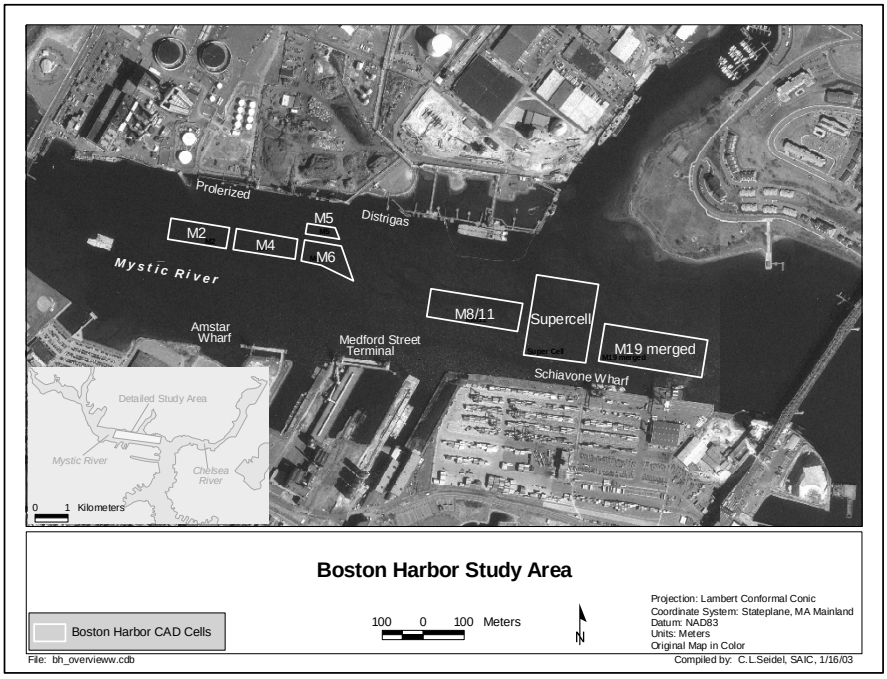
An Investigation of Sediment Dynamics in the Vicinity of Mystic River CAD Cells Utilizing Artificial Sediment Tracers

Disposal Area Monitoring System DAMOS



D A M O S

DISPOSAL AREA MONITORING SYSTEM

Contribution 150
December 2003

US Army Corps of Engineers ®
New England District

REPORT DOCUMENTATION PAGE

form approved
OMB No. 0704-0188

1. AGENCY USE ONLY (LEAVE BLANK)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 2003	FINAL REPORT

4. TITLE AND SUBTITLE
An Investigation of Sediment Dynamics in the Vicinity of Mystic River CAD Cells Utilizing Artificial Sediment Tracers

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
SAIC No. 624

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers-New England District
696Virginia Rd
Concord, MA 01742-2751

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Contribution No. 150

11. SUPPLEMENTARY NOTES
Available from DAMOS Program Manager, Regulatory Division
USACE-NAE, 696 Virginia Rd, Concord, MA 01742-2751

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT

The Disposal Area Monitoring System (DAMOS) Program sponsored a sediment transport study in the region of the Confined Aquatic Disposal (CAD) cells in the Mystic River, Boston, MA. The project was designed as a relatively small-scale pilot study to determine if fine-grained harbor sediments in the vicinity of the CAD cells are being resuspended and transported into the CAD cells. To achieve this goal, artificial fluorescent sediment tracer was deployed at positions upstream and downstream of the Supercell using two different tracer colors. Tracer particles were mixed with ambient material, frozen in blocks, and placed on the seafloor. Sediment grab sampling surveys were then conducted upstream and downstream, as well as within the Supercell, at two-week intervals (surveys T18 and T32). This tracer study indicated that both upstream and downstream transport of sediment, including deposition in the CAD cell, occurs in the study area and that vessel traffic in the river is likely the primary mechanism for resuspension of bottom sediments.

Concentrations of sediment tracer from the grab sample surveys showed that tracers from both deployment locations were transported in the upstream and downstream directions from the deployment site. Very high concentrations of tracer were evident at stations in the immediate vicinity of the deployment locations, at T18 for the upstream deployment site, and at T32 for the downstream deployment site. This indicates that following the initial deployment in blocks, a substantial volume of the tracer material remained in close proximity to the deployment location within the time-frames of this study. Lower concentrations of both upstream- and downstream-deployed tracers were observed throughout most of the survey area by T18, and more widely distributed to virtually all stations, and detected at lower concentrations, by T32. This provides evidence for continued redistribution of tracer material throughout the study area over time, as well as evidence of fine-grained material from both upstream and downstream locations being deposited in the CAD cell. Determining whether tracer material deposited in the CAD cell remains in the cell (being redistributed throughout the cell and eventually buried) would require a more comprehensive within-cell sampling scheme, including more stations throughout the cell and sub-samples at various depth intervals.

14. SUBJECT TERMS Boston Harbor, Mystic River Dredged Material

15. NUMBER OF TEXT PAGES: 32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified			

AN INVESTIGATION OF SEDIMENT DYNAMICS IN THE VICINITY OF MYSTIC RIVER CAD CELLS UTILIZING ARTIFICIAL SEDIMENT TRACERS

CONTRIBUTION #150

December 2003

Report No.
SAIC-624

Submitted to:

Regulatory Division
New England District
U.S. Army Corps of Engineers
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TABLE OF CONTENTS

LIST OF TABLES

page

LIST OF FIGURES

page

EXECUTIVE SUMMARY

In late August of 2002, SAIC performed a sediment transport study in the region of the Confined Aquatic Disposal (CAD) cells in the Mystic River, Boston, MA in conjunction with Environmental Tracing Systems (ETS) of Helensburgh, U.K.. The study was designed as a relatively small-scale pilot study, and the work was funded by the U.S. Army Corps of Engineers, New England District under the Disposal Area Monitoring System (DAMOS) Program. The purpose of the study was to determine if fine-grained harbor sediments in the vicinity of the CAD cells are being resuspended and transported into the CAD cells. To achieve this goal, artificial fluorescent sediment tracer was deployed at positions upstream and downstream of the Supercell using two different tracer colors. Tracer particles were mixed with ambient material, frozen in blocks, and placed on the seafloor. Sediment grab sampling surveys were then conducted upstream and downstream, as well as within the Supercell, at two-week intervals (surveys T18 and T32), and surface samples were sent to ETS for tracer analysis.

Concentrations of sediment tracer from the grab sample surveys showed that tracers from both deployment locations were transported in the upstream and downstream directions from the deployment site. Very high concentrations of tracer were evident at stations in the immediate vicinity of the deployment locations, at T18 for the upstream deployment site, and at T32 for the downstream deployment site. This indicates that following the initial deployment in blocks, a substantial volume of the tracer material remained in close proximity to the deployment location within the time-frames of this study.

In addition to the high concentrations found near each deployment site, lower concentrations of both upstream- and downstream-deployed tracers were observed throughout most of the survey area by T18, and more widely distributed to virtually all stations, and detected at lower concentrations, by T32. This provides evidence for continued redistribution of tracer material throughout the study area over time, as well as evidence of fine-grained material from both upstream and downstream locations being deposited in the CAD cell. At the time of the T18 survey, tracer concentrations were greater in the Supercell than outside it, and the increased concentrations of the tracer deployed downstream persisted in the Supercell for the T32 survey. This provides some evidence for preferential settling of tracer (hence, fine-grained sediment) in the Supercell.

Previous investigations in the vicinity of the Supercell have indicated that tidal currents are relatively weak and likely do not account for erosion of bed material. However, vessel traffic in the vicinity (e.g., passage of the liquid natural gas (LNG) carrier

M/V Matthews) caused substantial, short-term increases in current velocities that correlated with increased turbidity above the substrate. Therefore, vessel traffic in the river is likely the primary mechanism for resuspension of bottom sediments. This tracer study provided information on sediment transport indicating that both upstream and downstream transport of sediment, including deposition in the CAD cell, occurs in the study area. However, changes in tracer concentration from one survey to another cannot be explained with the available information, and could be due to dispersal and/or localized redistribution of tracer, resuspension of tracer with subsequent transport away from the study area, or burial.

Determining whether tracer material deposited in the CAD cell remains in the cell (being redistributed throughout the cell and eventually buried) would require a more comprehensive within-cell sampling scheme, including more stations throughout the cell and sub-samples at various depth intervals. Additional information to confirm whether there is net upstream or downstream transport of resuspended fine-grained sediment in this location of the Mystic River would also require a more comprehensive sampling scheme, and would require a broader field of stations in both upstream and downstream directions.

This pilot study provided useful information on field and laboratory methods using tracers that will be useful in future studies.

1.0 INTRODUCTION

In August and September 2002, SAIC conducted a sediment transport study in and around the Confined Aquatic Disposal (CAD) cells in the Mystic River, Boston, MA (Figure 1-1). The study was performed in conjunction with Environmental Tracing Systems, LTD (ETS), of Helensburgh, United Kingdom. An artificial, environmentally benign fluorescent sediment tracer produced by ETS was deployed on the seafloor 250 m upstream and downstream of the CAD cell designated as the 'Supercell' in order to determine sediment transport pathways in the vicinity of the cell. Sediment grab surveys were conducted in and around the Supercell at 18 and 32 days post-deployment to collect sediment that was later analyzed for tracer concentration (referred to as surveys T18 and T32, respectively). The next section presents a brief background of the dredging project in Boston Harbor, followed by the reasoning and objectives of this tracer study. Section 2 outlines the methods used to deploy and analyze sediment for tracer, and Section 3 presents the results of the analysis. This is followed by a discussion of the results as they relate to accretion in the CAD cell. Conclusions and recommendations are provided in Section 5.

1.1 Background

The Boston Harbor Navigation Improvement Project (BHNIP) was initiated in response to the need to deepen the Federal channels and berthing areas within Boston Harbor and surrounding tributaries. The project was jointly sponsored by the U.S. Army Corps of Engineers, New England District (NAE), and the Massachusetts Port Authority (MassPort). Due to the evaluation of test results on the maintenance portion of the sediments, open water disposal for those sediments was not deemed an option, and disposal of the sediments into CAD cells was selected as the preferred alternative. In this method, disposal 'pits' (hereafter referred to as 'cells') in the dredging project area were dug well below the maintenance depth, and the maintenance dredged material was placed within the cells. The cells were then capped with a minimum 1 m thick layer of sand to prevent both reintroduction of the dredged material and leaching of pore waters back into the water column (Hales 2001).

The original project plan called for approximately 44 CAD cells to be constructed within the tributaries and harbor channels. However, upon completion of the first cells within the Mystic River, it was determined that the highly cohesive glaciomarine clay (often referred to as Boston Blue Clay) beneath the harbor sediments allowed for construction of considerably deeper and steeper cells than originally thought feasible. Thus, only nine CAD cells were necessary, predominantly lying in the Mystic River (Figure 1-1). The water quality certification with the State of Massachusetts (WQC; Babb-Brott 1997) required capping within 30 to 60 days of dredged material placement. Various

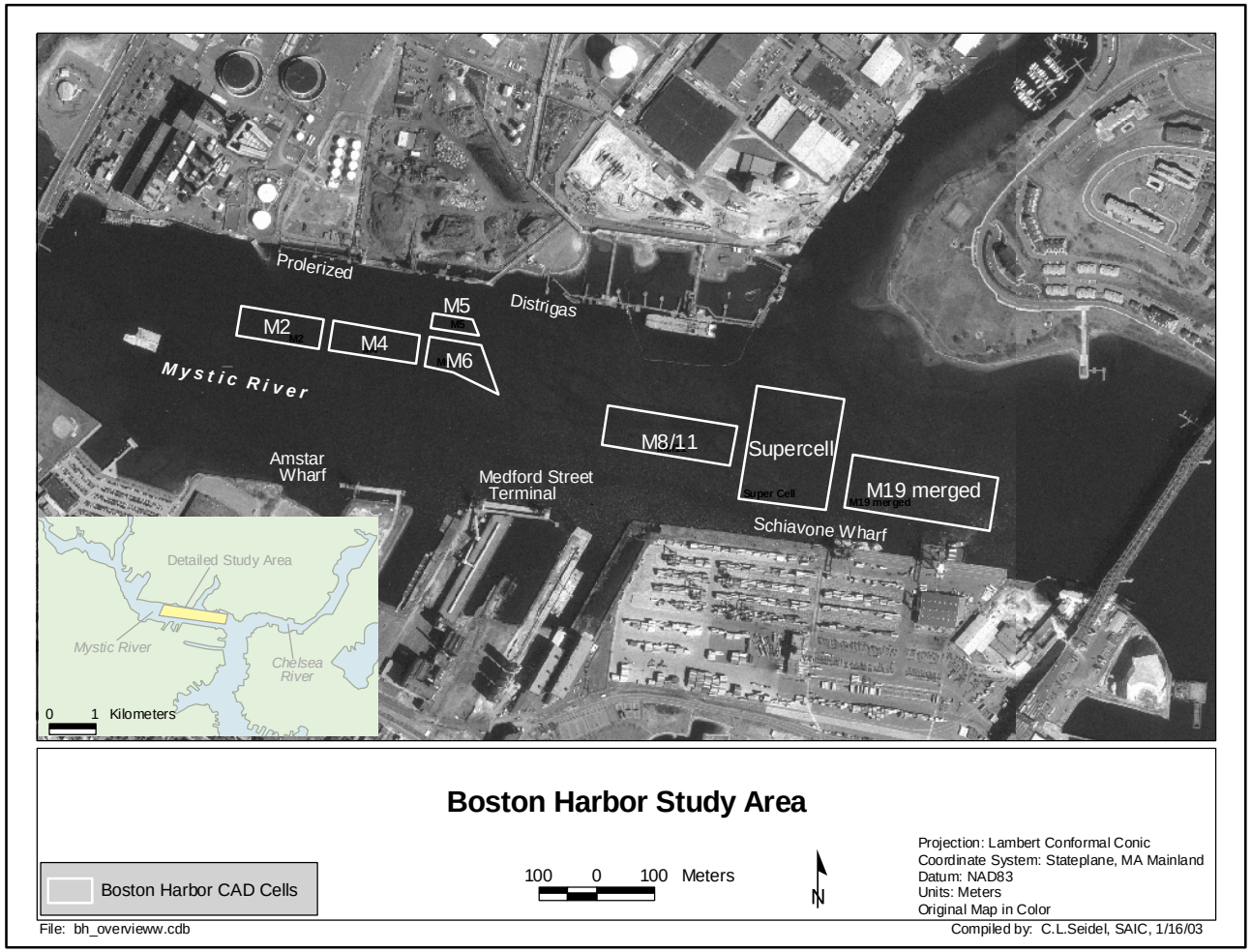

Figure 1-1. Aerial view of the CAD cells constructed in the Mystic River between 1998 and 2000 as part of the BHNIP

monitoring techniques were utilized during and after the placement of cap material to determine the efficacy of capping, including precision bathymetry, side-scan sonar, sub-bottom profiling, sediment coring, and surface sediment grabs (SAIC 2000a).

The postcap surveys conducted in the first cells within the harbor channel indicated mixing of the sand cap material with the recently deposited dredged material, resulting in a variable cap thickness and consistency (SAIC 2001a). In addition, fine-grained material was found above the sand cap, suggesting displacement of the dredged material during capping. It was proposed that extending the time between dredged material placement and capping would increase the effectiveness of the cap by allowing the dredged material to naturally consolidate. Thus, the time frame between placement and capping operations was increased to more than two months, on average. Subsequent postcap surveys in these cells demonstrated a more consistent and cleaner sand cap layer. It was concluded that in order to determine the readiness of a given CAD cell for capping operations, multiple parameters need to be considered, including the geotechnical properties of the deposited material, the size of the cell, and the geotechnical properties of the cell itself (e.g., porosity and shear strength of the walls) (SAIC 2000a).

In addition to these monitoring techniques, a study of the susceptibility of the sand cap and harbor sediments to erosion by tidal currents and transiting vessels was performed (SAIC 2001b), and subsequent modeling was conducted by the Engineer Research and Development Center (ERDC) of the U.S. Army Corps of Engineers (Hales 2001). These two studies demonstrated that the passage of vessels over uncapped cells did resuspend sediments, causing elevated turbidity levels, but that the effects typically lasted an hour or less. Deep draft container vessels (like the liquid natural gas carrier *M/V Matthews*) can also cause localized, short-term resuspension in capped cells, but such vessel passage did not erode the cap from the cell. It was also observed that the transit of large vessels through the harbor channel (without CAD cells) results in a turbidity plume with total suspended solids values similar to the effects of vessel passage over the uncapped cell M8/11.

A one-year postcap survey was performed in the CAD cells in 2001, which consisted of sediment coring within eight disposal cells. The primary conclusions from this monitoring were that the sand cap layer had remained intact and that the underlying dredged material continued to consolidate (SAIC 2001a). In addition, there appeared to be new accumulation of fine-grained sediment overlying the sand cap, particularly in Cell M2 and the Supercell. This finding raised the question: Was the presence of this fine-grained material the result of resuspension and subsequent redeposition of ambient harbor sediments onto the cap, or was it the result of a breach in the sand cap?

1.2 Objective of the Tracer Study

In order to address the question concerning the origin of fine-grained material found overlying the sand cap in Mystic River CAD cells, the use of an artificial sediment tracer that matched the geotechnical properties of the ambient harbor sediments was deemed the simplest, least expensive method. Conventional dyes have the disadvantage of breaking down over time, and there is typically little control over grain size and density of the particles to be tracked. ETS, a U.K.-based firm, has the capability to produce environmentally benign, fluorescent tracer particles at specific particle density and grain size. The primary objective of this study was to address the following questions:

- Are ambient fine-grained harbor sediments being transported into the Supercell?
- If so, is there a preferred direction to this transport?

The next section provides an overview of the sediment tracer technology and the methods used to quantify tracer concentration in discrete sediment samples. This is followed by a description of the methods used to deploy the tracer particles and the subsequent operations to collect sediment samples.

2.0 METHODS

2.1 Sediment Tracer Characteristics

ETS has many years of experience in utilizing artificial tracer particles to meet the needs of a wide variety of clients in diverse environments, including groundwater, potable water (reservoirs), sewer outfalls, and coastal dredging surveys. The EcoTrace™ particles consist of a non-toxic polyethylene material that can be manufactured in grain sizes from < 1 μm to > 10 mm, and in particle densities from < 1.0 to > 2.65 g·cm^{-3}. This allows ETS to mimic both individual sediment grains and/or flocculates of sediment. Multiple fluorescent colors are available, and the fiber-optic laser detection system can simultaneously analyze for different colors from the same sample. Two different color tracers were utilized for this study, to track upstream (magenta) and downstream (yellow) deployment locations.

Results from pre-dredging surveys in the project area demonstrated that the ambient surface sediments were predominantly silts and clays (SAIC 2000a). The tracers for this pilot study were therefore manufactured to resemble the fine-grained particle size fraction (silt and clay) of the ambient sediments from each deployment location. ETS used four laboratory analyses to compare the tracers to the ambient sediment from the upstream and downstream deployment locations: particle size analysis, density measurements (conducted by ETS and an independent laboratory), settling characteristics, and erodibility measurements (Appendix A). Results of these analyses indicated general similarity between the tracers and the ambient silts and clays. Median particle size (D_{50}) was slightly finer for the tracers than the ambient sediments, while the tracer particle density was slightly greater than for the ambient sediments. The settling characteristics were evaluated by comparing the settling behavior of ambient sediments with that of ambient sediments mixed with tracer particles in a settling tube. Results indicated the tracer particles had no apparent effects on the settling behavior in terms of mass per unit time, and ETS concluded that the tracer would behave comparable to the natural sediment at the project site. Erodibility experiments provided useful results for the downstream tracer, and indicated that the substrate would not be any more likely to erode with addition of the yellow tracer particles than without.

In addition to these analyses, ETS determined that their erodibility studies indicated that under normal site conditions (tidal currents not exceeding 0.2 m/s), bottom sediments and bottom sediments mixed with tracer would not likely be eroded.

2.2 Analysis of Particle Fluorescence in Sediment Samples

There are two methods of analyzing sediment for artificial tracer: Laser Scanning Microscopy (LSM) and Automated Flow Cytometry (AFC). The AFC method is preferable as it allows for a higher number of samples to be analyzed per unit time, including replicates from an individual grab sample. In this study, AFC was used for the Background, T1, and T18 surveys. Due to equipment problems, the initial results for the T18 survey were rejected, and therefore, the T18 and T32 samples were analyzed using LSM. It has yet to be shown that the results from the two methods are comparable. While the Background and T1 survey results using the AFC method yielded very low and/or zero counts (see Section 3.0 and Appendix Tables A-1 and A-2), as expected for conditions prior to deployment and release of tracer from the frozen blocks, no conclusive evidence about the comparability of the AFC and LSM methods can be drawn from this study. Because the use of these tracers does not include complete recovery/accounting for all the deployed tracer material, the primary value the analyses provide is information about the presence or absence of tracer, and relative concentrations. Therefore, the change in analysis methods should not affect overall conclusions from the study. A detailed description of the two methods is provided below.

2.2.1 Laser Scanning Microscopy

Sediment samples analyzed using Laser Scanning Microscopy (LSM) were first diluted with deionised water, then sonicated (to break up flocculates) and shaken. A subsample was then pipetted evenly onto a track-etched membrane. The membrane was placed on a glass microscope slide and was covered with a glass cover slip. The cover slip was fixed in place with clear varnish.

The sample was examined using a blue-light filter under laser excitation at 480 nm light wavelength, at which multiple colors can be clearly identified. The colored particles corresponding to tracer particles were counted and results were quoted as the number of counts per 0.1 ml of the prepared, wet sediment sample, expressed as counts per ml fraction, or ‘cpmf.’

It is important to note that in addition to processing a relatively small volume of sediment from the grab sample collected at each station (two replicate, 5 ml sediment samples were collected from the upper 5 mm of each grab sample), a smaller subsample was then extracted for this scanning technique. Additionally, while duplicate sediment samples were collected from each grab sample in the field, duplicate samples were not analyzed in the laboratory, which would provide more information on the repeatability of the method.

2.2.2 Automated Flow Cytometry

Flow cytometry is another laser technique that is used to measure the number, fluorescence intensity, and wavelength of sediment samples (which may or may not contain the artificial tracer). Samples were transferred to sample tubes and placed in a 60 ml sample container. Deionised water (containing Decov™ surfactant) was added to each sample tube, mixed thoroughly and then sonicated. After a settling period of 60 seconds, 1 ml of sample was withdrawn from approximately 1 cm beneath the liquid surface. This sample aliquot was then filtered through a 180 μm gauze and analyzed.

The sample was placed within the sample chamber of the flow cytometer (Beckman Coulter, Model EPICS XL). Then 0.1 ml of the sample was drawn by the machine and a linear particle stream was exposed to a focused laser beam of 488 nm wavelength. The intensity of fluorescent emission between 500–650 nm wavelength from the particles was measured, together with the total number of particles passing the laser. All results were provided as the number of positive (identifiably fluorescent) counts per 0.1 ml of wet sediment sample, expressed as counts per ml fraction, 'cpmf.'

2.3 Tracer Block Preparation

In addition to manufacturing tracer particles that would be comparable to the ambient sediments, several other considerations were incorporated into the study design to increase the likelihood that the tracers would behave like the natural sediments. First, the tracer particles were mixed with ambient surface sediments prior to deployment, to allow the tracer particles to bond to and flocculate with the natural sediment as would occur in the natural environment. Secondly, the tracer-sediment mixtures were frozen into blocks that would form a relatively low profile (15 cm) on the river substrate, to minimize any preferential scour that might be expected to occur around a protuberance on the substrate. A tracer-to-sediment ratio of approximately 4:1 was used in order to reduce the total volume of material to be deployed, thus simplifying the deployment and minimizing the size of the frozen blocks. Dry tracer was first wetted with harbor water, and then hand mixed in plastic tubs with sediment collected from each deployment location, attempting to match the consistency of the *in situ* sediment. The magenta and yellow tracer were used to distinguish between upstream and downstream deployment locations as indicated above. The final volume of sediment/tracer mixture was approximately 64 liters for the magenta tracer mixture and 60 liters for the yellow tracer mixture.

There are multiple methods of deploying the tracer particles into the environment depending on the project goals and scientific considerations. For this study, the frozen block method of tracer placement was selected to mimic naturally deposited sediment as

much as possible, and to prevent tracer leaching into the water column or dispersal on the seafloor during placement. Ice encapsulation has been used multiple times by ETS in the past, and was determined to be the most advantageous method for this project.

Hollow casts of fresh-water ice were formed, and simultaneously, sediment/tracer was frozen in smaller tubs to fit within the cast. The frozen blocks of sediment/tracer mixture were then placed within the cast (Figure 2-1), covered with an approximately 3 to 4 cm layer of the ambient sediment and subsequently frozen again, encapsulating the mixture. Thus, when the frozen casts were deployed, only ice or plain sediment (top of the cast) were in contact with the harbor water during descent to the bottom. Ultimately, six blocks were formed for each tracer color. Each block was encapsulated with approximately 4 cm of either sediment or frozen fresh water to ensure sufficient block structural integrity, and enough encapsulation material to survive the transit to the site and subsequent release. In addition, a plate of steel was placed at the bottom of each tracer block to add weight and aid sinking. All freezing took place at the Coldwater Seafood Company, which owns a pier on the Island End River, adjacent to the study area. Thus, blocks were taken from the freezer to the survey vessel and deployed within a half-hour, with minimal melting.

Prior to tracer block deployment, a 'dummy block' was formed using only harbor sediment (without tracer) encapsulated in ice. This block was then released from the pier at the freezing facility to assess the rate of descent into the water column. The block was observed to sink at a rate of approximately 1 to 1.5 $m \cdot s^{-1}$. This test of the dummy block, without a steel plate incorporated, provided adequate evidence that deposited blocks would sink sufficiently fast, and would remain on the substrate even if adhesion to the steel plate were lost early in the melting process.

2.4 Tracer Deployment

Differentially-corrected Global Positioning System (DGPS) data in conjunction with Coastal Oceanographic's HYPACK® navigation and survey software was used to provide real-time navigation to an accuracy of ±3 m. A Trimble DSMPro GPS receiver was used to obtain raw satellite data and provide vessel position information in the horizontal control of North American Datum of 1983 (NAD 83). The DSMPro GPS unit also contained an integrated differential beacon receiver to improve overall accuracy of the satellite data to the necessary tolerances. The U.S. Coast Guard differential beacon broadcasting from Portsmouth, NH (288 kHz) was utilized for real-time satellite corrections. The DGPS data were exported to HYPACK® data acquisition software for position logging and helm display on the survey vessel.

Figure 2-1. Placement of frozen sediment/tracer mixture within ice casts for final freezing

In order to determine the origin of sediment found within the Supercell, it was necessary to deploy tracer particles both upstream and downstream of the cell utilizing two different-colored tracers. Sites were chosen approximately 250 m upstream (magenta) and downstream (yellow) from the Supercell, along the main axis of the navigable channel. Figure 2-2 shows the two deployment sites as circles encompassing the drop locations.

All 12 blocks of tracer mixture were successfully deployed on 25 August 2002. The most significant impediment to survey operations was the presence of the LNG carrier *M/V Matthews* on the same day. (Note: Figure 2-2 also includes a scale drawing of the outline of the LNG carrier *M/V Matthews* in the northwestern corner of the river on the image.) Due to security concerns, a half-mile region forward and aft of the tanker was closed within the shipping channel during transit, and a 305 m (1000 ft) security zone was maintained as it berthed. As the upstream deployment location lay within the security zone, it was necessary to wait for vessel departure prior to beginning the tracer deployment. Logistically, it was considered optimal to deploy at slack tide; high tide was predicted to occur at 19:23 GMT (15:23 local time). As soon as the channel was clear following the transit of the carrier, yellow tracer blocks were delivered to the downstream site, with the first being deployed at 19:47 GMT and the last at 20:00 GMT. The deployment vessel was brought on station while blocks were placed on a wire rack hanging from a davit on the starboard side of the vessel. Once on station, the blocks were lowered into the water and subsequently released to the bottom. Deployment of the magenta blocks at the upstream site occurred from 20:24 to 20:31 GMT.

2.5 Sediment Sampling

The first sediment sampling effort took place two months prior to tracer deployment, on 26 June 2002, and consisted of the collection of 12 background samples disbursed throughout the sampling grid (Figure 2-2). The purpose of collecting background samples was to determine if the *in situ* sediments contained any natural fluorescence signature that might interfere with the detection of tracer, thus influencing the optimal choice of tracer color (fluorescence signature).

The second sediment sampling effort occurred immediately following tracer deployment on 25 August 2002. A small, eight-station grab sample survey (referred to as T1) was taken to determine if, in the course of deployment, there was any inadvertent tracer release, either through descent in the water column, or upon release at the bottom.

Subsequent sampling was performed at 14-day intervals, after one Spring-Neap cycle, heretofore referred to as T18 (12 to 13 September 2002), and one monthly cycle, referred to as T32 (26 to 27 September 2002). The sampling grid consisted of 50 points

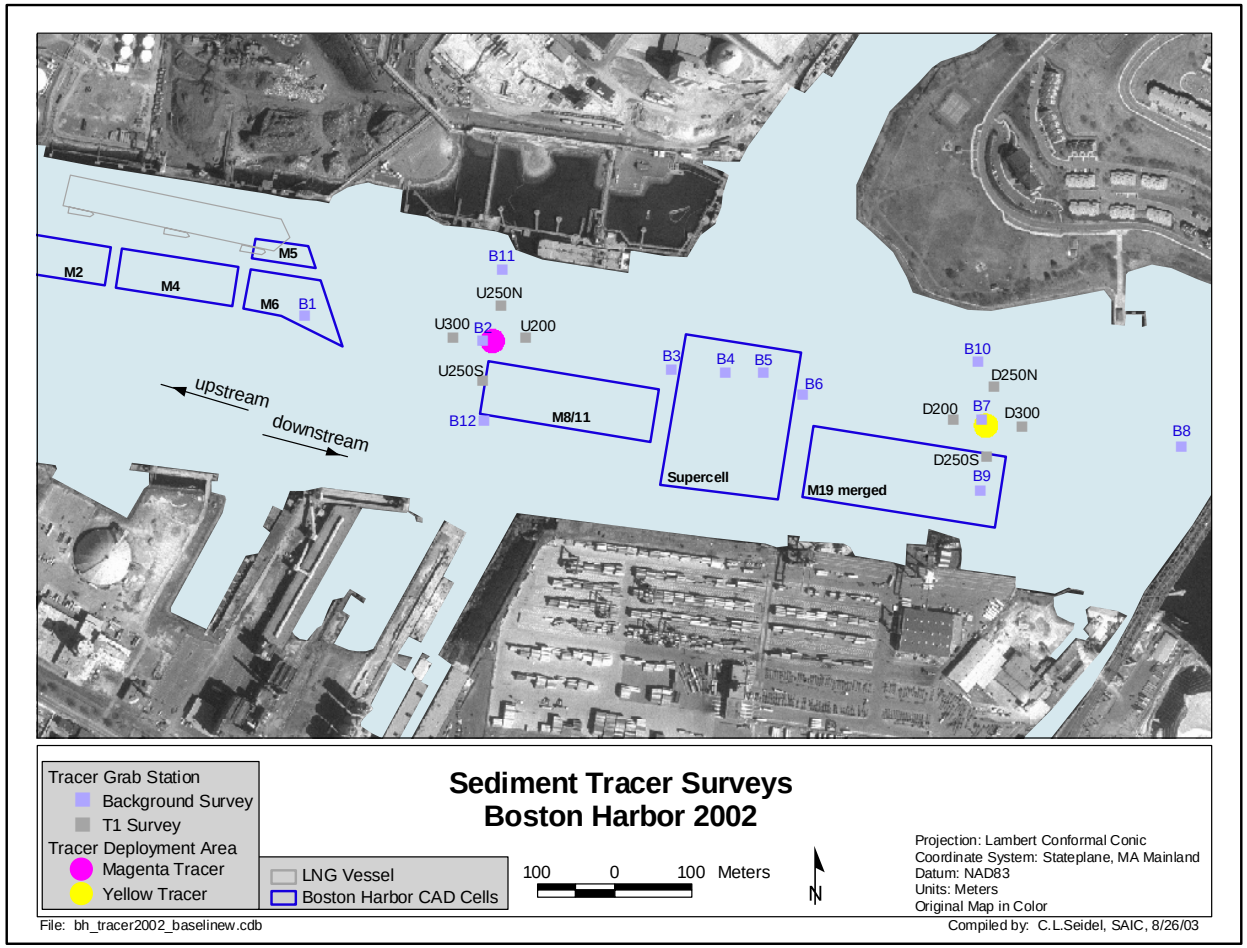

Figure 2-2. Background survey stations within the Mystic River, and locations of the two deployment positions. Circles indicate the area encompassing the six tracer block release locations for each color

distributed between: 1) the area immediately surrounding each deployment location; 2) the main axis of the channel; and 3) the Supercell (Figure 2-3). As the Supercell was the focus of the study, the main axis of the deployment and sampling locations was offset to the north to avoid interference from other cells (i.e, M8/11 and M19). Nonetheless, some sampling points lay within other CAD cells, providing additional data on the potential for sediments to collect in the CAD cells. Note that Station D250N2 was not sampled on the T32 survey due to extremely low tides.

A large (0.1 m^2) Van Veen type sediment grab was used during the background and T1 surveys, and a small (0.04 m^2) Van Veen grab was used during the T18 and T32 surveys. A 10 ml tube was used to subsample at least 5 ml of the surface layers of the grab (sampling to a depth of no more than 5 mm), and two samples were taken from each grab for analysis and archival purposes. As often as possible (but at every station within the Supercell), visual descriptions of the contents of the sediment grab were logged in the field notebook. Since these data were not recorded for every station, they are not included in the report.

The approach of collecting sediment samples for analysis from the upper 5 mm of each grab sample may compromise the representativeness of the sediment sample, if vertical mixing of tracer material or sedimentation on top of the tracer has occurred. Therefore, this sampling approach only provided a semi-quantitative estimate of the tracer presence.

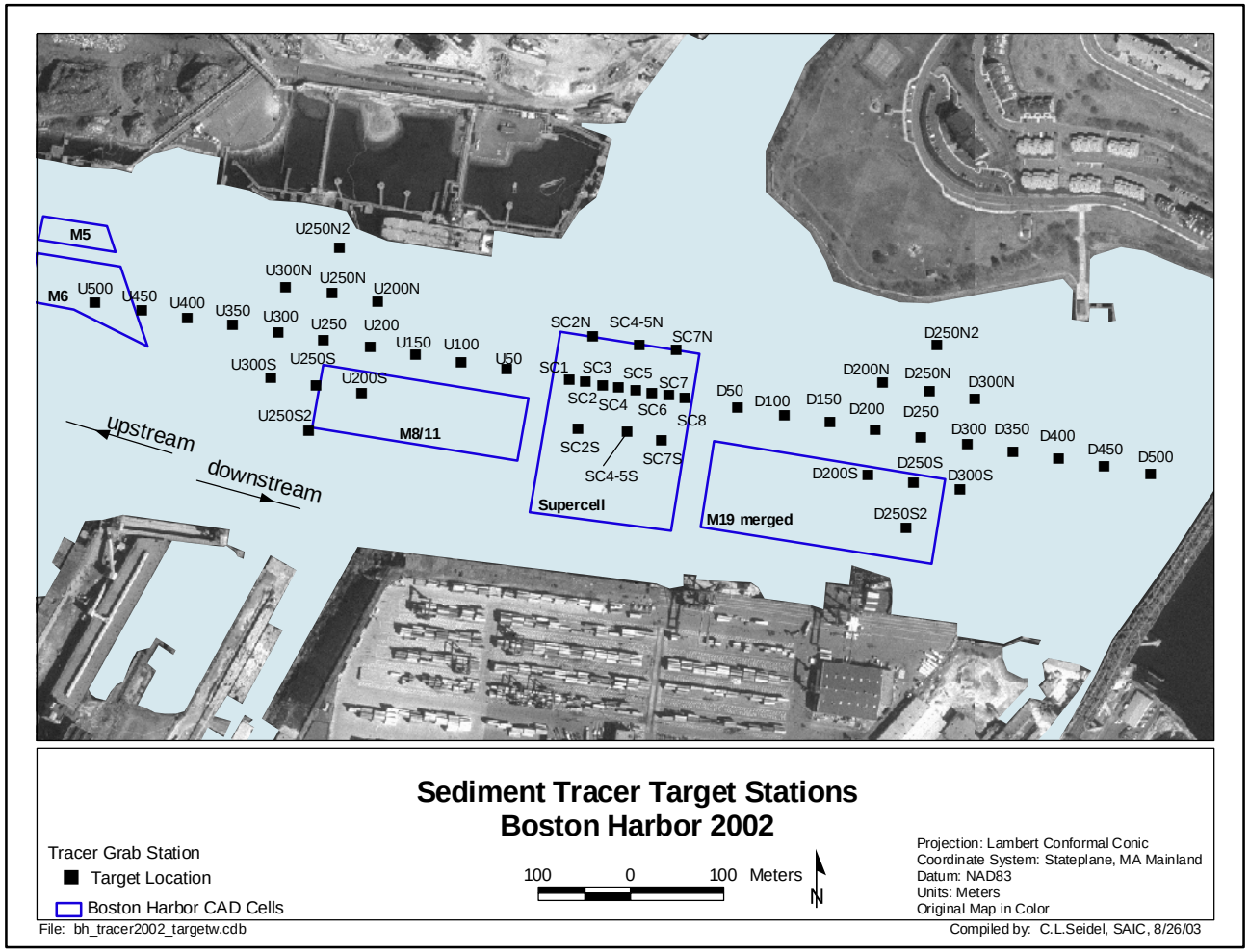

Figure 2-3. Target grab sample locations for the T18 and T32 surveys of the tracer study

3.0 RESULTS

ETS reported the concentration of tracer observed at a particular location in terms of positive particle identifications per 0.1 ml of wet sediment, or, counts per ml fraction (cpmf; see Section 2.2). All tracer concentrations reported by ETS are listed in Appendix B, and the T18 and T32 survey results are plotted on maps of the study area. Automated flow cytometry was used to analyze samples from the background and T1 surveys, and laser microscopy was used to analyze samples from the T18 and T32 surveys, as the cytometry system was inoperable at the time of receipt of the T18 and T32 sediment samples.

Tracer concentration results from the background survey are listed in Appendix Table B-1. As noted, background fluorescence was low, with counts ranging from 0 to 4 cpmf for the magenta fluorescence signature and 0 to 3 cpmf for the yellow fluorescence signature. A uniform value of 5 cpmf was subsequently used to subtract background values from any subsequent surveys.

For the T1 survey, a small cruciform, eight-station survey was conducted in the area immediately surrounding the deployment locations following the deployment of the blocks, to assess if there was any spreading of tracer upon deployment (Figure 2-2). Zero counts were obtained at all T1 stations surrounding the deployment locations, confirming that tracer blocks were still intact upon reaching the seafloor (Table B-2).

3.1 T18 Survey Results

Tracer concentrations from the T18 survey (Table B-3) are plotted in Figures 3-1 and 3-2 for the magenta (upstream) and yellow (downstream) tracer colors, respectively. The tracer data have been broken into six classes of increasing range as follows: 0, 1–25, 26–75, 76–150, 151–300, and 300 and above. Variable concentrations were apparent with widespread distribution of relatively low counts (up to 158 cpmf) and more localized areas with counts in the tens of thousands. Such high tracer concentrations were encountered for magenta in the immediate vicinity of the deployment location at T18 (250 m upstream of the Supercell), and at three adjacent stations located to the north and east (marked by an asterisk). For the remainder of the stations, magenta tracer concentrations less than 150 counts were noted, as well as several zero values. Magenta tracers were detected at 13 out of 18 upstream stations, 9 out of 14 Supercell stations, and 9 out of 18 downstream stations for the T18 survey. Exclusive of the four high values near the deployment site, slightly higher concentrations of magenta tracer occurred at the upstream stations (counts up to 30 cpmf) and within the Supercell (counts up to 48 cpmf; Figure 3-1).

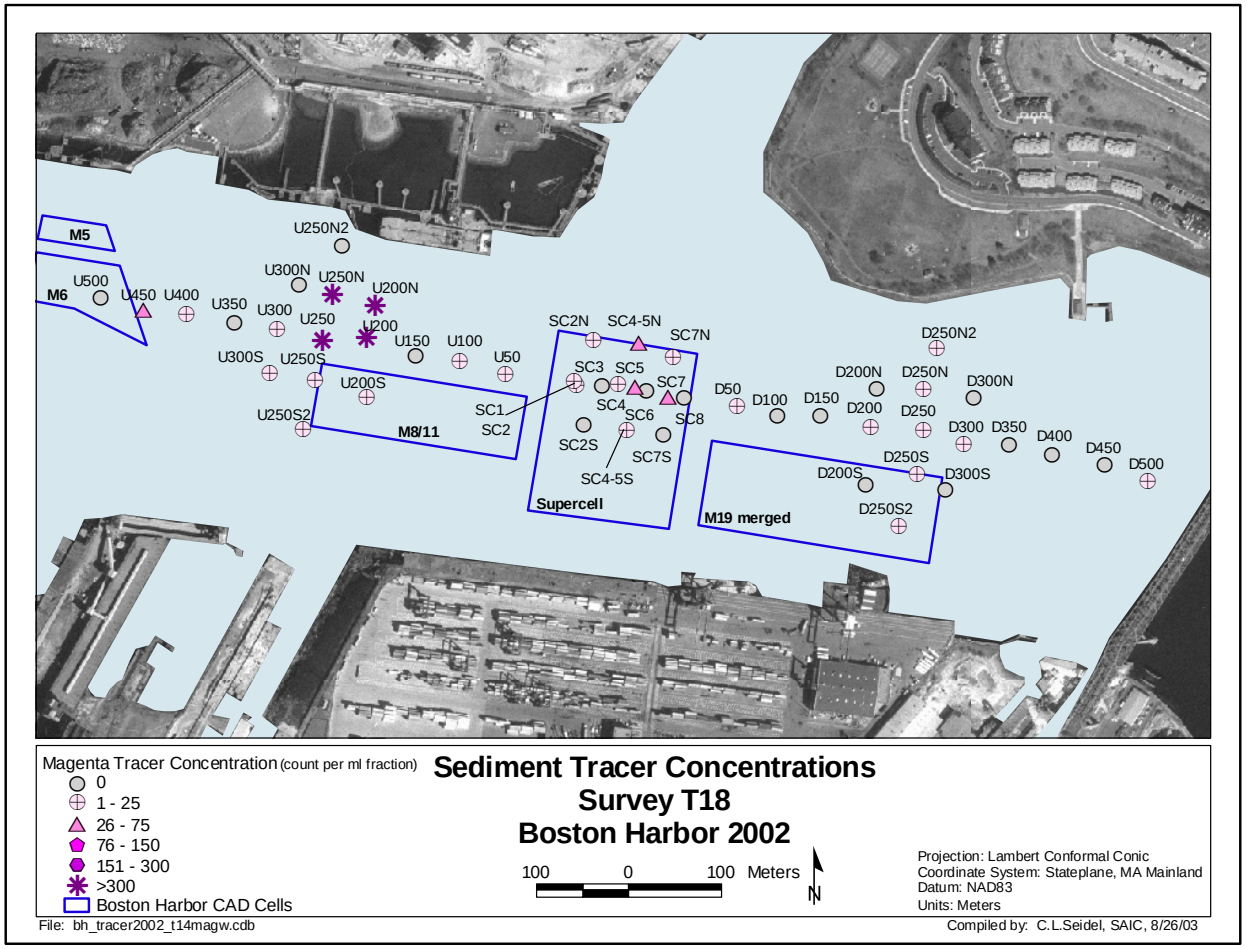

Figure 3-1. Concentrations of magenta tracer found within the Mystic River 18 days after deployment. Magenta tracer was placed 250 m upstream of the Supercell at Station U250.

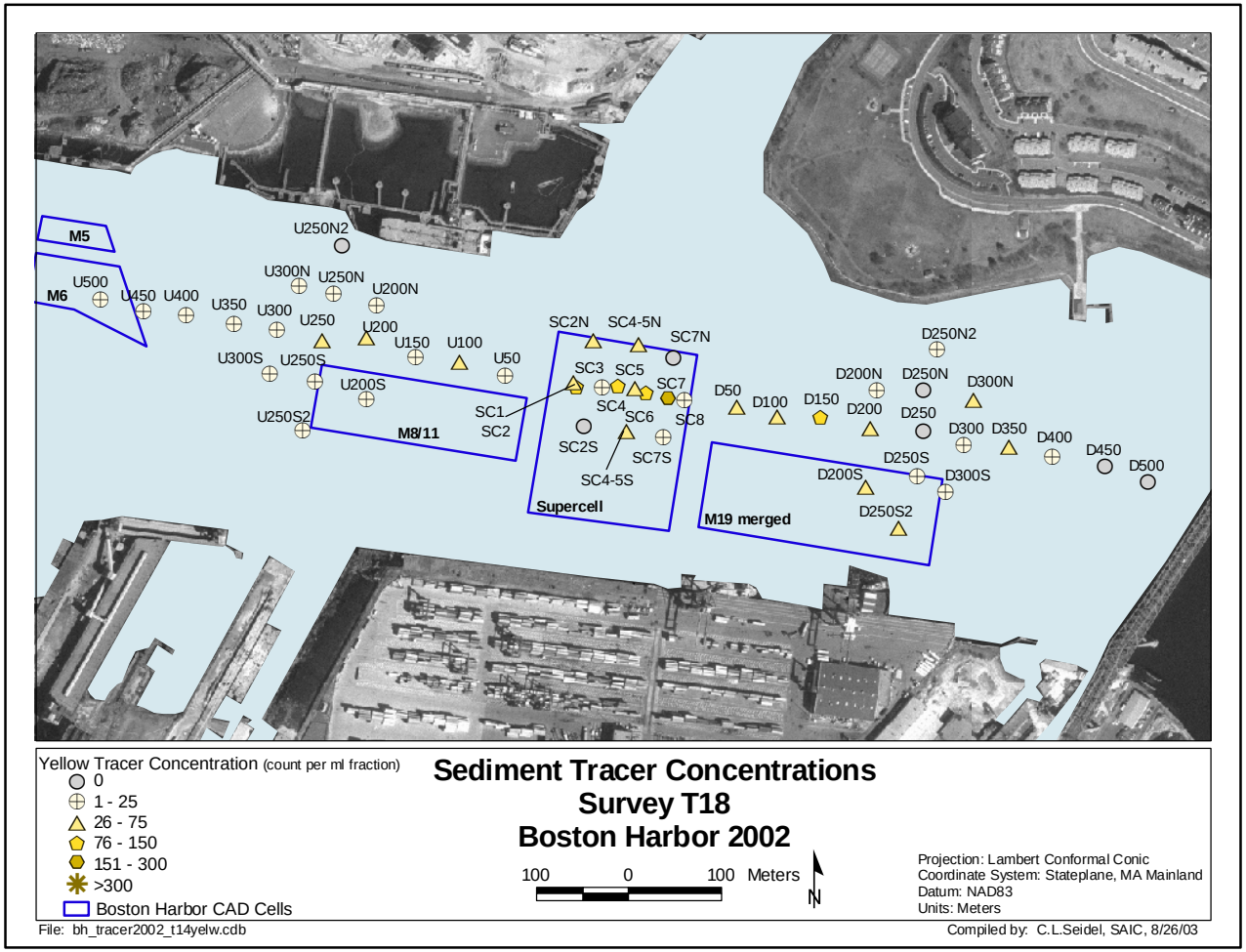

Figure 3-2. Concentrations of yellow tracer found within the Mystic River 18 days after deployment. Yellow tracer was placed 250 m downstream of the Supercell at Station D250.

Results from the yellow tracer did not show any high concentrations during the T18 survey (Figure 3-2). The highest concentrations (106 to 158) occurred within the Supercell. Lower tracer concentrations were encountered upstream and downstream of the cell. There were moderate counts of yellow tracer throughout the survey region in general, including tracer detected at 17 out of 18 upstream stations, 12 out of 14 Supercell stations, and all 14 downstream stations. There were higher counts of yellow upstream of the cell than magenta (exclusive of the four very high magenta counts near the deployment site), even though magenta was deployed upstream of the cell. In addition, the concentrations of yellow tracer within the Supercell were higher than magenta counts, and there were fewer null values for yellow than magenta, as well.

3.2 T32 Survey Results

Yellow and magenta tracer were detected at virtually all sample stations for the T32 survey (all but one station in the Supercell that lacked magenta tracer; Table B-4) and counts were generally lower for both colors after an additional 14 days (Figures 3-3 and 3-4). Even though overall counts of both yellow and magenta tracer were lower, results still showed higher counts of yellow tracer than magenta throughout. The most obvious difference between surveys was that there were very high counts of yellow tracer (maximum of 82,804) noted at the downstream deployment location and the next three stations upstream (Figure 3-4) at T32 compared to the earlier survey at T18 (maximum count of 158). Another interesting result from the T32 survey was the dramatic decrease in concentration of the magenta tracer in the region where very high counts were previously obtained during the T18 survey.

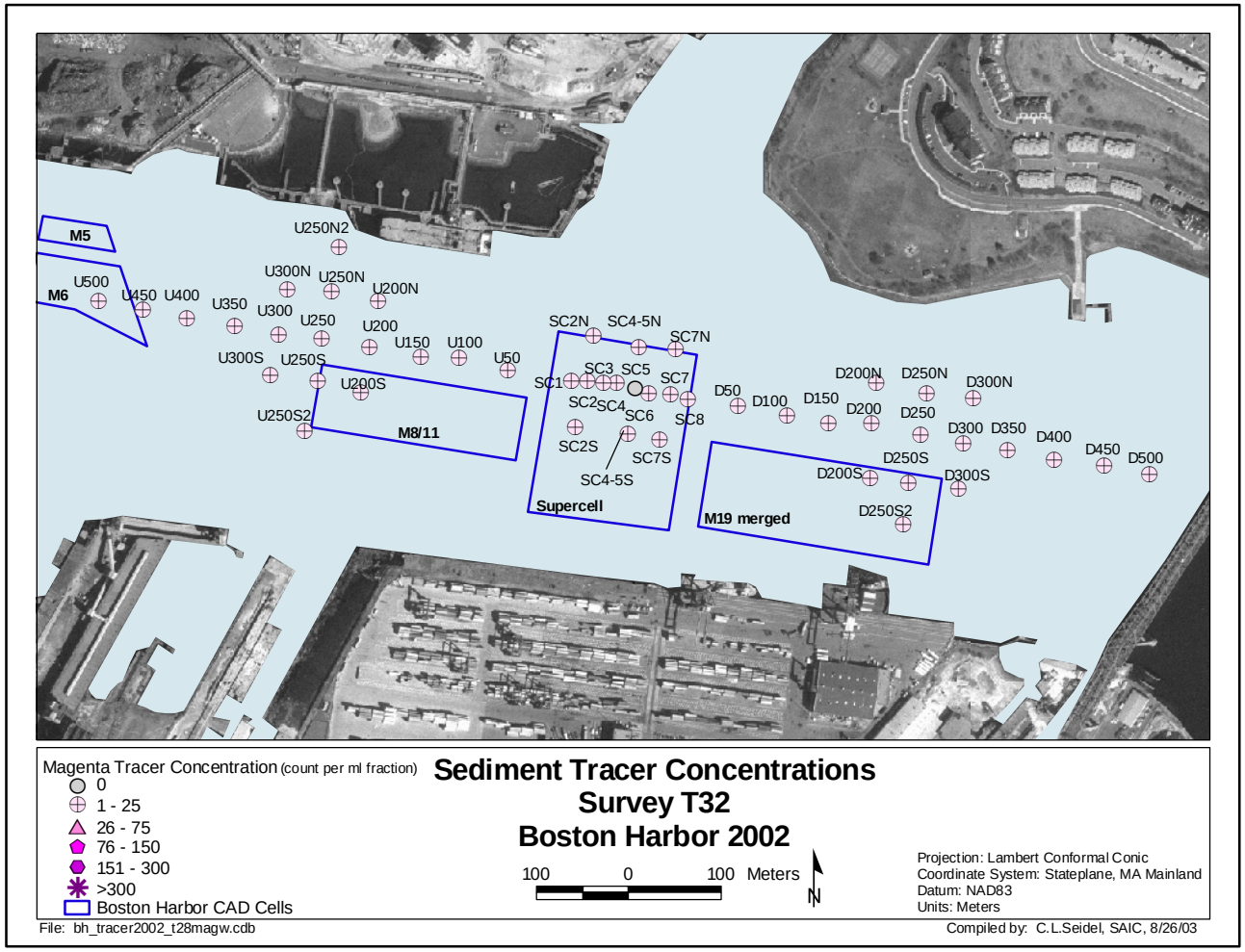

Figure 3-3. Concentrations of magenta tracer found within the Mystic River 32 days after deployment. Magenta tracer was placed 250 m upstream of the Supercell at Station U250.

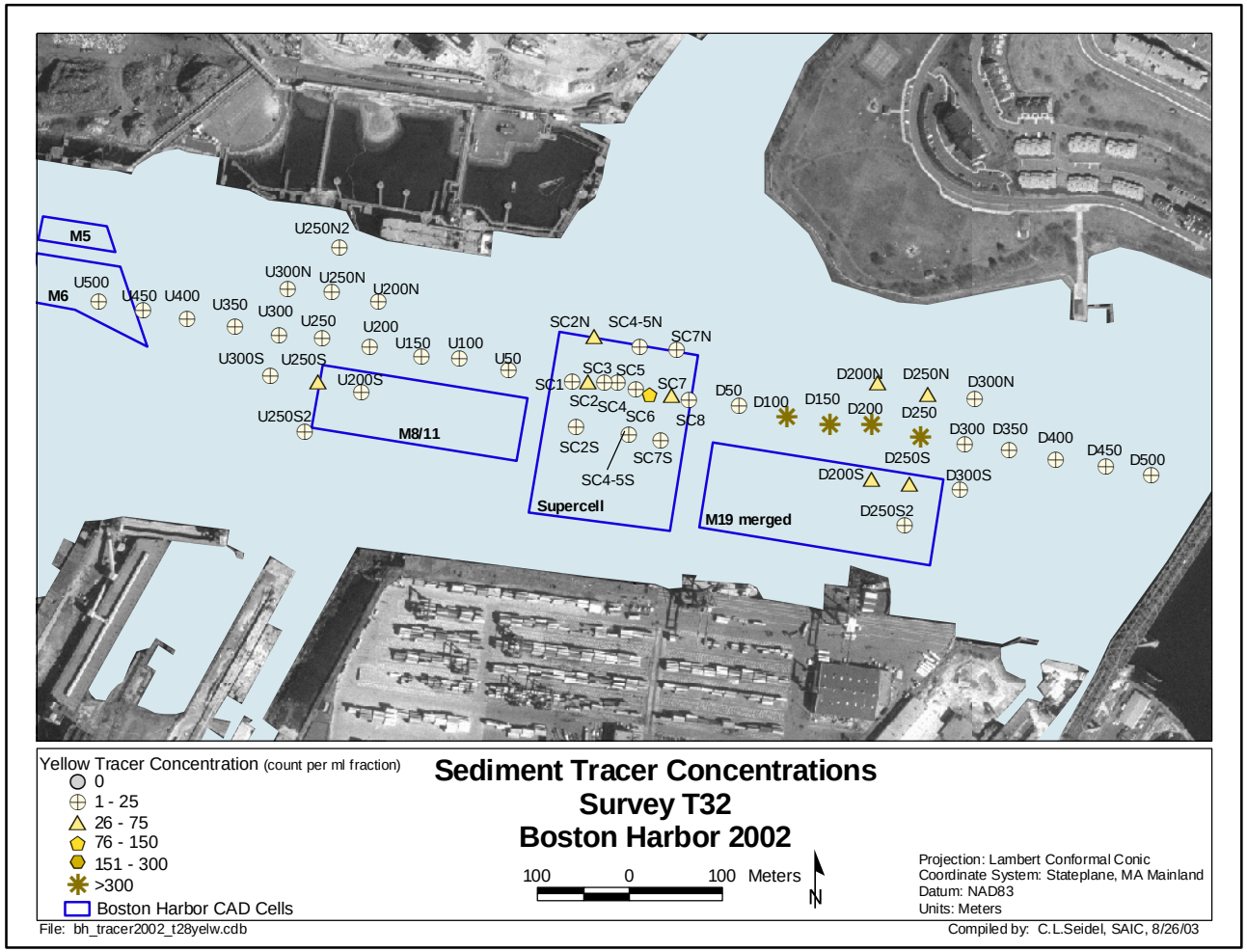

Figure 3-4. Concentrations of yellow tracer found within the Mystic River 32 days after deployment. Yellow tracer was placed 250 m downstream of the Supercell at Station D250.

4.0 DISCUSSION

The results of this pilot study indicate that tracer particles, were transported in both upstream and downstream directions from the deployment locations into the Supercell. It is therefore likely that fine-grained sediments are transported in both upstream and downstream directions in the study area. Yellow and magenta tracer were detected at numerous stations throughout the study area for the T18 survey, and virtually all stations for the T32 survey (all but one station in the Supercell that lacked magenta tracer; Table B-4). The fact that tracer counts at most stations were generally lower for both colors after an additional 14 days (T32 survey; Figures 3-3 and 3-4) suggests continued dispersal of tracer throughout the study area, although the net effects of dispersal and burial cannot be discerned from these results.

The fact that very high counts of tracer were detected in close proximity to the deployment locations for both the magenta (T18) and yellow (T32) tracers indicates that when the tracer blocks thawed, the material was relatively slowly dispersed from the deployment location. The lack of high counts of yellow tracer at/near the deployment site during the T18 survey, and subsequent very high counts at the deployment site and adjacent, upstream stations during the T32 survey, most likely indicate variability in the sampling technique used.

Other possible explanations seem less plausible (e.g., that the yellow tracer had been transported out of that area by the time of the T18 survey but had been re-transported back to that area by the T32 survey; that the bulk of the yellow tracer in close proximity to the deployment site was covered with a layer of sediment during the T18 survey, and therefore not sampled along with the sediment sample collected from the upper 5 mm of sediment in the grab sample) but cannot necessarily be discounted from consideration.

In contrast, the substantial decrease in magenta tracer counts that was detected in the vicinity of the deployment location from the T18 to T32 survey provides some evidence for relatively rapid dispersal of magenta tracer by the time the T32 survey was conducted, while the yellow tracer results provide evidence for *lack* of rapid dispersal of yellow tracer at the time of the T32 survey.

In the case of the magenta tracer, burial with ambient sediments could provide a plausible alternative explanation for the decreased counts during the T32 survey. With the information available from this study, it is not possible to discern if lower counts were due to localized dispersal, burial, or resuspension and transport out of the study area.

These uncertainties in part reflect sampling inadequacies, and suggest that a more comprehensive sampling strategy may be required to adequately characterize the transport

of fine-grained sediment in the area to more clearly map transport of tracer from the deployment locations with time.

A more comprehensive sampling scheme could include collection of a more representative sediment sample from each grab sample; analysis of duplicate samples from each grab sample; a finer grid of sample stations, particularly in close proximity to the deployment location; and more frequent sampling rounds following deployment.

The results provide conflicting evidence for net upstream versus downstream transport of material, and conclusions cannot be made with the results of this study. However, an evaluation of tracer counts with the high deployment area counts eliminated from consideration indicate preferential settlement of tracers in the Supercell, as indicated in the count summary (very high counts near deployment locations omitted) shown in Table 4-1.

The primary goal of the sediment tracer study was to investigate fine-grained sediment transport pathways in the vicinity of the Supercell in order to determine if deposits found overlying the sand cap within the Supercell could be attributed to ambient harbor sediments. The two most likely processes responsible for this potential sediment transport are tidal current migration and resuspension and subsequent deposition due to passing vessels. The observed presence of tracer material both upstream and downstream of the deployment location indicates that material is transported in both directions in the vicinity of the Supercell. The presence of tracer within the cell well above the background fluorescence and at greater concentrations than observed at upstream and downstream stations clearly demonstrates that fine-grained harbor sediments are deposited in the CAD cell and that the cell may provide a preferential settling location. Thus, there is a very strong likelihood that fine-grained sediments now present on top of the sand cap are largely a result of natural deposition.

Based on the range of tracer counts depicted in Table 4-1, statistical comparisons were conducted using Analysis of Variance (ANOVA) to determine if there were statistically significant differences in the means between tracer counts at the downstream, upstream, and Supercell stations. Comparisons of the average tracer counts are shown graphically in Figures 4-1 and 4-2. These plots provide a graphical depiction of the higher average counts in the Supercell stations for the T18 survey (Figure 4-1), and show that for that survey, the remotest sampling stations for each tracer (i.e., upstream stations for yellow and downstream stations for magenta) had substantially lower average tracer counts than the stations within the Supercell and in the vicinity of the deployment area.

Table 4-1. Summary of Findings for both Magenta and Yellow Tracers during the T18 and T32 Surveys

Survey	Location	Magenta No. of stations where detected	Magenta Range of counts (cpmf)	Yellow No. of stations where detected	Yellow Range of counts (cpmf)
T18	Upstream	13/18	0-30	17/18	0-38
	Supercell	9/14	0-48	12/14	0-158
	Downstream	9/18	0-10	14/14	0-80
T32	Upstream	18/18	1-15	18/18	3-27
	Supercell	13/14	0-16	14/14	7-77
	Downstream	18/18	1-19	18/18	4-41

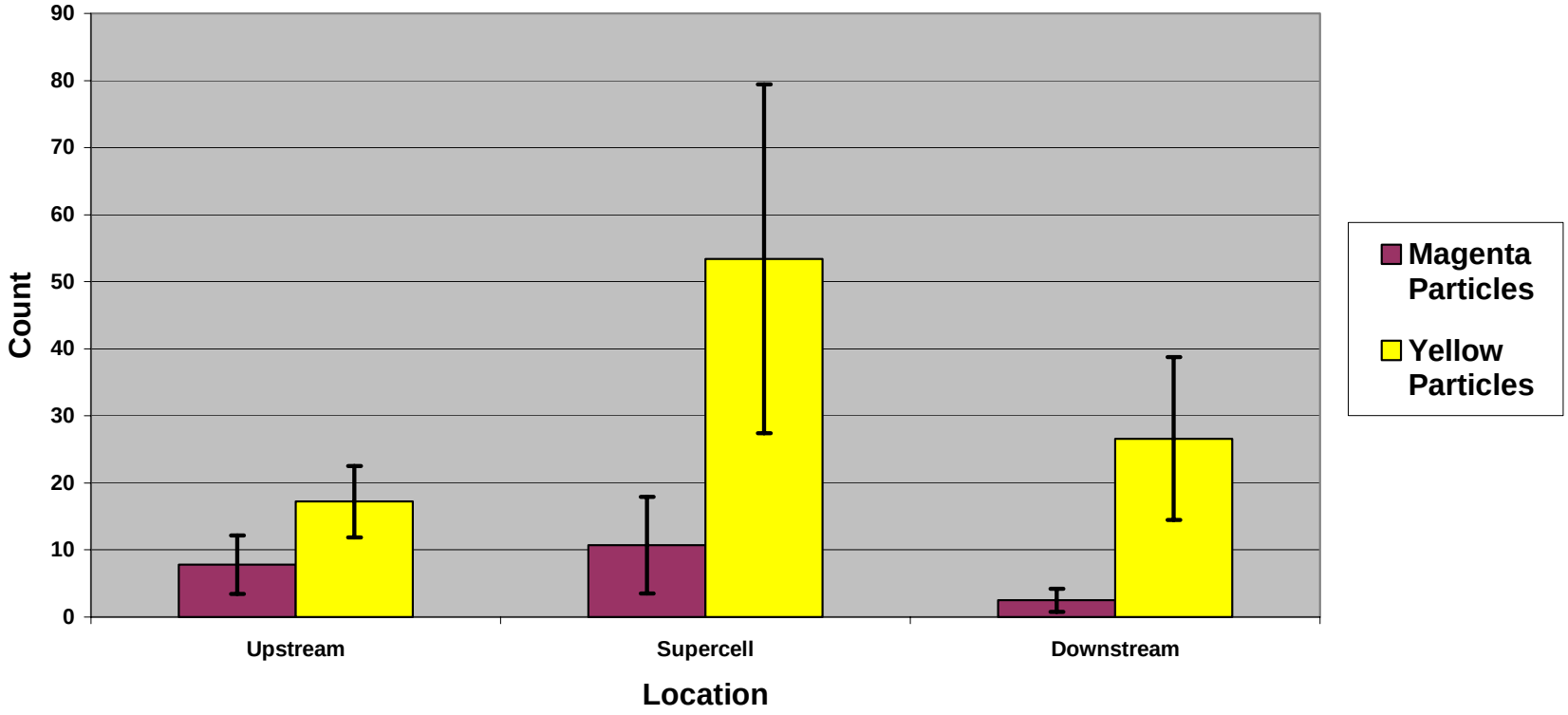

Figure 4-1. Histogram displaying mean tracer particle count for magenta and yellow tracer particles captured within the Supercell, as well as upstream and downstream stations during the T18 Survey

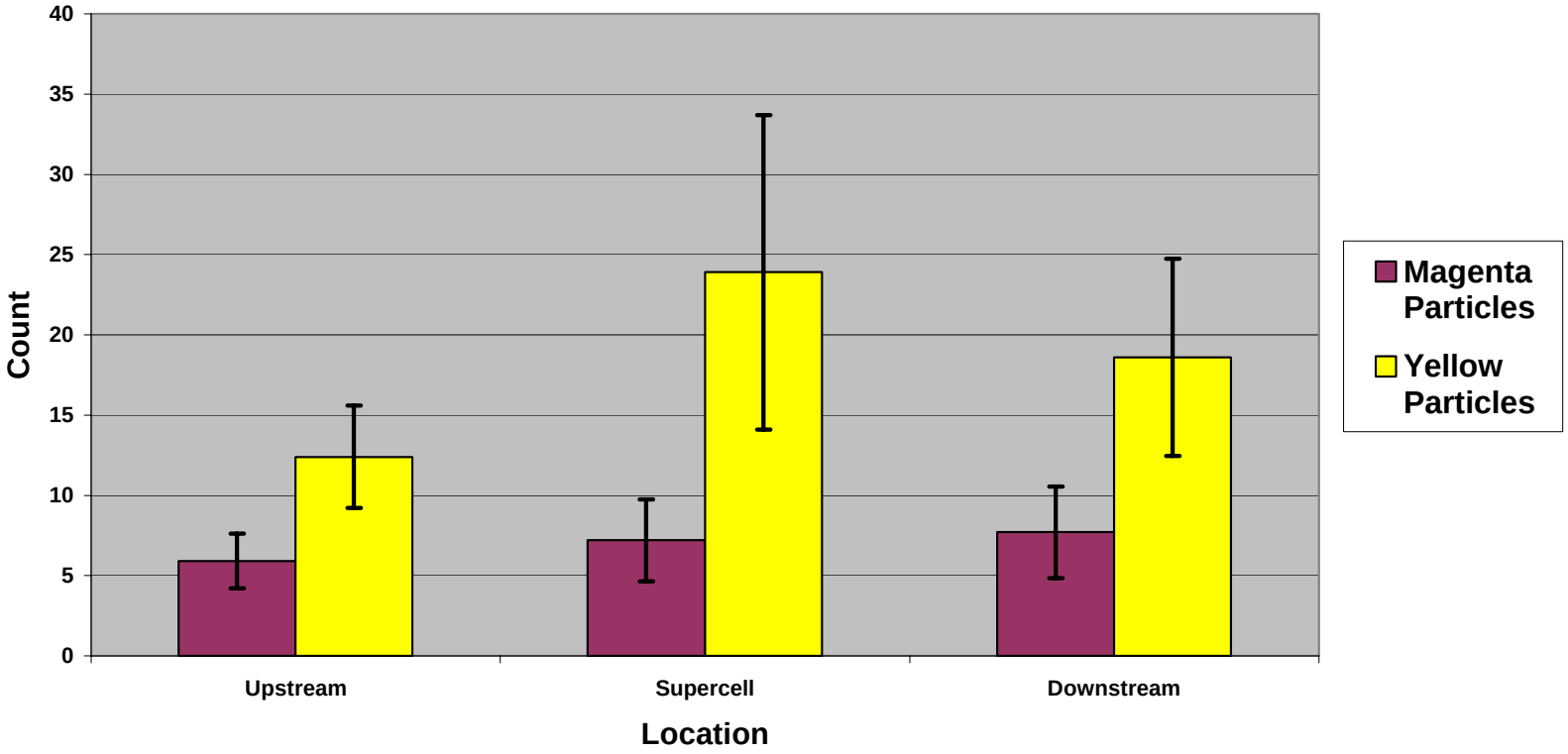

Figure 4-2. Histogram displaying mean tracer particle count for magenta and yellow tracer particles captured within the Supercell, as well as upstream and downstream stations during the T32 Survey

The graphical representation of average tracer counts for the T32 survey (Figure 4-2), displays similar results for the yellow tracer and relatively uniform average counts among all station locations for the magenta tracer.

Analysis of Variance (ANOVA) was used to test the significance of the differences in average tracer counts between upstream, downstream and Supercell stations for both surveys (Tables 4-2 and 4-3). Significance at the 95% confidence level is indicated by a probability (p) less than 0.05, indicating a statistically significant difference between means (Zar 1984).

ANOVA results for the magenta tracer for the T18 survey yielded a probability of 0.055 (Table 4-2a). While some statisticians do not give any weight to probability (p) values greater than 0.05, others would argue that a probability value very close to 0.05 (e.g., 0.055 for the magenta tracer results) suggests the possibility of a correlation (e.g., correlation between average counts and location) that warrants further investigation. Based on the ANOVA results, results of the T18 survey provided an indication that there were significant differences in means between stations for the yellow tracer ($p=0.008$, Table 4-2b).

Results of ANOVA for the T32 survey support the findings of a relatively uniform distribution of magenta tracer among the three sampling locations ($p=0.515$, Table 4-3a), and indicate the apparent differences in average counts for the yellow tracer were not statistically significant ($p=0.064$, Table 4-3b).

The magenta tracer was recovered in high concentrations in close proximity to the deployment location during the T18 survey. The ANOVA results suggest there may have been a difference in the average counts from the downstream stations, which seems reasonable for the stations farthest from the deployment location. When considering stations beyond the immediate near-deployment area (e.g., beyond the very high tracer counts), the average counts at the Supercell stations were higher, but don't appear to be significantly higher than the upstream stations. While the higher average counts in the Supercell stations alone suggest there may have been preferential settling of tracer in the Supercell, they don't appear to have been significantly different than the average counts for the upstream stations. Additionally, by the time of the T32 survey, magenta tracer was distributed much more uniformly across all stations sampled, and there was no evidence of preferential settlement of tracer in the Supercell.

Table 4-2a. ANOVA Results Comparing Magenta Tracer Counts from the T18 Survey for Downstream, Upstream, and Supercell Stations

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	Probability (p)
Between	561.6	2	280.8	3.10	0.055
Error	3895	43	90.58		
Total	4457	45			
	Downstream	Upstream	Super Cell		
Mean	2.5	7.9	10.7		
Standard Deviation	3.4	8.7	14.4		

Table 4-2b. ANOVA Results Comparing Yellow Tracer Counts from the T18 Survey for Downstream, Upstream, and Supercell Stations

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	Probability (p)
Between	1.08×10^4	2	5419	5.413	0.008
Error	4.7×10^4	47	1001		
Total	5.8×10^4	49			
	Downstream	Upstream	Super Cell		
Mean	26.6	17.2	53.4		
Standard Deviation	24.3	10.6	52		

Table 4-3a. ANOVA Results Comparing Magenta Tracer Counts from the T32 Survey for Downstream, Upstream, and Supercell Stations

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	Probability (p)
Between	30.83	2	15.41	0.6742	0.515
Error	1052	46	22.86		
Total	1082	48			
	Downstream	Upstream	Super Cell		
Mean	7.7	5.9	7.2		
Standard Deviation	5.7	3.4	5.1		

Table 4-3b. ANOVA Results Comparing Yellow Tracer Counts from the T32 Survey for Downstream, Upstream, and Supercell Stations

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	Probability (p)
Between	1051	2	525.4	2.943	0.064
Error	7496	42	178.5		
Total	8547	44			
	Downstream	Upstream	Super Cell		
Mean	18.6	12.4	23.9		
Standard Deviation	12.3	6.4	19.6		

Tracer counts for both surveys suggested that the yellow tracer became dispersed from the deployment area more slowly than the magenta tracer, as very high counts near the deployment area were observed during the T32 survey (by which time the magenta tracer was much more uniformly distributed throughout the survey area). Evaluation of the average yellow tracer counts excluding the very high, near-deployment area counts, indicates higher average counts at the downstream and Supercell stations, with a statistically significant difference for the T18 survey. This trend persisted somewhat during the T32 survey, but was not found to be statistically significant. As with the magenta tracer findings discussed above, it would be reasonable to detect lower average yellow tracer counts at the stations farthest from the deployment area (e.g., the upstream stations). The T32 survey provided evidence for continued dispersal of tracer to all stations throughout the study area and lack of evidence for a significant "preference" for a particular settlement location.

The lack of a persistent, significant trend of higher average counts at the Supercell stations suggests that while tracer material settled in the cell, the cell may not be providing a preferential settlement location. It could be that particles are readily transported over the cell in suspension (i.e., to upstream station locations), and/or that particles are transported into and out of the cell under ambient hydrodynamic conditions (e.g., resuspended by the wakes of passing vessels).

It must be emphasized that these findings are limited by the use of a relatively limited data set, uncertainties regarding representativeness of the samples analyzed for tracer, and the fact that sampling only accounted for a portion of the tracers and did not evaluate possible effects of burial and transport out of the sample area. It is possible, but would not be detectable in this study, that substantially greater amounts of tracer were deposited in the Supercell and subsequently buried by ambient sediments. Therefore, final conclusions cannot be determined with the available information.

Previous data on near-bottom currents showed that the average tidal currents are very weak both within the Supercell and in the channel adjacent to the cells, and tidal current variability is not likely to resuspend bottom sediments above background concentrations (SAIC 2000b). Average tidal currents typically ranged from 5 to 10 $cm \cdot s^{-1}$, with no apparent difference in magnitude between the flood and ebb cycles. The two-week deployment also showed episodic current events up to 20 $cm \cdot s^{-1}$. Results of a separate, one-day current meter deployment conducted during passage of the LNG *M/V Matthews* through the study area indicated that increased current velocities and fairly substantial, short-lived resuspension events result from the vessel wake, and that the potential shear

stress associated with vessel passage is sufficient for sediment resuspension (SAIC 2001b, Hales 2001).

Net drift of sediments resuspended by passing vessels would depend on the direction of the tidal currents at the time the resuspension event occurred, but would generally consist of relatively short transport distances given the weak current regime (SAIC 2001a). Turbidity plumes above background concentrations were evident for a short duration following passage of the vessel (e.g., within 30 minutes of vessel passage) and would be subjected to minimal horizontal advection during that time (SAIC 2001b).

Because of the large size and deep draft of the *M/V Matthews*, and the close proximity of its berthing area to the study site, it would be expected to have an impact on sediment resuspension in the project area. The vessel generally transits upstream while fully loaded as close to flood tide as possible to take advantage of deep-water conditions, and transits downstream with the ebb tide. This would suggest that resuspension caused by the vessel would contribute to net downstream transport in the study area. However, while various survey efforts have focused on the *M/V Matthews* because of its predictable traffic patterns and deep draft (Table B-5), a variety of vessels transit the study area and could potentially contribute to resuspension events at various stages of the tide. Therefore, it would be difficult to predict a net or preferred direction of sediment drift based on the number of vessel transits and tide stage.

A determination of net upstream or downstream transport of fine-grained material is not possible with the information available from this study. Results provide some evidence for net upstream transport (e.g., yellow tracer maxima at the deployment location and next three stations upstream; dispersal of yellow tracer to more stations throughout the study area than magenta tracer at the T18 survey; higher concentrations of yellow tracer at all stations throughout the study area compared to magenta tracer). Other results appear to indicate net downstream transport (e.g., magenta tracer maxima at the deployment location and stations immediately downstream). There could be confounding or other factors responsible for these observations and a conclusive determination cannot be made with the information available from this small pilot study.

Confounding factors that cannot be evaluated in this study include the effects of localized tracer dispersal, transport out of the study area, and burial. Each of these processes could be contributing to the observed decreases in tracer concentration at sampling stations between the T18 and T32 surveys. A more conclusive determination of whether there is a preferred net direction of transport would require a more thorough evaluation of tracer dispersal (e.g., more stations sampled) and burial (e.g., tracer counts at various depth intervals in a sample).

5.0 CONCLUSIONS

Despite irregularities in observed post-deployment tracer concentrations, the data obtained in this study show that *in situ* fine-grained sediments from the surrounding navigable Mystic River channel are resuspended and transported into the Supercell and presumably, the other CAD cells in the study area. Previous studies show that vessel passage is a primary mechanism for resuspending bottom sediments at this location (SAIC 2000b, SAIC 2001a). Results of this tracer study suggest that immediately following a resuspension event the CAD cells may provide a preferential depositional location for sediments resuspended from the channel bottom in the immediate vicinity. It is not clear if this is a constant process by which the cell will eventually fill in with surrounding harbor sediments. Overall decreases in tracer concentrations at the sampling stations over time may be due to continued dispersal throughout the study area (e.g., southern portion of Supercell not included in the sample area), burial (not assessed with the study design), or repeated resuspension and transport out of the cell (less likely given the ambient current regime and previous observations on the duration of turbidity maxima associated with vessel passage).

5.1 Recommendations

The results of this pilot study lead to the following recommendations that may help resolve uncertainties in interpreting results and addressing the initial study objective of determining if there is a preferred direction of transport in the vicinity of the Supercell:

- In obtaining a sediment sample from each grab sample, the likely depth of sediment/tracer mixing should be considered to ensure a representative sample. The sampling approach in this study, consisting of collecting a small sediment sample from the upper 5 mm of the grab sample, may not have provided representative results.

- The tracer burial hypothesis could be tested by obtaining additional sediment grabs at the deployment sites and within the Supercell and taking small 'short-core' samples from the grab. Samples could be then taken from several horizons within the core to examine tracer concentration versus depth, or composite samples could be analyzed.

- Duplicate samples and a more rigorous statistical approach to the tracer analyses would improve confidence in the tracer counts.

- Continued investigations into the comparability of tracer materials to ambient sediments at the deployment site are recommended to ensure the tracer particles mimic the natural sediments.

- Grab sampling efforts that include a more comprehensive grid of stations (e.g., at more stations near each deployment location, and throughout the entire Supercell) would provide more complete information on sediment deposition and dispersal throughout the study area.

- To determine if there is preferred, net upstream or downstream transport within the study area, additional grabs continuing farther upstream and downstream from the deployment site, possibly as far upstream as the Mystic River Locks, would be useful. Presence of the tracer farther upstream or downstream of the deployment locations would provide evidence in support of a preferred transport direction.

6.0 REFERENCES

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APPENDIX A

Tracer + Sediment Grainsize analyses:

Particle size determinations were carried out on a Sequoia LISST 100 laser diffraction analyser by ETS.

Sample: Tracer - Violet (<45um) (Upstream site)

Run	Clay	V. fine silt	Fine silt	Med. Silt	Coarse silt	V. coarse silt	Sand	Sand	Silt	Clay
				% in size	band				% in size	band
1	19.65	24.37	47.27	8.48	0.08	0.00	0.15	0.15	80.21	19.65
2	20.19	22.94	46.59	10.07	0.20	0.00	0.00	0.00	79.81	20.19
3	20.05	22.58	47.36	10.29	0.15	0.00	0.00	0.00	79.95	20.05
4	19.25	22.61	46.80	9.00	0.10	0.00	0.00	0.00	80.75	19.25
5	19.99	22.25	47.97	11.77	0.32	0.00	0.00	0.00	80.01	19.99
6	19.43	22.98	48.30	9.50	0.17	0.00	0.00	0.00	80.57	19.43
7	20.80	22.73	46.83	9.48	0.14	0.00	0.02	0.02	79.17	20.80
8	21.03	21.80	47.74	9.33	0.10	0.00	0.00	0.00	78.97	21.03

Sample: Tracer Yellow (<45um) (Upstream site)

Run	Clay	V. fine silt	Fine silt	Med. Silt	Coarse silt	V. coarse silt	Sand	Sand	Silt	Clay
				% in size	band				% in size	band
1	17.48	18.79	31.93	28.29	2.88	0.00	0.63	0.63	81.88	17.48
2	19.71	18.21	33.55	27.16	1.37	0.00	0.00	0.00	80.29	19.71
3	20.05	16.63	34.25	27.30	1.76	0.00	0.00	0.00	79.95	20.05
4	19.72	17.53	32.30	28.58	1.88	0.00	0.00	0.00	80.28	19.72
5	19.09	17.13	32.74	29.76	1.20	0.00	0.08	0.08	80.83	19.09
6	19.82	17.49	32.09	28.95	1.65	0.00	0.00	0.00	80.18	19.82

Sample: Sediment Upstream 250m site (<45um) (Violet tracer drop zone)

Run	Clay	V. fine silt	Fine silt	Med. Silt	Coarse silt	V. coarse silt	Sand	Sand	Silt	Clay
				% in size	band				% in size	band
1	7.56	9.89	21.64	31.82	23.73	5.14	0.23	0.23	92.21	7.56
2	8.20	10.66	20.65	31.62	23.64	5.05	0.18	0.18	91.62	8.20
3	8.14	9.76	21.86	31.22	23.76	5.10	0.16	0.16	91.70	8.14
4	8.81	10.19	21.01	31.82	23.21	4.79	0.17	0.17	91.02	8.81
5	7.98	10.78	21.36	31.21	23.58	4.87	0.22	0.22	91.80	7.98
6	8.02	9.69	21.64	31.23	23.95	5.28	0.19	0.19	91.79	8.02
7	8.17	10.00	21.53	31.71	23.24	5.09	0.26	0.26	91.57	8.17
8	7.69	10.81	21.27	31.29	23.87	4.90	0.18	0.18	92.13	7.69

Sample: Sediment Downstream 250m site (<45um) (Yellow tracer drop zone)

Run	Clay	V. fine silt	Fine silt	Med. Silt	Coarse silt	V. coarse silt	Sand	Sand	Silt	Clay
				% in size	band				% in size	band
1	7.04	10.25	22.28	28.97	22.16	8.14	1.16	1.16	91.80	7.04
2	6.66	10.70	20.76	28.03	21.84	10.23	1.78	1.78	91.55	6.66
3	6.61	10.44	21.41	28.07	21.34	9.37	2.76	2.76	90.63	6.61
4	6.41	11.10	21.07	29.14	21.44	8.89	1.95	1.95	91.65	6.41
5	6.64	10.64	21.86	27.94	21.67	9.07	2.18	2.18	91.18	6.64
6	6.05	10.47	21.56	27.21	21.96	10.06	2.69	2.69	91.26	6.05
7	6.63	10.21	21.56	27.18	21.84	10.18	2.40	2.40	90.97	6.63
8	6.45	10.06	21.69	28.03	21.57	9.79	2.41	2.41	91.13	6.45

Density measurements

Methodology

Density tests were carried out by Cheshire Engineering Consultancy UKAS Accredited Laboratory, in accordance with British Standard BS 812: Part 2: 1995 Test 5.7 – Method for determination of particle density of filler, extract provided:

British Standard BS 812: Part 2: 1995 Testing aggregates
Part 2. Methods of determination of density

5.7 Method for determination of particle density of filler

5.7.1 ***Apparatus***

5.7.1.1 *Density bottle*, of 50 ml or 100 ml.

5.7.1.2 *Small funnel*.

5.7.1.3 *Balance*, of capacity 200 g, accurate to 0.001 g.

5.7.1.4 *Vacuum desiccator and pump*, capable of reducing the pressure below 50 mbar.

5.7.1.5 *Well ventilated oven*, thermostatically controlled to maintain a temperature of 105 °C ± 5 °C.

5.7.1.6 *Water bath*, capable of maintaining a temperature of 25 °C ± 0.1 °C.

5.7.1.7 *Supply of water*, free from any impurity (e.g. dissolved air) that would significantly affect its density. If distilled or deionised water is not available in sufficient quantity, tap water which has been freshly boiled and cooled to room temperature may be used. This water should be used throughout the test.

5.7.2 ***Dilatometric liquid***

Preferably purified xylene. Redistilled kerosene kept over a dehydrating and deacidifying agent, e.g. Portland cement, may be used. When the filler is known not to react with water, then water may be used as a dilatometric liquid.

5.7.3 ***Test procedure***

5.7.3.1 *Calibration of density bottle*

Weigh the density bottle and stopper, both of which shall be clean and dry (mass *A*). Then fill the bottle with the water described in 5.7.1.7, immerse it nearly up to the top of its neck in the water bath and maintain it for not less than 60 min at a temperature of 25 °C ± 0.1 °C. then insert the stopper, remove the bottle from the bath, dry the outside thoroughly and weight the bottle as quickly as possible (mass *B*).

5.7.3.2 *Determination of density of dilatometric liquid*
Using the procedure described in 5.7.3.1 determine the mass of the density bottle and stopper when filled with the dilatometric liquid (mass *C*).

5.7.3.3 *Determination of particle density of filler*

Dry the filler for 4 h in the oven at a temperature of 105 °C ± 5 °C and cool it in the desiccator to room temperature. The density bottle and stopper should be clean and dry. Then add the filler to the bottle through the funnel, so as to fill the bottle approximately one-third full [~15–20 g] and weigh the bottle with filler and stopper (mass D). Then add sufficient dilatometric liquid to cover the filler and half fill the bottle. Release entrapped air by giving the

bottle a few light taps on the bench and then gradually subjecting the bottle and contents to reduced pressure (approximately 50 mbar). In a vacuum desiccator for at least 5 min. Repeat this procedure for releasing air until no further bubbles appear.

Then add dilatometric liquid to fill the bottle completely and keep the bottle with contents for not less than 60 min in the water bath controlled at a temperature of 25 °C ± 0.1 °C. Then insert the stopper, remove the bottle from the bath, dry the outside thoroughly and weigh the bottle with its contents (mass E).

5.7.4 ***Calculations***

The density of the dilatometric liquid (d_L) is given by the formula:

$$\frac{C-A}{B-A}$$

The particle density of the filler is given by the formula:

$$\frac{(D-A)}{(B-A)-\frac{(E-D)}{d_L}}$$

where

A is the mass of stopper and density bottle empty (in g);

B is the mass of stopper, density bottle and water (in g);

C is the mass of stopper, density bottle and dilatometric liquid (in g);

D is the mass of stopper, density bottle and filler (in g);

E is the mass of stopper, density bottle, filler and dilatometric liquid (in g).

Two separate determinations shall be made and both results recorded. If these results differ by more than 0.02, they shall be discarded and two fresh determinations made.

5.7.5 ***Reporting results***

The mean result shall be reported to the nearest 0.01 as the particle density of the tested material.

Results

Yellow tracer – 1.47 S.G (see attached result from Cheshire Engineering Consultancy).

Violet tracer – 1.67 S.G (see attached result from Cheshire Engineering Consultancy).

Cheshire Engineering Consultancy
Part of Cheshire CC Engineering Service

UKAS TESTING 0065

Cheshire County Council
Geotechnical Services Laboratory
Backford Hall
Chester
Cheshire CH1 6EA
TEL : 01244 603511
FAX : 01244 603581

Particle Density of Pigmented Tracing Dye

BS 812 : Part 2 : 1995 Test 5.7

Project : Particle density tests on coloured tracing dye powders.
Material : Pigmented Powder (Tracing Dye)
Source : Environmental Tracing Systems - Helensburgh
Spec. : Proprietary coloured tracing dye (powder)
Location : Supplied by post: Material reference Boston Harbor Yellow Tracer
Date Sampled : 04/07/2003 Sampled By : — Date Received : 07/07/2003
Sampling Cert. Received ? :N Cert. Attached ?: N

Project No: 7810301
Sample Num : 03R0042
Test Num : 1
Ticket No. : n/a
Site Ref : See above
Date Tested : 10/07/2003
Report No: 7810301 / 03R0042 / 1

Sample Description : Yellow tracing powder

Particle Density of Tracing Dye: 1.47

Passing sieve (mm) : 0.125
Dilatometric Liquid used: Kerosene

No departures from specified test procedure.

Client Engineer Fraser Taylor
Environmental Tracing Systems
Morar House
Upper Colquhoun Street
Helensburgh
Argyll
G84 9AJ

Copy To :

Simon Jefferies

S. C. Jefferies
Laboratory Team Leader
17 July 2003

Cheshire Engineering Consultancy
Part of Cheshire CC Engineering Service

UKAS TESTING 0965

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Particle Density of Pigmented Tracing Dye

BS 812 : Part 2 : 1995 Test 5.7

Project : Particle density tests on coloured tracing dye powders.
Material : Pigmented Powder (Tracing Dye)
Source : Environmental Tracing Systems - Helensburgh
Spec. : Proprietary coloured tracing dye (powder)
Location : Supplied by post: Material reference Boston Harbor Violet Tracer

Project No: 7810301
Sample Num : 03R0043
Test Num : 1
Ticket No. : n/a
Site Ref : See above

Date Sampled : 04/07/2003 Sampled By : ---
Date Received : 07/07/2003
Date Tested : 10/07/2003

Sampling Cert. Received ? :N Cert. Attached ?: N

Report No: 7810301 / 03R0043 / 1

Sample Description : Violet tracing powder

Particle Density of Tracing Dye:	**1.67**
Passing sieve (mm) :	0.125
Dilatometric Liquid used:	Kerosene

No departures from specified test procedure.

Client Engineer Fraser Taylor
Environmental Tracing Systems
Morar House
Upper Colquhoun Street
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Copy To :

Simon Jefferies

S. C. Jefferies
Laboratory Team Leader
17 July 2003

Settling velocity tests

Methodology

Settling velocity tests using Bottom Withdrawal Settling Tube (as per Owen 1970)

1.1 Method for determination of particle settling velocity

1.1.1 ***Apparatus***

1.1.1.1 *Settling tube*¸ 1.20 m in length with tap on bottom, graduated in 10 cm increments from where the tapering section ends at the top of the narrow tap section.

1.1.1.2 *Timer*, to measure 240 minutes.

1.1.1.3 *Balance*, accurate to 0.001 g.

1.1.1.4 *Thermometer*, accurate to 0.1 °C.

1.1.1.5 *Deionised water*.

1.1.1.6 *Anhydrous sodium chloride*.

1.1.2 ***Preparation of sample for analysis***

1.1.2.1 Determine the volume required to fill the settling tube to the 1.00 metre mark.

1.1.2.2 Determine the mass of sediment required to give a final concentration of approximately 1 gram per litre of sediment.

1.1.2.3 Thoroughly disperse material in deionised water and leave overnight to equilibrate.

1.1.2.4 Add sufficient anhydrous sodium chloride and deionised water to the salinity of seawater relevant for each test.

1.1.3 ***Tests***

1.1.3.1 Shake the sediment suspension vigorously and then immediately collect a small sample of the mix. This represents Time zero – T0.

1.1.3.2 Pour the mix into the settling tube to fill up to 1m mark. Start the timer immediately.

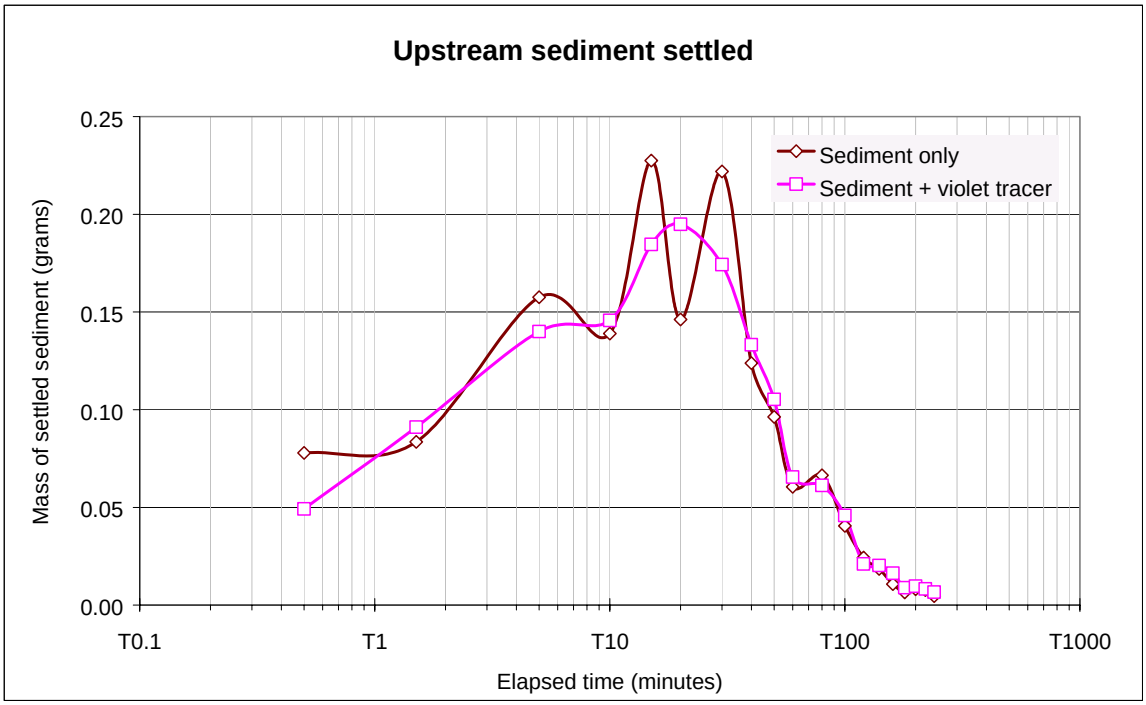
1.1.3.3 Collect a small sample from the tap at intervals for 4 hours, collecting all the visible settled sediment. A suitable choice of times would be T0.5, T1.5, T5, T10, T15, T20, T30, T40, T50, T60, T80, T100, T120, T140, T160, T180, T200, T220 and T240, where the time is given in minutes.

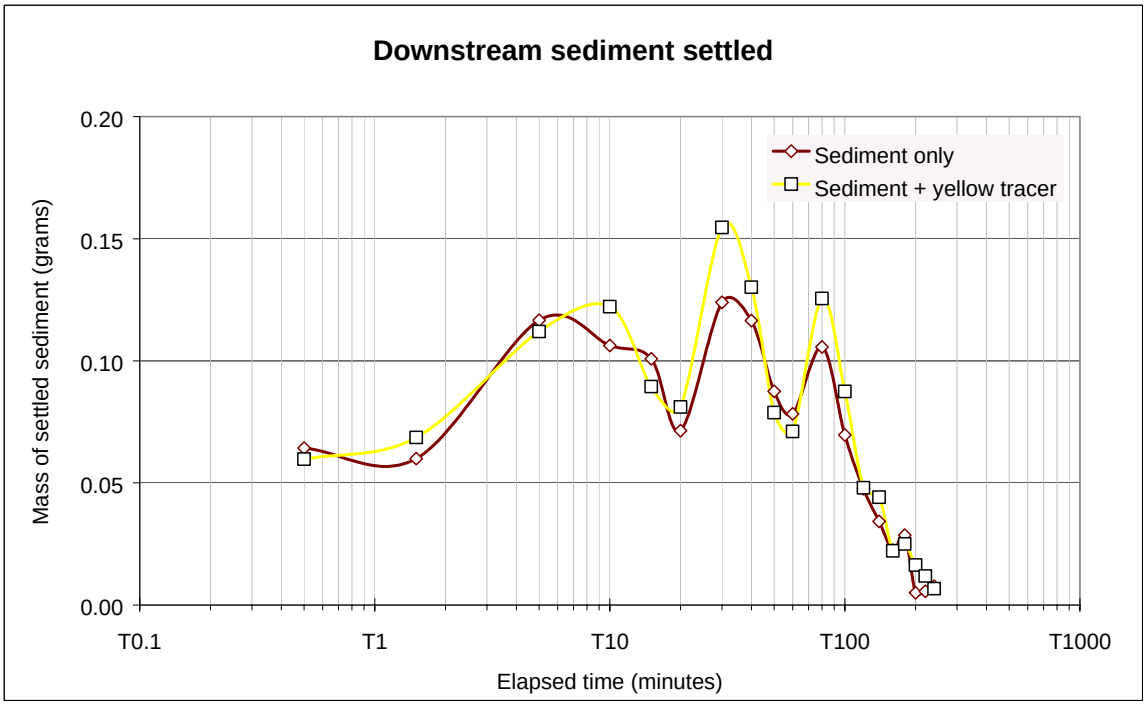
1.1.3.4 Decant the volume remaining in the column after T240 into a suitable container and shake vigorously. Collect a sample from the container. This represents Time >T240.

1.1.3.5 All samples T0 to T240 should be analysed for gravimetric solids mass over time.

1.1.3.6 Note the temperature of water at the start and end of trial and at intervals during trial and ensure that the temperature varies by no more than 1.0°C during the trial.

Results


Upstream sediment settled
Mass of settled sediment (grams)
0.25
0.20
0.15
0.10
0.05
0.00
T0.1
T1
T10
T100
T1000
Elapsed time (minutes)
Sediment only
Sediment + violet tracer


Downstream sediment settled
Mass of settled sediment (grams)
0.20
0.15
0.10
0.05
0.00
T0.1
T1
T10
T100
T1000
Elapsed time (minutes)
Sediment only
Sediment + yellow tracer

APPENDIX B

Table B-1.
Boston Harbor Background Survey (26 June 2002)
Tracer Particle Counts per 0.1 ml Wet Sediment.
Method: Automated Flow Cytometry (AFC)

Station	Easting	Northing	Latitude	Longitude	Magenta	Yellow
B2	236290.8	904135.8	42.38688644	-71.05927862	1	0
B11	236315.8	904228.8	42.38772261	-71.05896991	4	1
B12	236292.6	904033.4	42.38596431	-71.05926343	2	3
B1	236060.6	904169.6	42.38720104	-71.06207193	1	2-3
B3	236535.6	904099.5	42.38654831	-71.0563082	0	1
B4	236605.3	904095.3	42.3865075	-71.05546289	0	0
B5	236654.6	904094.5	42.38649736	-71.05486401	0	2
B6	236705.4	904066.6	42.38624361	-71.05424863	1	2
B9	236937.1	903942.9	42.3851195	-71.05144232	0	3
B7	236937.2	904034.8	42.38594648	-71.05143536	1	3
B10	236932.8	904109.2	42.38661711	-71.05148416	2	1-2
B8	237197.4	903999.2	42.38561408	-71.04827833	0	0

Table B-2.
Boston Harbor T1 Survey (25 August 2002)
Tracer Particle Counts per 0.1 ml Wet Sediment.
Method: Automated Flow Cytometry (AFC)

Station	Easting	Northing	Latitude	Longitude	Magenta	Yellow
D300	236990.8	904025.4	42.38585933	-71.05078578		0
D250S	236944.8	903987	42.38551599	-71.05134685		0
D250N	236953.4	904076.8	42.38632455	-71.05123655		0
D200	236901.9	904035	42.38595041	-71.05186438		0
U200	236346.1	904140.7	42.38692772	-71.05860664	0	
U250N	236314.1	904182.4	42.38730489	-71.05899286	0	
U300	236252.4	904141	42.38693469	-71.05974548	0	
U250S	236290.5	904085.7	42.38643552	-71.05928541	0	

Table B-3.
Boston Harbor T18 Survey (12 to 13 September 2002)
Tracer Particle Counts per 0.1 ml Wet Sediment.
Method: Laser Microscopy

Station	Time	Date	Easting	Northing	Lattitude	Longitude	Magenta	Yellow
D100	20:26:47	9/11/1998	236789.3	904052.4	42.38611255	-71.05323054	0	42
D150	20:49:43	9/11/1998	236835.4	904053.3	42.38611812	-71.05267066	0	80
D200	19:52:18	9/11/1998	236889.3	904041.1	42.38600547	-71.0520164	7	52
D200N	19:34:38	9/11/1998	236897.1	904082.5	42.3863779	-71.05191916	0	9
D200S	16:56:49	9/11/1998	236940.6	903989.2	42.3855359	-71.05139723	4	24
D200S	20:07:03	9/11/1998	236884.3	903977	42.38542909	-71.05208205	0	46
D200S2	16:47:38	9/11/1998	236920.5	903934.2	42.38504207	-71.05164543	10	47
D250	17:07:48	9/11/1998	236947.1	904037.4	42.3859697	-71.05131533	1	0
D250N	19:25:51	9/11/1998	236947.3	904082.8	42.38637814	-71.05130964	6	0
D250N2	19:43:50	9/11/1998	236961.6	904125.4	42.38676169	-71.05113399	2	1
D300	16:31:01	9/11/1998	236990.5	904022.5	42.38583368	-71.05078888	1	24
D300N	16:23:46	9/11/1998	237001.4	904071.2	42.38627132	-71.05065352	0	28
D300S	16:38:25	9/11/1998	236971.1	903972.4	42.38538321	-71.0510284	0	18
D350	16:16:31	9/11/1998	237039.9	904021	42.38581802	-71.05018993	0	31
D400	16:08:47	9/11/1998	237085.8	904011	42.38572581	-71.04963293	0	12
D450	15:54:22	9/11/1998	237143.1	904000.1	42.38562441	-71.04893707	0	0
D50	20:35:43	9/11/1998	236745.2	904064	42.3862187	-71.0537651	9	64
D500	15:42:26	9/11/1998	237188.7	903983.3	42.38547163	-71.04838451	5	0
SC1	22:17:22	9/11/1998	236569.8	904089.5	42.38645687	-71.05589436	2	61
SC2	22:05:09	9/11/1998	236572.6	904086.6	42.38642991	-71.05585982	10	78
SC2N	22:31:28	9/11/1998	236590.7	904135	42.3868656	-71.05563707	3	26
SC2S	22:50:33	9/11/1998	236580.6	904042.6	42.38603378	-71.05576521	0	0
SC3	21:56:31	9/11/1998	236600.6	904085	42.38641455	-71.05551977	0	5
SC4	21:47:49	9/11/1998	236617.5	904087	42.38643168	-71.05531478	18	138
SC4-5N	16:44:51	9/12/1998	236640	904130.7	42.38682422	-71.05503901	26	62
SC4-5S	16:55:25	9/12/1998	236626.2	904036.5	42.38597664	-71.05521244	8	48
SC5	21:38:19	9/11/1998	236636.4	904083.1	42.38639541	-71.05508551	28	56
SC6	21:29:47	9/11/1998	236647.8	904080	42.38636706	-71.05494702	0	106
SC7	21:18:55	9/11/1998	236671.3	904073.1	42.38630428	-71.05466232	48	158
SC7N	22:39:47	9/11/1998	236677.4	904117	42.38669921	-71.05458521	7	0
SC7S	20:58:57	9/11/1998	236666	904032.5	42.38593849	-71.05472877	0	4
SC8	21:08:01	9/11/1998	236689.2	904071.4	42.38628778	-71.0544453	0	6
U100	23:12:03	9/11/1998	236445.9	904112.4	42.3866682	-71.05739755	11	28
U150	23:20:46	9/11/1998	236398.3	904117.2	42.38671399	-71.05797432	0	12
U200	13:05:00	9/12/1998	236345.8	904138.8	42.38691108	-71.05861039	282444	38
U200N	15:15:30	9/12/1998	236356.2	904174.1	42.38722784	-71.05848188	249332	24
U200S	16:26:31	9/12/1998	236345.2	904073	42.38631829	-71.05862291	15	24
U250	13:23:29	9/12/1998	236298.6	904135.7	42.38688501	-71.05918439	335650	30
U250N	15:02:51	9/12/1998	236309.9	904185.6	42.38733362	-71.05904452	148410	7
U250N2	14:52:35	9/12/1998	236319.1	904236.9	42.38779548	-71.05892884	0	0
U250S	15:59:53	9/12/1998	236289.5	904092	42.38649247	-71.0592974	7	24
U250S2	16:16:00	9/12/1998	236277.1	904038.8	42.38601338	-71.05945145	8	17
U300	13:41:22	9/12/1998	236248.5	904147.1	42.3869897	-71.05979197	14	22
U300N	14:42:06	9/12/1998	236272.4	904194.9	42.38741936	-71.05949909	0	6
U300S	15:26:23	9/12/1998	236241.4	904099	42.38655709	-71.05988169	5	18
U350	13:51:10	9/12/1998	236203.1	904153.3	42.38704789	-71.06034279	0	10
U400	13:59:42	9/12/1998	236151.3	904163.2	42.38713969	-71.06097099	4	16
U450	14:08:28	9/12/1998	236104.8	904167.3	42.38717866	-71.06153531	30	13
U50	23:02:29	9/11/1998	236495.1	904098.6	42.38654193	-71.05680057	16	25
U500	14:22:51	9/12/1998	236058.8	904180.2	42.38729719	-71.06209312	0	5

Table B-4.
Boston Harbor T32 Survey (26 to 27 September 2002)
Tracer Particle Counts per 0.1 ml Wet Sediment.
Method: Laser Microscopy

Station	Time	Date	Easting	Northing	Lattitude	Longitude	Magenta	Yellow
D100	16:42:49	9/26/2002	236799.7	904054	42.38612575	-71.05310451	2	21218
D150	16:34:50	9/26/2002	236845.5	904046.5	42.38605607	-71.05254808	1	12079
D200	16:18:35	9/26/2002	236891.4	904046.2	42.38605129	-71.05199057	1	82804
D200N	15:33:42	9/26/2002	236897.1	904089.9	42.38644488	-71.05191905	14	31
D200S	15:05:20	9/26/2002	236890.3	903986.6	42.38551478	-71.05200785	11	29
D250	16:11:03	9/26/2002	236944.4	904033.4	42.38593373	-71.0513485	2	28244
D250N	15:43:02	9/26/2002	236950.3	904077.8	42.38633307	-71.05127401	19	41
D250S	15:23:27	9/26/2002	236931.2	903982	42.3854718	-71.05151244	17	38
D250S2	14:55:57	9/26/2002	236926.3	903935.9	42.38505701	-71.0515738	6	10
D300	14:31:14	9/26/2002	236990.5	904024.4	42.38585025	-71.05078901	8	13
D300N	15:59:33	9/26/2002	237001.7	904073.4	42.38629084	-71.05064986	4	4
D300S	14:46:00	9/26/2002	236984.9	903974.5	42.38540173	-71.05085996	2	5
D350	14:21:59	9/26/2002	237038.4	904017.2	42.38578388	-71.05020778	8	9
D400	14:10:40	9/26/2002	237088.4	904006.8	42.38568769	-71.04960138	11	16
D450	14:01:38	9/26/2002	237143	903999.7	42.38562091	-71.04893819	9	10
D50	13:52:44	9/26/2002	236746.9	904065.3	42.38623068	-71.05374413	4	18
D500	16:51:58	9/26/2002	237191.7	903991.1	42.38554135	-71.04834819	12	18
SC1	18:08:23	9/26/2002	236567	904090.8	42.38646871	-71.05592755	16	24
SC2	17:59:13	9/26/2002	236583.5	904091.5	42.38647415	-71.05572787	11	46
SC2N	18:32:33	9/26/2002	236591.2	904140.4	42.38691401	-71.05563017	13	38
SC2S	19:17:49	9/26/2002	236571.3	904042.2	42.38603035	-71.05587878	9	12
SC3	17:51:00	9/26/2002	236601.1	904089.6	42.3864563	-71.05551316	6	21
SC4	18:41:13	9/26/2002	236615.4	904090.2	42.38646041	-71.05534044	1	8
Sc4-5N	19:09:59	9/26/2002	236640.3	904128.7	42.38680656	-71.05503537	15	22
SC4-5S	17:42:03	9/26/2002	236628.1	904033.9	42.38595296	-71.0551899	9	10
SC5	17:30:54	9/26/2002	236635.5	904083.1	42.38639599	-71.05509667	0	15
SC6	17:20:51	9/26/2002	236650.7	904077.8	42.38634739	-71.05491243	2	77
SC7	17:13:00	9/26/2002	236673.8	904076.4	42.38633379	-71.05463175	6	35
SC7N	18:49:53	9/26/2002	236679.4	904125.4	42.3867742	-71.05456003	6	9
SC7S	19:00:42	9/26/2002	236661.7	904027.7	42.38589628	-71.05478117	4	11
SC8	17:02:29	9/26/2002	236692.2	904071.8	42.3862916	-71.05440835	3	7
U100	19:37:25	9/26/2002	236445	904117	42.38670983	-71.05740806	3	14
U150	19:50:26	9/26/2002	236404	904117.5	42.38671616	-71.05790581	6	5
U200	19:58:16	9/26/2002	236349.1	904128.8	42.38682108	-71.05857204	5	15
U200N	15:18:23	9/27/2002	236348.7	904128.4	42.38726	-71.05847	4	13
U200S	20:07:51	9/26/2002	236339.2	904079	42.38637321	-71.05869503	9	16
U250	13:58:32	9/27/2002	236297	904137.4	42.38690084	-71.05920396	5	13
U250N	15:29:02	9/27/2002	236306.8	904187.4	42.3873506	-71.05908156	5	17
U250N2	15:07:33	9/27/2002	236315.8	904235.1	42.38777898	-71.05896923	1	9
U250S	20:30:36	9/26/2002	236293.1	904091.5	42.38648744	-71.05925408	15	27
U250S2	20:20:55	9/26/2002	236278	904037	42.38599786	-71.0594405	9	18
U300	14:12:06	9/27/2002	236250	904141.9	42.38694299	-71.0597742	5	9
U300N	14:57:53	9/27/2002	236260.1	904191.2	42.38738653	-71.05964797	5	10
U300S	20:43:49	9/26/2002	236241.4	904097.4	42.38654323	-71.05988142	10	22
U350	14:22:54	9/27/2002	236202.6	904151	42.38702775	-71.06034974	3	7
U400	14:32:19	9/27/2002	236151.2	904158.9	42.38710053	-71.06097332	8	15
U450	14:44:41	9/27/2002	236102.9	904168.1	42.38718559	-71.06155845	6	3
U50	20:58:37	9/26/2002	236497.7	904103.6	42.38658691	-71.05676844	1	3
U500	19:29:39	9/26/2002	236055.5	904177.9	42.38727655	-71.06213432	6	8

Table B-5.
Transit Dates for the Liquid Natural Gas (LNG)
Carrier *M/V Matthews* During the Study Period

Inbound	Outbound
27 August 2002	28 August 2002
8 September 2002	9 September 2002
17 September 2002	19 September 2002
25 September 2002	27 September 2002

INDEX