests that the interference due to cyanobacertia can be patchy and not homogeneous, therefore making a simple background subtraction not applicable. It is suggested that further information be collected concerning the concentrations of cyanobacteria in the Massachusetts Bay. If the concentration of cyanobacteria appears to be significant so that interference constitutes a problem, then information concerning the variability of this background interference should be collected.

It is suggested that special attention be placed on the dye injection pump so that it does not clog up and interrupt the dye addition process and jeopardize the study, as in the Annacis Island study (Seaconsult, 1997a).

If possible, the farfield survey should be extended longer than the proposed 12.5 hours. Dr. Roberts suggests that this would provide very useful scientific data on the far field diffusion of the wastefield due to oceanic turbulence, and/or gravitational spreading. It may also be useful to take grab samples during the farfield survey and analyzed for dye and coliform concentration to obtain data on the bacterial decay rate.

5.3 Comparison to Other Dye Studies

The proposed study is as extensive a study of initial dilution as any of the several reviewed as part of this assessment. The protocol has been developed at such a level of detail that it is possible to make useful commentary on the workplan. The major difference between this and other studies is the relatively low targeted concentration of dye in the effluent (50 ppb), which is a function of the relatively large size of the MWRA discharge.

Section 6
Summary of Comments and Recommendations

The MWRA's "Combined work / quality assurance project plan (CW / QAPP) for the plume tracking: 1999-2000" has been reviewed and the following comments and recommendations are offered:

- Although the winter survey (non-stratified water column) will provide information concerning the extent of the surfacing of the effluent plume, it is not necessary to respond to the requirements of the permit.

- ADCP data should be collected during the entirety of the study. In addition, the spatial variability in currents throughout the dye study area should be evaluated in the shakedown cruise to decide whether more fixed current meters should be deployed.

- The location of the ZID survey track should be reevaluated based on the specific field conditions (effluent flow rate, stratifications, and currents) found on the day of the dye study.

- In lieu of the diffuser centerline survey tracks, transects down current of the diffuser should be conducted to evaluate the change in effluent dilution as a function of distance.

- Although it is important to keep dye concentrations as low as possible, the targeted initial dye concentration should be reevaluated to ensure that background dye concentrations do not limit the range of measurable dilution ratios, i.e., nearfield and farfield dilution ratios.

- The chlorination / dye interaction test outlined in Section 14.3.4 of the dye study plan should be conducted during the shakedown cruise with the dye added as outlined in Section 7.2.1 and the test sample taken after the hypochlorite mixers. If this test shows that chlorine may compromise the accuracy of the study, then the possibility of interrupting chlorination for the duration of the dye study should be investigated or the targeted initial effluent concentration should be increased to compensate for this potential dye loss.

- More information concerning the concentration of cyanobacteria in Massachusetts Bay should be collected and evaluated for possible interference with the Rhodamine WT fluorometry readings.

- Special attention should be placed on the dye injection pump so that it does not clog up.

- If possible, the duration of the farfield survey should be extended and grab samples should be taken and analyzed for dye and coliform concentration.

Overall the protocols outlined in the study plan are very thorough. The level of detail in the study is a high as any of the other dye studies reviewed in this evaluation. There is a considerable amount of data to be collected in this study, in a short time frame. Therefore, it should be ensured that the quantity of data collected does not compromise the quality of the data collected.

Section 7
Bibliographies

Albro, C. 1994a. Combined Work / Quality Assurance Project Plan for Deer Island Dye Plume Tracking Study. Task 20-16 MWRA Harbor and Outfall Monitoring Project. Battelle Ocean Sciences, Duxbury, MA.

Albro, C. 1994b. Deer Island Dye Plume Tracking Survey Report. Battelle Ocean Sciences, Duxbury, MA.

Blumberg AF, Ji Z, Ziegler CK. 1996. Modeling outfall plume behavior using far field circulation model. J. Hydraulic Eng. 122(11): 610-616.

Bruce et. al. 2000. Combined Work / Quality Assurance Project Plan (CW / QUAPP) for Plume Tracking: 1999-2000. MWRA Environmental Quality Department Report ENQUAD ms-58. Batelle, Duxbury, MA.

Cavinder, T. 1994. Dilution Study: Key West POTW Discharge, Key West, FL. May 9-16, 1994. U.S.E.P.A. Environmental Services Division, Ecological Support Branch, Athens, GA.

Cavinder, T. 1992. Dilution Study: Arlington East POTW Discharge, St. Johns River, Jacksonville, FL. . U.S.E.P.A. Environmental Services Division, Ecological Support Branch, Athens, GA.

EPA / MADEP. 1999. Authorization to discharge under the National Pollutant Discharge Elimination System. Boston: Environmental Protection Agency & MA Department of Environmental Protection. Report State Permit No MA0103284. 32 p.

Faisst, W.K., et. al. 1990. Iona Outfall Plume Characterization Study. Hydraulic Engineering, Volume 1: Proceedings of the 1990 National Conference. H.H. Chang and J.C. Hill (eds.). ASCE, 1990. pp. 20-25.

Hazen and Sawyer. 1994. Southeast Florida Outfall Experiment II, Participating Outfalls, Final Report and Appendices. Prepared for Broward County Office of Environmental Services, City of Hollywood Utilities Department and Miami-Dade Water and Sewer Department.

HydroQual, Inc., 1999. Bays Eutrophication Model (BEM): Modeling Analysis for the Period of 1992-1994.

HydroQual, Inc. 1997. Outfall Diffuser Studies: City of Erie, Pennsylvania.

HydroQual, Inc. and Normandeau Associates, 1995. A Water Quality Model for Massachusetts and Cape Cod Bays: Calibration of the Bays Eutrophication Model (BEM). MWRA Environmental Quality Department Technical Report Seris No. 95-8.

Jones BH, Washburn U, Wu Y. 1991. The dispersion of ocean outfall plumes: physical and biological dynamics; July 8-12, 1991; Long Beach CA. p 74--85.

Leibundgut, Ch. And Hadi, S. 1997. A contribution to toxicity of fluorescent tracers. Tracer Hydrology 97. Kranjc (ed.). Balkema, Rotterdam.

McDougall TJ. 1990. Bulk properties of "hot smoker" plumes. Earth and Planetary Science Letters 99: 185-194.

MWRA. 1988. Secondary Treatment Facilities Plan, Volume V: Effluent Outfall. Final Report.

Petrenko AA, Jones BH, Dickey TD. 1998. Shape and initial dilution of sand island, Hawaii sewage plume. Journal of Hydraulic Engineering 124(6): 565-571.

Petrenko AA, Jones BH, Dickey TD, Hamilton P. 2000. Internal tide effects on a sewage plume at Sand Island, Hawaii. Continental Shelf Research 20:1-13.

Petrenko AA, Jones BH, Dickey TD, LeHaitre M, Moore C. 1997. Effects of a sewage plume on the biology, optical characteristics, and particle size distributions of coastal waters. Journal of Geophysical Research 102(C11):25061-25071.

Roberts, P.J.W. and Snyder, W.H. 1993. Hydraulic Model Study for Boston Outfall. I: Riser Configuration. Journal of Hydraulic Engineering, 119: 9.

Roberts PJW. 1989. Dilution hydraulic model study of the Boston wastewater outfall. Atlanta: Georgia Institute of Technology. Report SCEGIT 89-101. 190 p.

Roberts PJW. 1999. Modeling Mamala Bay outfall plumes. I: near field. Journal of Hydraulic Engineering 125(6): 564-573.

Roberts PJW, Ferrier, A., and Daviero, G. 1997. Mixing in Inclined Dense Jets. Journal of Hydraulic Engineering, ASCE, 123(8): 693-699, and also Discussion, Volume 125, Number 3.

Roberts PJW and Snyder WH. 1993. Hydraulic model study for Boston Outfall. I: riser configuration. Journal of Hydraulic Engineering 119(9): 970-987.

Roberts PJW and Snyder WH. 1993. Hydraulic model study for Boston Outfall. II: environmental performance. Journal of Hydraulic Engineering 119(9): 988-1002.

Roberts, P.J.W. and Wilson, D. 1990. Field and Model Studies of Ocean Outfalls. Hydraulic Engineering, Volume 1: Proceedings of the 1990 National Conference. H.H. Chang and J.C. Hill (eds.). ASCE, 1990. pp. 1-7.

Roldao J, Carvalho JLB, Roberts PJW. Field observations of dilution on the Ipanema Beach outfall.

Roldao, J., Pecly, J. and Leal, L. 1997. ‘In situ’ determination of the dilution efficiency of submarine sewage outfalls with the help of fluorescent dye tracers.

Tracer Hydrology 97. Kranjc (ed.). Balkema, Rotterdam.

Seaconsult Marine Research Ltd. 1992. EDIS Verification Study Phase 2: Field Survey and Dispersion Modelling. Prepared for the Capital Regional District, Victoria, BC.

Seaconsult Marine Research Ltd. 1994. Wastewater Dilution and Dispersion for the Ganges Treatment Plant Outfall. Prepared for the Capital Regional District, Victoria, BC.

Seaconsult Marine Research Ltd. And ABR Consultants. 1997a. Annacis Island Wastewater Treatment Plant, Stage IV Expansion: Pre-discharge Monitoring Dilution / Dispersion Study. Prepared for the Great Vancouver Sewerage and Drainage District.

Seaconsult Marine Research Ltd. 1997b. Dilution and Dispersion Study of the Lulu Island Wastewater Treatment Plant Effluent Discharge During Low River Flow Conditions. Prepared for the Greater Vancouver Regional District, Burnaby, BC.

Stamates SJ, Craynock JF, Proni JR, Fox-Norse V, Tomey DA. 1996. Acoustic reflector of opportunity distribution as a surrogate for inferring effluent distribution in a survey of Massachusetts Bay; September 23-26, 1996; Ft. Lauderdale, Florida. Marine Technological Society. p 313-320.

Washburn L, Jones BH, Bratkovich A, Dickey TD, Chen M-S. 1992. Mixing, dispersion, and resuspension in vicinity of ocean wastewater plume. Journal of Hydraulic Engineering 118(1): 38-58.

Wu Y, Washburn L, Jones BH. 1994. Buoyant plume dispersion in a coastal environment: evolving plume structure and dynamics. Continental Shelf Research 14(9): 1001-1023.

Comments on: ***Combined work/quality assurance plan for plume tracking 1999-2000,*** **Report ENQUAD ms-58. June 9, 2000.**

By Philip J. W. Roberts, Georgia Institute of Technology, August 16, 2000.

The plume tracking work plan is very thorough and well thought-out, almost all of the concerns of such a study were addressed in detail. Below are some comments and suggestions.

It is implied that the effluent will be chlorinated during the tests. Potential effects of chlorine on the fluorescent dye are discussed on pages 17 and 41, and tests will be done to assess the decay of fluorescence in samples of dye and effluent mixtures. I would suggest that the same tests be done on the samples collected during the actual field tests (i.e. collect a large enough volume of the grab samples to allow measuring the fluorescence of each sample at, say, one hour intervals). This would confirm the decay, or lack of decay, during the actual tests. If fluorescence decay due to chlorine is a problem, could chlorination be suspended for the period of the field tests?

Presumably, the mixing basins will allow for full mixing of the tracer dye with the effluent.

I am not familiar with the accuracy of a boat-mounted ADCP in measuring currents as compared to a bottom-moored instrument. Will the accuracy of measuring from the boat, which is subject to wave motions, be sufficient? If not too costly, it may be worth adding a moored ADCP to enable continuous measurements at one point. A USGS mooring site is mentioned, but the exact location is not given. It is implied that this consists of three (electromagnetic?) meters at various depths. This may suffice for the fixed measurements.

It would appear that the major uncertainty at present is the background level of fluorescence and its variation in time and over depth. The dye tracer concentrations after dilution will be very low, of the order of 0.5 μg/L. The fluorometer accuracy is stated to be 0.1 μg/L. If the background level, and more importantly its variability, is of comparable magnitude, there may be considerable uncertainty in the calculated dilutions. It is stated (p. 9) that the measured dilutions will be corrected for background levels. While this can be done if the background level is constant, if it varies over depth, this correction is trickier as the diluting water that is entrained into the plume comes from different depths that are not known. The results may therefore require some careful interpretation to avoid over or underestimating dilutions.

The shakedown cruise is an excellent idea and should help answer questions about possible background interference.

It is important to use appropriate density profiles to enable comparisons with the mathematical model, RSB, as the plume itself will affect vertical salinity profiles.

What sampling rate will be used for the Chelsea fluorometer?

Can the boat really traverse to within ±15 m?

Will one sampling boat be adequate, or would it be more useful to have two boats, with one guided by the other?

I checked for the effects of dispersion in the outfall pipe that will elongate and attenuate concentrations at the leading edge of the tracer slug traveling in the outfall. This should not be a major problem; the dye concentration should reach about 90% of its final value about 30 minutes after the first traces appear at the ports. Field sampling should not commence until the dye concentrations at the ports have essential reached its final value.

What flexibility is there to allow for changes in conditions and unexpected results, how will changes be decided, and who is responsible for such decisions? On p. 19 it is stated that the Chief Scientist will be responsible. Who is the Chief Scientist? This title does not appear on the organization chart, Figure 8. For example, in the nearfield surveys, Figure 6, if no dye appears upcurrent (to the North say) of the diffuser, there is no point in continuing to measure there, and it would be preferable to make repeated traverses across the plume downcurrent of the diffuser. How would this be decided?

I would like to track the plume for longer than the 12.5 hours proposed in the farfield surveys. Could a second (cheaper?) boat be used to track the dye plume for longer times and distances? This is a good opportunity to obtain very useful scientific data on the far field diffusion of the wastefield due to oceanic turbulence, and/or gravitational spreading. Also, I would suggest obtaining grab samples during the farfield surveys and to measure their dye and coliform concentrations to obtain data on the bacterial decay rate (T_{90}).

The document, and other written comments, refers to the Zone of Initial Dilution (ZID). The meaning and definition of the ZID seems to be a source of some confusion, however. As far as I am aware, the only "official" discussion of and use of the term ZID is the EPA Technical Support Document for 301(h) waiver applications (U.S. EPA, 1994). There it is stated that the ZID extends to *one* water depth around the diffuser, i.e. about 30 m in this case. This definition and use of the ZID is unfortunate, as it may not always incorporate the region of "initial mixing." Similarly, the terms near and far fields do not have generally agreed definitions. This is discussed more below.

In the terminology of mixing zones (see discussions in Roberts et al., 1997 and elsewhere), near field refers to the region in which mixing and dilution occur as a result of turbulence generated by the discharge itself. This is primarily due to the buoyancy of the discharge, and, to a lesser extent, its momentum. Far field refers to the region where mixing and dilution is due to oceanic turbulence. These are hydrodynamic definitions, not regulatory ones. If the ZID is taken as one water depth (or any specified distance from the discharge), it becomes a *regulatory* mixing zone, as opposed to a *hydrodynamic* mixing zone. The near field will generally be longer than one water depth. Intensive turbulent mixing occurs within the near field and instantaneous concentrations can be much higher than time-averaged values.

These distinctions may be important here (especially given the controversial nature of the outfall). The NPDES permit does not specifically mention a ZID, nor does it give the locations where dilutions shall be measured. The permit states: …*the permittee shall field test and certify whether the outfall's minimum dilution is equal to, or greater than, the predicted minimum dilution specified in the following document, "Hydraulic Model Study of the Boston Wastewater Outfall, II: Environmental Performance", 1993, by Roberts and Snyder*. The dilutions measured and reported in that paper are near field dilutions, i.e. those measured at the end of the near field. With no current, these were measured at 1.5 times the water depth (53.6 m). The distances for flowing currents were not reported in the above paper; they were up to 122 m for the faster currents (25 cm/s). It is possible that currents can sweep the plumes out of the ZID so that dilution at the ZID is lower than would occur with no current, even though dilution would continue to increase rapidly beyond the ZID. (Note that RSB predicts near field dilutions.)

Within the near field the plumes are energetically turbulent, with wide variations in instantaneous tracer concentrations. Sampling within the near field is therefore tricky, especially with the proposed method, as the results may fluctuate widely and be difficult, if not impossible, to interpret. So measuring too close to the diffuser may give lower dilutions compared to the hydraulic model, especially with the different sampling techniques (i.e. virtually instantaneous in the field, time-averaged in the model), and may lead to the impression that the diffuser is not achieving the expected dilution. Conversely, sampling beyond the near field is easier, as the self-induced turbulence and the concentration fluctuations have (by definition) died down. I would therefore be cautious about sampling too close to the diffuser, and would not run the proposed tracks along the diffuser axis as this would be unlikely to provide useful data. It may be better to run traverses parallel to the diffuser axis but at different distances from the diffuser, say at 60 and 120 m. I would prefer to run some tracks *perpendicular* to the diffuser axis or in a generally down current direction to see how dilution varies with distance.

The main point of all this is that the results must be carefully interpreted and analyzed to avoid reaching inappropriate conclusions about the diffuser performance in terms of dilution.

Another difficulty of interpretation is that it is highly unlikely that conditions will correspond exactly to those that were tested in the hydraulic model, i.e. the flowrate, density stratification, and current speed and direction, will all be different.

References

Roberts, P. J. W., Ferrier, A., and Daviero, G. (1997). "Mixing in Inclined Dense Jets." Journal of Hydraulic Engineering, ASCE, 123(8), 693-699, and also Discussion, Volume 125, Number 3.

U. S. EPA (1994). "Amended Section 301(h) Technical Support Document." *EPA 842-B-94-007*, Oceans and Coastal Protection Division, Office of Wetlands, Oceans and Watersheds, United States Environmental Protection Agency, Washington, DC.

Comments on: Combined Work/Quality Assurance Project Plan (CW/QAPP) for Plume Tracking: 1999-2000.

Submitted by: Burton H. Jones, Ph. D.

Date: September 11, 2000

General Comments:

The plan provides a generally appropriate approach to evaluating the dilution from the Massachusetts Bay outfall of the MWRA. Rhodamine WT is the most appropriate tracer for this kind of study. The overall timing of the two cruises is appropriate to sample the region around the diffuser during periods of minimum and maximum stratification. The use of in situ and pumped sampling for characterization the key variables around the outfall is a valuable approach for sampling effluent plumes and it appears that Battelle is set up in most respects for this type of sampling.

Specific Comments:

Typical conditions:

No reference is made in the research plan to typical conditions in the vicinity of the outfall. Are there typical modes to the currents that enable the researchers to have some expectation of the direction that the effluent plume will go when it leaves the diffuser? Are there primary current directions that are most likely? To what extent are the currents tidally dependent? And how does the sampling plan anticipate these conditions?

Are there likely to be strong density fronts near the outfall? Advection of these fronts past the outfall could cause a rapid change in plume behavior (i.e. hgt. of rise, dilution, etc.).

Field Program:

The discussion under the Background Survey indicates that the sampling will include upstream sampling to obtain characteristic background samples outside of the effluent plume. If the currents are tidally oscillating, it is possible that "old" plume may be present upstream so those true background characteristics are not actually obtained. I suggest that this sampling should be done a couple of kilometers off to the side of the mean flow rather than along the axis of the mean flow (i.e. upstream).

It is also stated that "background measurements will be used to correct values of parameters used as dilution tracers". This assumes that these "background" values are homogeneous. If, for instance, the Rhodamine fluorescence measurement is contaminated by cyanobacteria fluorescence, these populations are likely to be somewhat patchy and therefore subtracting a constant background value may not be accurate. It may be necessary to determine the variability of the background observations, not just some mean value.

Where is the USGS current meter mooring relative to the study site, and how is it instrumented. If it is possible to have the USGS mooring equipped with conductivity sensors and transmissometers, this would be very helpful. I know that the USGS mooring group has this capability.

There is also an indication that there is a wave buoy nearby. Does the wave buoy measure both wave height and direction, or simply wave height and period?

To what extent is weather likely to be a factor in the sampling? Winter storms and summer tropical storms can interrupt either of the two seasonal periods. These types of experiments need to be planned and scheduled in advance. What contingency plans exist? Also, what are the operational limits of the research vessel and sampling mode?

ZID sampling:

I am concerned that the 60 m offset from the diffuser line for the ZID evaluation may be too close if currents are significant. This can be evaluated with the RSB model and with input of data from historical current measurements in the region. It seems that if currents are 20 cm/s, the range may be too close. If the time for initial mixing is "several minutes", say 5 minutes, then 20 cm/s is the limit below which the plume ZID will lie within the 60 m sampling perimeter.

No time span is given for completion of the sampling of the surveys. Given the boat speeds presented and the size of the tracks, the time frame is relatively short (< 2 hours for the nearfield survey). But the document does indicate that the boat will be slowed every 300 m to allow the package the approach the bottom.

The expected horizontal resolution of the towyo sampling is not specified. It is possible to infer this from the numbers presented, but it would be useful to know what sort of horizontal resolution the investigators expect to attain.

Nearfield surveys:

The race track design used for the nearfield survey will work, but may not be optimal for minimizing temporal aliasing of the sampling. It is, of course, not possible to remove temporal aliasing from ship-based operations but it is useful to minimize it. If any current meter telemetry is available an opportunistic sampling could be developed that would allow the boat to sample downstream rather than sampling the entire circuit. If no telemetry is available, then the racetrack design is probably the best approach.

Deliverables:

This is a small point, but in Table 7 it appears that Battelle will provide a data report before the sensor processing is completed. I assume that part of the data comes from the sensors, and therefore the sensor processing is needed in order to complete the data report.

Project Organization:

Battelle has involved good outside collaborators with the project. This should help to ensure the success of the overall program.

Dye addition and monitoring:

The chlorination issue does need to be taken seriously. In one effort that we assisted with the chlorination significantly reduced Rhodamine fluorescence.

Hydrographic measurements:

Throughout the document the Sea Tech transmissometer is repeatedly listed with a 20-cm pathlength. Is the pathlength truly 20-cm? The standard pathlength is 25 cm. This is not a major issue, just a detail question.

On-board discrete water sampling:

I recommend that a CTD or at least a temperature and conductivity sensor with a sampling frequency of at least 1 Hz be placed in the shipboard end of the pump system to provide time synchronization between surface sampling and in situ measurements. Salinity is probably the most effective measurement for evaluating mixing and time delay in such systems, especially for dissolved components. The correlation and time lag between the in situ salinity and the surface salinity provide the necessary parameters needed to couple batch and in situ measurements. The transmissometer may be OK, but there may be problems and smoothing of the particulate signal as the particles go through the pump. Salinity doesn’t suffer from this problem.

Ammonium and Phosphate analysis:

Has anyone checked the quality of the ammonium data from frozen samples? The filtration is a good step.

Photodegradation:

This section concerns me. While some photodegradation of Rhodamine fluorescence is likely, I don't think that the in situ values can be corrected based on the simple experiment with the 15L tank exposed to direct sunlight. Photodegradation is most likely due to UV light that is attenuated fairly rapidly in seawater. To apply an appropriate correction to the field data would require that a time history of the light exposure of the dye be available. To apply a correction would require a fluorescence/dosage curve, and situ measurements of at least PAR, and preferably UV. I don't see any ambient light measurements listed in the sampling plan.

Data Reduction: Hydrographic and navigation data

Is there any rationale for the 2-second averaging of the in situ data? I think the averaging should be referenced against the desired vertical resolution and the dive/climb rate of BOSS. If the vertical rate is 1 m/s, this limits vertical resolution to 2 m.

Dilution estimates:

The dye approach is the best method for estimating dilution, but analysis of the salinity/temperature relationship can be used as a secondary check on the dye results to at least bracket the dilution (e.g., Washburn et al., 1992).

References:

Washburn, L., B. H. Jones, A. Bratkovich, T. D. Dickey, and M.-S. Chen (1992) Mixing and dispersion processes in the vicinity of ocean wastewater plumes. *Journal of Hydraulic Engineering*, ASCE, **118**(1), 38-58.

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
http://www.mwra.state.ma.us