PROVIDENCE RIVER AND HARBOR MAINTENANCE DREDGING PROJECT – SUMMARY AND LESSONS LEARNED

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ABSTRACT

The Providence River and Harbor Maintenance Dredging Project (PRHMDP) was an extensive dredging project designed and implemented to address the increasing navigational constraints within the principal commercial waterway in Rhode Island. Project planning began in 1994, and the main project was completed in 2005. The project included removal of over 4.4 million cubic meters (5.8 million cubic yards) of dredged material, which necessitated identification of disposal options for sediments of varying quality. Both confined aquatic disposal (CAD) cells and an offshore site were developed and used for sediment disposal during the project.

An Environmental Impact Statement (EIS) was prepared to identify and evaluate dredging and disposal options to minimize environmental impact while achieving the goals of the project. The EIS included extensive predictive modeling to support assessment of potential impacts of dredging and disposal on marine resources. Extensive environmental monitoring was performed during and following PRHMDP dredging and disposal operations. Monitoring was conducted to fulfill the requirements of the Water Quality Certification and the environmental monitoring plan developed for the project and included sequential bathymetric surveys, sediment-profile image surveys, sediment grabs, water column surveys, and fisheries and lobster studies.

Environmental concerns related to the dredging and particularly the disposal of dredged material extended the assessment of the project and delayed implementation for many years. However, through careful planning and execution, environmental impacts of this large project were either avoided or minimized, and it was considered successful by all metrics. Monitoring results did not identify any observed field conditions that were substantially outside the model predictions developed during the evaluation phase. Recommendations include use of flexible, adaptive monitoring approaches on future projects to achieve more efficient and effective monitoring surveys once system behavior is understood and initial assumptions are confirmed.

Keywords: Dredging, CAD cells, Navigation, Offshore disposal, Monitoring, Rhode Island

INTRODUCTION

The Providence River and Harbor Maintenance Dredging Project (PRHMDP) was an extensive dredging project designed and implemented to address the increasing navigational constraints within the principal commercial waterway in Rhode Island. Project planning began in 1994, and the main project was completed in 2005. The project included removal of a large volume of dredged material, which necessitated identification of disposal options for sediments of varying quality. An environmental impact study was undertaken to identify and evaluate dredging and disposal options to minimize environmental impact while achieving the goals of the project. This paper provides an overview of the project, a summary of the environmental studies performed prior to, during, and after the project, and an analysis of the results and potential implications for future projects.

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The Federal Navigation Project, a 27 kilometers (16.8 mile) long channel, begins near the head of Providence Harbor in northern Rhode Island and follows the Providence River on a southerly course (Figure 1). Providence River and Harbor together constitute the principal commercial waterway in Rhode Island. The primary purpose of the PRHMDP was to restore the navigation efficiency in the Federal channel and safety of the Providence River Shipping Channel for deep draft vessels that currently transit the project area. To restore the Federal channel to its authorized dimensions, an estimated 3.3 million cubic meters (4.3 million cubic yards (mcy)) of material needed to be removed. In addition, 27 non-Federal projects were dredged while the Federal project was undertaken, making use of the disposal sites selected for the Federal project and adding approximately 248,495 cubic meters (325,000 cubic yards (cy)) of additional material that was removed.

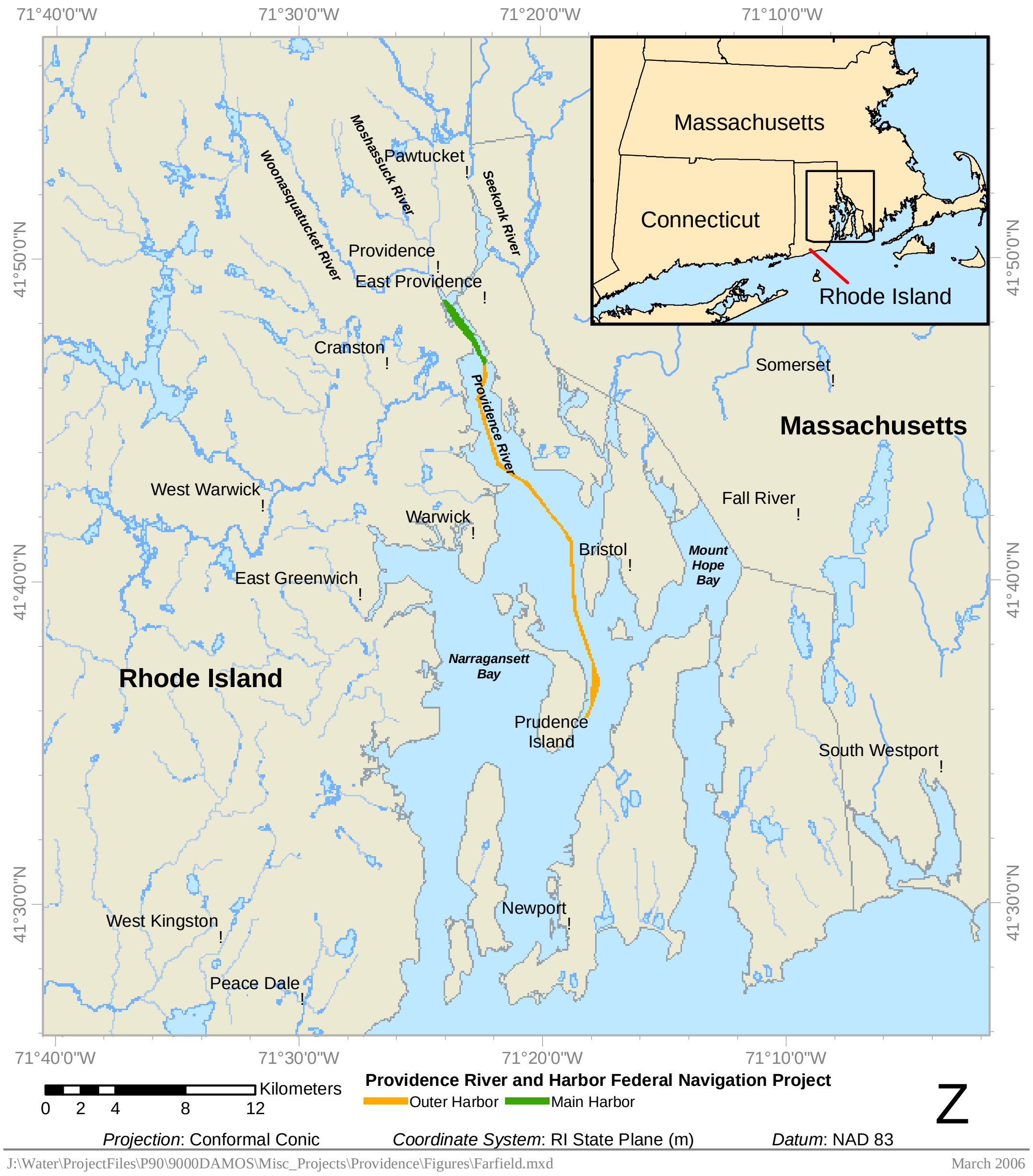


Figure 1. Providence River and harbor maintenance dredging project in Narragansett Bay

EIS DEVELOPMENT

Public concerns regarding the PRHMDP were raised during the scoping process and in response to the publication of the draft Environmental Impact Statement (DEIS) in August 1998 (USACE 1998). Concerns generally fell into three main categories: dredging, disposal alternatives, and potential environmental impacts. Dredging concerns involved the timing of the dredging to minimize impact on the biological community and the extensive size of the dredging project. A substantial effort was undertaken to evaluate the need for and effectiveness of environmental windows and sequencing to time the dredging operations to minimize impact. The second dredging concern, the size of the project, was addressed by assessment of four alternatives to the original project size with dimensions smaller than the congressionally-authorized project. Upon further analysis, the Corps of Engineers concluded that the full project dimensions, with some minor reductions in the area of dredging, best served the needs and goals of the project. Concern over disposal location alternatives resulted in extensive screening and evaluation of both upland and open water sites. Ultimately, Rhode Island Sound Disposal Site (RISDS) was designated as a new open water disposal site, and in-channel confined aquatic disposal (CAD) cells were established for disposal of material not suitable for open water disposal. Environmental concerns related to potential water quality and fisheries impacts were addressed by several modeling and field studies to fully evaluate potential environmental impacts.

Predictive Modeling

Predictive modeling was performed as part of the EIS to support assessment of potential impacts of dredging and disposal operations on marine resources, primarily focused on predicting total suspended solids (TSS) in the water column in the vicinity of the operations. Predictive models were developed and applied to site-specific data, and water column TSS concentrations were predicted for a range of potential conditions and/or scenarios. These model results were used to compare impacts on aquatic biota for the various alternatives. The models generally incorporated conservative assumptions, so that predicted TSS concentrations were likely the upper bounds of what could be expected. In general, model results indicated that TSS concentrations declined rapidly with distance from the operation, and upon cessation of the operation, predicted water quality returned quickly to ambient conditions. During dredging and disposal operations, monitoring data were collected and later compared to model results.

Windows and Sequencing

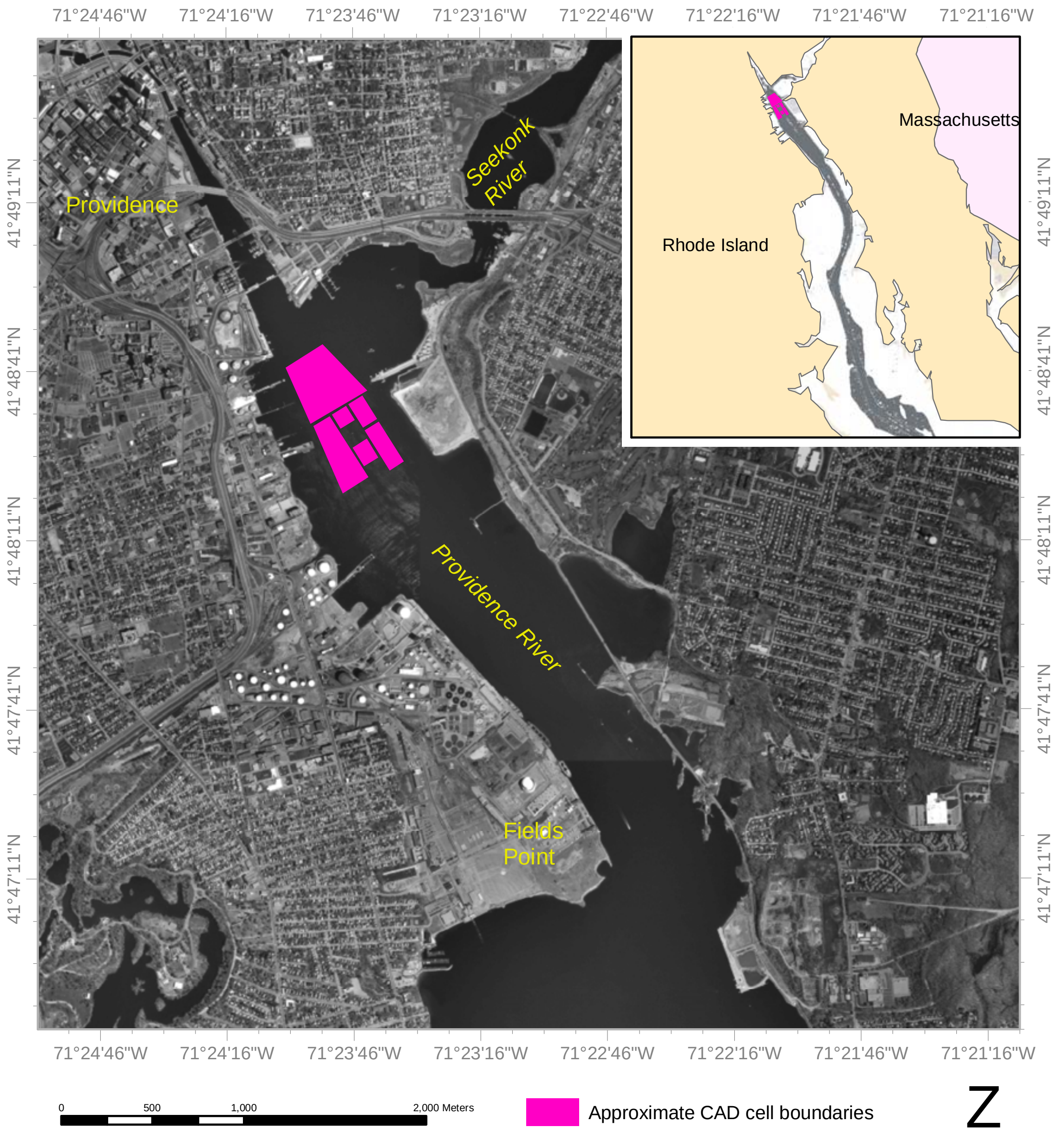
Environmental windows and sequencing are management practices used during dredging projects to help protect marine resources and limit potential environmental impacts. Environmental windows are implemented to avoid dredging during periods when sensitive life history stages of marine organisms are likely to be present and significantly affected by sediments suspended during dredging and disposal operations. Environmental sequencing allows dredging to occur continuously, but the dredging is scheduled to avoid particular areas during time periods when sensitive marine organisms are abundant.

Extensive predictive modeling of dredging and disposal impacts on water column TSS and an assessment of impacts to aquatic organisms due to dredging indicated minimal impacts due to the operations. Sequencing was determined to be a feasible alternative to strict windows for PRHMDP due to the long length of the dredging area (7 miles) and the differences in surrounding habitats along the different reaches. Sequencing of dredging operations was selected as an appropriate means to protect marine organisms. A sequencing scheme was developed during project planning to avoid winter flounder larvae and spawning areas, a shellfishing area, and quahog spawning habitat during critical times of the year.

DREDGING AND DISPOSAL OPERATIONS

Dredging to support the PRHMDP commenced in April 2003 with CAD cell construction and continued generally around the clock through January 2005. A total of 3.8 mcy of maintenance material was dredged from the project area. In addition, 1.5 million cubic meters (2.0 mcy) of native parent material was dredged to create the CAD cells. In the project planning phase, the sediments to be dredged were evaluated in accordance with Section 103 of MPRSA to determine suitability for unconfined open water disposal. All maintenance material was determined to be suitable for open water disposal into RISDS, with the exception of 0.9 million cubic meters (1.2 mcy) of unsuitable material that was disposed in the CAD cells.

CAD cells were constructed below the channel at the head of Providence Harbor in order to sequester the dredged material determined to be unsuitable for unconfined open water disposal (Figure 2). In order to build cells sufficiently large to contain all of the unsuitable maintenance material from the project, a series of smaller cells were constructed first. The surficial material removed during initial clearing of the CAD cells was unsuitable for unconfined open water disposal and was temporarily stored in barges until it was placed into completed cells.



Projection: Conformal Conic *Coordinate System*: RI State Plane (m) *Datum*: NAD 83

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Figure 2. Location of CAD cells within Providence River

Maintenance dredging was executed according to the sequencing designed to minimize impacts to biological resources in each reach. The majority of the maintenance dredging occurred from February 2004 through January

2005. All reaches in the project were dredged to -12.8 m (-42 ft) MLLW. Maintenance material was disposed at RISDS or in the CAD cells, depending on sediment quality.

The CAD cells were originally planned to be capped at the conclusion of the PRHMDP with material determined to be suitable for unconfined open water disposal (USACE 2001). However, due to the limited disposal options for dredged material that is unsuitable for open water disposal or beneficial use, the Rhode Island Coastal Resources Management Council (RICRMC) requested that the CAD cells be left uncapped for several years. At the completion of the dredging in 2005 there was over 305,840 cubic meters (400,000 cy) of additional capacity available. Ultimately, the cells are planned to be capped with suitable maintenance material from State and private projects as cell capacity is reached.

Over the course of the project, approximately 4.4 million cubic meters (5.3 mcy) of dredged material determined to be suitable for unconfined open water disposal was disposed at RISDS. The parent material from the CAD cells was primarily used to develop a continuous ridge of sediment along the western boundary of RISDS to form an artificial berm to increase the capacity of the disposal site and limit the lateral spread of unconsolidated sediment. The suitable maintenance material removed from the project area was directed to a series of disposal points across the site to create a relatively linear deposit. Disposal locations were selected to maximize the settlement of material within the disposal site (SAIC 2004).

ENVIRONMENTAL MONITORING

Extensive environmental monitoring was performed during PRHMDP dredging and disposal operations. Activities included monitoring of maintenance dredging, CAD cell construction, disposal into the CAD cells, disposal at RISDS, and a fisheries study. The monitoring was a combination of that required to fulfill the requirements of the Water Quality Certification for the project, commitments made in the EIS Record of Decision, and associated research. Methods are summarized in this section, and the results are summarized in the discussion section below. For a detailed discussion of the monitoring programs and results, see the PRHMDP Synthesis Report (ENSR 2008).

Maintenance Dredging

A study was undertaken by the USACE Engineer Research and Development Center (ERDC) to characterize the spatial dimensions and suspended sediment concentration gradients of plumes generated during maintenance dredging (Reine et al., *in prep.*). Plume characterization data were collected during local dredging at flood tide. Plumes were characterized by deployments of moored optical backscatter sensors (OBS) for turbidity measurements and mobile acoustic Doppler current profiler (ADCP) surveys to map TSS concentration gradients. Current velocity data were also obtained from the ADCP surveys, which allowed for real-time tracking of the plume. TSS was estimated from ADCP data using Sediview Software provided by Dredging Research Ltd. The Sediview Method (Land and Bray 2000) derived estimates of suspended solids concentration in each ADCP data bin by converting relative backscatter intensity to TSS concentration. Plumes were tracked temporally and spatially until they were no longer distinct from ambient conditions.

CAD Cell Construction

Plumes were monitored during CAD cell construction by ERDC (Reine and Clarke, *in prep.*) to provide basic information on plumes associated with CAD cell construction and to make inferences regarding biological impacts. Plumes were characterized using OBS to measure turbidity and ADCP to estimate TSS concentrations. ADCP was also used to collect current velocity data. Monitoring locations included ambient, near-field and far-field stations, as determined by ADCP real time plume signatures. The Sediview Method was used to estimate real time TSS from the acoustic backscatter data. ADCP transects were run repeatedly through the near-field to determine the closest distance to the dredging operations that could be surveyed without interference from air bubbles resulting from the bucket dredging.

Disposal into CAD Cells

The Water Quality Certificate for the project included requirements for monitoring following disposal into CAD cells under a variety of tidal conditions and at various project milestones. Required monitoring included: 1) real-time measurement of turbidity, backscatter and current (using ADCP), temperature, salinity, and dissolved oxygen (DO) to track plume movement and assess water mass movement and water quality; 2) collection of water samples for analysis of TSS during all plume monitoring events; 3) collection of water samples for analysis of copper and silver during all plume monitoring events; 4) collection of water samples for toxicity testing during a subset of the plume monitoring events; and 5) more extensive DO monitoring during summer neap tide disposal events.

Compliance location was established based on the CAD cell location and tide cycle and the results of the predictive modeling. A series of 13 surveys were performed to monitor disposal of dredged material into the CAD cells.

Disposal at RISDS

Various monitoring efforts were conducted at the open water disposal site, RISDS, during and following disposal including characterization of disposal plumes and periodic bathymetric surveys. A post-disposal benthic community survey and assessment of lobster abundance were also conducted at RISDS.

Two sediment plume tracking and assessment surveys were completed over RISDS during disposal operations (SAIC 2005a, SAIC 2005b). Upon disposal of material at RISDS, oceanographic equipment aboard two survey vessels obtained a variety of measurements related to sediment plume formation and subsequent transport (current speed and direction, physical characteristics of the receiving water, turbidity, etc.). A series of optical and acoustic remote sensors were employed for the collection of digital data, while water column samples were obtained for determination of TSS concentrations and toxicity. The overall morphology, transport rate, and diffusion of each disposal plume were monitored until conditions were indistinguishable from ambient conditions.

A series of six bathymetric surveys were performed at RISDS to provide baseline conditions and to document the changes in seafloor topography resulting from dredged material deposition. The survey results were also used to direct disposal locations for berm formation, maintain even distribution of dredged material, and to ensure that pre-established disposal locations resulted in minimal sediment transport outside of the disposal site. The final bathymetric survey illustrated a well defined berm with sufficient remaining capacity in the artificial containment cell.

A benthic survey was performed at RISDS approximately six months following the last disposal event at the site. The survey included SPI, plan view imaging, and sediment grab samples for benthic community analysis (ENSR 2007b). Images and grab samples collected within RISDS were primarily focused on the sediments within the artificial containment cell, where the PRHMDP maintenance material was directed. Stations were also occupied within three surrounding reference areas. The survey was designed to assess benthic recolonization following cessation of disposal, and to compare conditions at RISDS to surrounding, ambient conditions.

A study of lobster abundance was conducted in 2005 to address concerns over the potential effects of dredged material disposal at RISDS on local lobster populations (DAMOSVision 2007). This investigation followed several previous studies of lobster abundance at sites in Rhode Island Sound being considered for dredged material disposal in the PRHMDP EIS process. In 1999, lobster abundance was quantified at three sites under consideration for selection to receive dredged material for the PRHMDP. The site with the lowest lobster abundance was selected for placement of dredged material. The objective of the 2005 study was to examine differences in lobster abundance between the three sites, and compare the 2005 results with those from 1999, in order to assess whether the disposal of dredged material at RISDS resulted in significant changes in lobster abundance.

Fisheries Protection

Sequencing of dredging operations in the PRHMDP was conducted in large part due to concerns for potential impacts to winter flounder (*Pseudopleuronectes americanus*), particularly from dredging-induced sediment deposition during the sensitive life stages of eggs and larvae adjacent to the channel. Little is known about the effects of dredging on winter flounder egg survival and hatching. In an attempt to provide more information on which to base decisions for future dredging projects, laboratory and field studies were conducted by USEPA's Narragansett Laboratory and University of Rhode Island Graduate School of Oceanography in association with PRHMDP, including comparing egg survival between dredging and background conditions and evaluation of sedimentation on hatch success.

DISCUSSION

The PRHMDP was performed with no violations of State Water Quality Criteria and no observed significant impact to the marine environment. The project was also completed within the scheduled time and budget. Predictive modeling was performed as part of the EIS to gauge potential impacts, and extensive monitoring was performed during implementation of the project. This section provides a comparison of the predictive modeling with the field measurements as well as discussion of other relevant aspects of the project.

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Dredging

General Performance

The dredging for CAD cell construction and the maintenance dredging of channels that were part of the PRHMDP were performed according to plans and met the needs and expectations of the project. The sequencing, while causing some scheduling difficulties for the dredging contractor, allowed the dredging to continue in an efficient manner with nearly all of the dredging performed within the preferred sequence periods, minimizing environmental impacts.

Sediment plumes observed during maintenance dredging consisted of relatively narrow bands of elevated suspended sediment concentrations that decayed rapidly with increasing distance from the dredging operation. TSS concentrations as high as 1000 mg·l^{-1} were found in the near field adjacent to the dredge. Once at steady state, the suspended solids plumes extended vertically throughout the water column adjacent to the dredge, but the surface component dissipated within 152.4 m (500 ft) of the dredging. Moving down-current, the highest TSS concentrations were found in a central core less than 48.8 m (160 ft) wide within the bottom 2.1 to 3.05 m (7 to 10 ft) of the water column. The plumes were generally detectable against background conditions to a width of 152.4 m (500 ft) and to a maximum distance of 914.6 m (3000 ft) from the dredging.

Sediment plumes generated by the dredging associated with CAD cell construction also dissipated rapidly, resulting in the bulk of re-suspended sediments settling inside the CAD cell. Maximum observed TSS concentrations exceeded ambient conditions by as much as 250 mg·l^{-1} in the near-field (<106.7 m, 330 ft). These occurrences were largely limited to depths greater than the natural channel bottom within the CAD cell itself. Plumes were detectable within 487.8 m (1600 ft) of the dredging operation. These plumes traveled less distance than the maintenance dredging plumes, due in part to slower flood and ebb currents during the CAD cell construction surveys and also attributed to the coarser nature of the native material being dredged.

Comparison with Model Predictions

Appendix L of the FEIS (USACE 2001) presented the results of the modeling study that was performed to predict the extent and duration of sediment plumes resulting from dredging within the Federal Navigation Channel. A hydrodynamic model (WQMAP) was applied to generate representative current patterns in Providence River and upper Narragansett Bay. These currents were used as input to SSFATE, a suspended sediment fate and transport model, to predict TSS throughout the water column resulting from dredged material released within the channel. Predictions of dredged material released at three locations were developed for a range of release rates, selected to represent different types of buckets and barge filling processes. The release rates ranged from 1.5 to 4% of the total dredged material removed.

The model predicted the highest TSS concentrations at depth in the water column, with TSS concentrations decreasing quickly with distance from the simulated dredging operation (Table 1). Maximum TSS concentrations predicted at the location of the simulated dredging operation ranged from 22 to 150 mg·l^{-1}, depending on release rate and release location. The model predicted TSS concentrations decreased by 50% within 150 m, and by 66% within 300 m of the simulation dredging operation.

Table 1. Maximum predicted TSS concentration during maintenance dredging

	Fox Point Reach		**Bullock Point Reach**		**Rumstick Neck Reach**	
Location	**Maximum TSS (mg·l$^{-1)}$**	**Depth of Maximum TSS (m)**	**Maximum TSS (mg·l^{-1})**	**Depth of Maximum TSS (m)**	**Maximum TSS (mg·l^{-1})**	**Depth of Maximum TSS (m)**
300 m up-river	16-39	9	5-14	7	15-41	9
150 m up-river	22-59	9	13-35	9	19-51	9
Source	54-150	11	27-53	7	22-60	9
150 m down-river	14-35	5-7	9-18	9	13-35	7
300 m down-river	12-30	1	8-15	9	8-21	9

To assess the utility of the model approach used in the FEIS, the model-predicted TSS was compared with the observed TSS and turbidity for maintenance dredging activities. In order to compare the results, the observed turbidity data were transformed to TSS and the model results scaled to the actual dredging activities recorded during the project.

Monitoring activities of channel maintenance dredging included ADCP, turbidity and TSS data collection. Grab samples of TSS were used to convert ADCP backscatter and turbidity measurements to TSS (Land et al. 2007). Based on these data, a correlation between TSS and turbidity was developed. The observed data presented in the report as turbidity were converted to TSS based on this correlation. The conversion from turbidity to TSS allowed for direct comparison of the observed and the modeled data.

In order to compare modeled and observed data, it was necessary to compare dredging operations and conditions (simulated and actual) to ensure that the two sets of data were comparable. This comparison indicated that some of the assumptions applied in the modeling were different than actual operations. The modeled production rate was based on an estimated rate specified by the USACE New England District, while the actual production rate, calculated from field observations, was much higher. Similarly, a range of release rates were assumed for the model, assumed to be representative of different bucket types and operation protocols, while the observed release rate derived from a regression analysis of the TSS data indicated a higher release rate.

The modeled sediment release rates were 9 to 24 times lower than the release rate derived from the regression analysis of the observed data. However, analysis of the model results indicated that the predicted TSS concentration approximately scaled linearly with release rate (FEIS, App L of App D, USACE 2001). Therefore, to compare the observed with the modeled values, the model results were scaled so that the release rates were equivalent (by multiplying the predicted values for the highest release rate by a factor of 9).

The observed and scaled (to account for actual release) predicted TSS concentrations resulting from channel dredging were very comparable (Table 2 and Figure 3). Observed concentrations in the immediate vicinity of the dredging operations were on the same order of those predicted by the scaled SSFATE model results, whereas the footprint of the observed plumes was smaller than predicted. The plumes were only observed in the deepest portion of the channel, and did not spread to the shallower areas adjacent to the channel as predicted. The down-current extent of the observed plume was also generally less than that predicted by the model.

Table 2. Comparison of observed and predicted TSS concentration following maintenance dredging

Observed			Predicted			
Distance to Dredge (m)	**Depth (m)**	**Max observed TSS (mg/L)**	**Distance to Dredge (m)**	**Depth (m)**	**Max Predicted TSS (mg/L)**	**Scaled Max Predicted TSS (mg/L)**
134	6	346				
			150	9	35	315
201	6	167				
			300	7	14	126
			300	9	15	135
351	6	126				

Because of the underestimate of the source strength, the model predictions of TSS in the water column in the vicinity of the operation presented in the FEIS were lower than the observed values. This comparison of predicted and observed TSS resulting from dredging operations demonstrates the importance of accurate estimates of source strength in the prediction of TSS plumes.

Biological Impacts

The primary biological concern for the dredging area that was identified in the EIS was potential impacts to flounder egg hatching success. The dredging sequencing was orchestrated to avoid dredging and disposal in areas where and at times when eggs and larvae were thought to be plentiful. Thus, it was expected that this biological resource was not negatively impacted by the PRHMDP. However, because impacts of dredging and disposal on flounder egg hatching success are poorly understood, laboratory and field studies were conducted, largely to provide information on which to base future decisions about dredging sequencing on projects with similar biological concerns. The laboratory experiments conducted by Berry et al. (2004) demonstrated the potential for impacts to hatching success of winter flounder (*Pseudopleuronectes americanus*) eggs following exposure to fine-grained sediments. The monitoring results of suspended solids generated by the dredging indicated that the dredged material footprint was less than predicted, as discussed above, reducing the potential for depositional impacts. However, the amount of sediment deposition resulting from the dredging operations on a time scale that may impact hatching is poorly understood, thus limiting the ability to extrapolate the results of the laboratory studies to the PRHMDP. In order to better apply the laboratory results, modeling or monitoring of such deposition may be useful for future projects with similar fisheries concerns.

In a related field study, winter flounder eggs deployed adjacent to dredging operations did not display any hatching impacts relative to eggs deployed at a background location (Klein-MacPhee et al. 2004). The limited potential for impacts indicated by the water column and biological monitoring, coupled with the sequencing of dredging operations around active winter flounder spawning periods, support a conclusion that impacts to this species were effectively minimized.

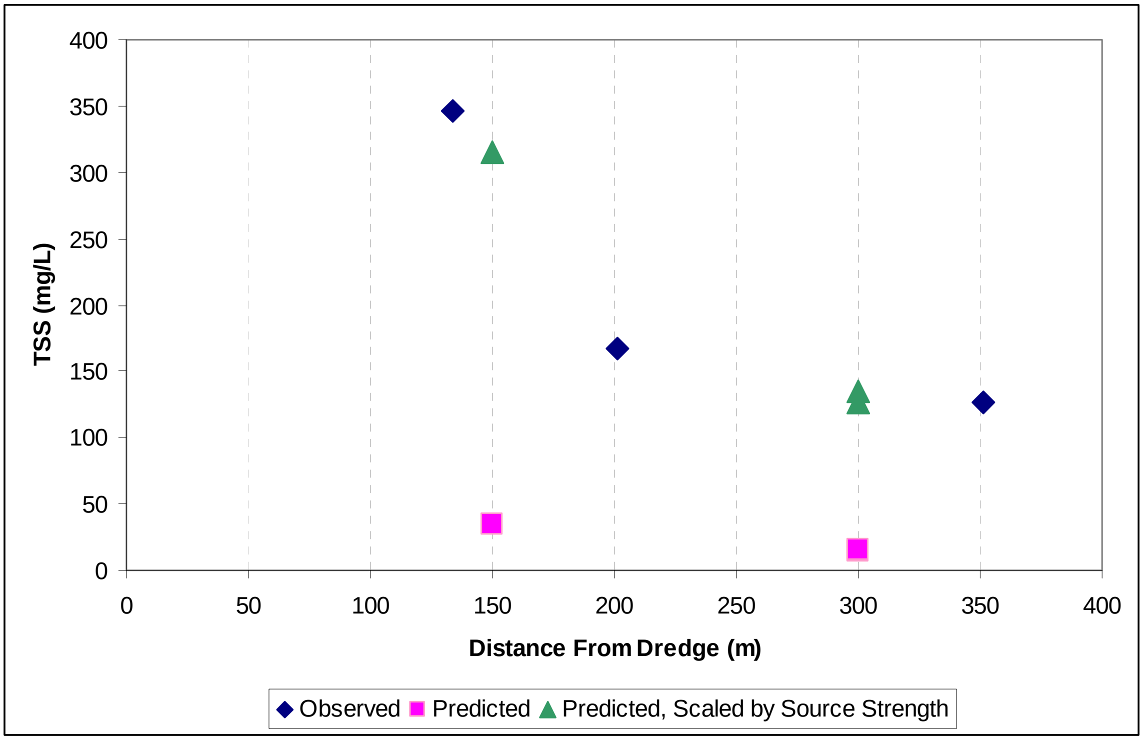

Figure 3. Modeled and observed TSS during maintenance dredging operations

Disposal into CAD Cells

General Performance

Dredged material unsuitable for open water disposal was placed into the CAD cells constructed within the Providence River Federal Navigation Channel. The CAD cells proved to be stable structures, providing sufficient space for the placement of dredged material unsuitable for open water disposal. The size, depth, and side slopes of the cells allowed for successful disposal, with no apparent transport of material out of the cells during or following placement.

Eleven separate monitoring surveys were performed to track suspended solids plume formation and transport related to the disposal as specified in the Water Quality Certification for the project. The plumes were generally not discernable by real-time measurements of acoustic or optical backscatter at the Water Quality Certification specified compliance point 457.3 m (1500 ft) down-current of the disposal (i.e., the outer boundary of the mixing zone), and TSS concentrations generally fell to within a factor of two above background levels at this distance down-current. Thus, similar to suspended solids plumes generated by dredging, plumes from disposal into the CAD cells were generally limited to the near-field (i.e., less than 457.3 m (1500 ft)). However, unlike the dredging plumes, those related to the disposal were transient, given the single pulse input of suspended solids during disposal.

Given the low intensity of the disposal plumes, the suspended solids were not likely to have negatively impacted resident biota beyond the immediate vicinity of the disposal. Analysis of water samples collected in each of the 11 surveys for dissolved silver and copper at the 457.3-m (1500-ft) down-current compliance location did not identify any disposal related increases in concentration of these parameters. Further, sampling for toxicity testing (performed during four of the surveys) did not identify water column impacts at the 457.3-m (1500-ft) down-current location. Dissolved oxygen measurements performed during each survey as well as during two dedicated surveys during neap tide periods with lower levels of tidal flushing did not identify any disposal related impacts. Taken together, the real-time and analytical measurements demonstrated that the disposal operations did not result in significant negative environmental impacts for the measured parameters outside of the near-field mixing zone.

Comparison with Model Predictions

A numerical model was applied to predict the depositional footprint and resulting suspended sediment concentrations in the water column resulting from disposal of dredged material into the CAD cells (FEIS, Appendix L and Appendix P, USACE 2001). STFATE (Short Term Fate) is a numerical model developed to simulate the dynamics of dredged material disposal plumes resulting from disposal from a split-hull barge in open water. STFATE predicts release dynamics and physical mixing and contaminant dilution during the first few hours after the release of dredged material into the water column based on what is known about 1) the disposal operation, 2) the ambient physical conditions at the release site, and 3) the physical characteristics of the dredged material.

The STFATE model simulations were performed on a 15.2-m (50-ft) resolution grid centered on the disposal site. A worst-case velocity profile was selected to simulate spring tide currents that would result in the maximum expected extent of plume transport. A series of STFATE simulations were run to predict TSS for various sediment types and for various barge volumes. STFATE modeling predicted TSS to be as high as 1000 $mg \cdot l^{-1}$ immediately after release. Concentrations were predicted to decline to 30 $mg \cdot l^{-1}$ above background one hour after release. Over the next four hours, concentrations were predicted to decline from 30 $mg \cdot l^{-1}$ to 2 $mg \cdot l^{-1}$ above background. The results for two model runs with the likely range of sediment physical characteristics one to four hours after release are presented in Table 3 and Figure 4. These STFATE estimated concentrations assume that no dredging-induced plume was present in the reach at the time of disposal.

Table 3. Maximum predicted TSS concentration following disposal into CAD Cells (6000 cy Release)

	TSS ($mg \cdot l^{-1}$)	
Time (hr)	**60% clumps, 30% free water**	**80% clumps, 30% free water**
1	30	21
2	7	5
3	4	2
4	2	2

When compared with observed data, the STFATE model results over predicted water column TSS concentrations from disposal into the CAD cells. The model predicted a discrete plume one hour following disposal with central concentrations of 50-100 $mg \cdot l^{-1}$ with concentrations returning to near background approximately three hours following disposal (Figure 5, lower left panels). ADCP acoustic backscatter data for a representative sampling event revealed a distinct signature just down-current of the disposal cell shortly after the disposal event, but by one hour following the disposal, the acoustic signal had diminished and remained in the same location (Figure 5, right panel). By 1.5 hours following disposal, the acoustic signal diminished further with limited movement down-current. Although the predicted TSS concentrations (left panel, Figure 5) are in $mg \cdot l^{-1}$ and cannot be directly compared with the observed backscatter (dB) (right panel, Figure 5), samples collected during this and the other surveys indicate that TSS concentrations were approaching background levels by one hour after disposal, with only remnants of a discernable plume.

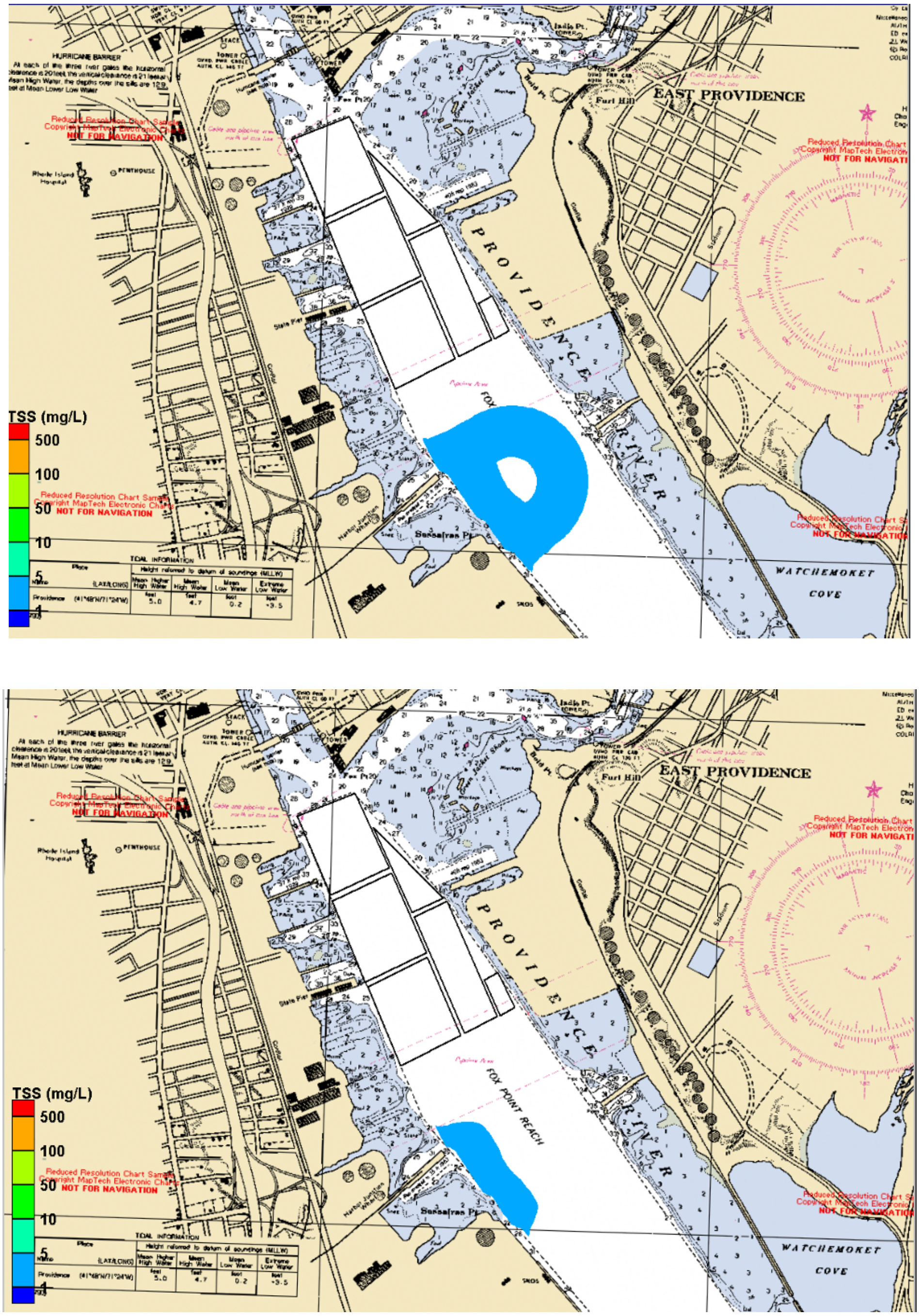

Figure 4. Predicted distribution of TSS concentration following disposal into CAD cells (6000 cy release, four hours after release (60% clumps and 30% free water [upper] and 80% clumps and 30% free water [lower]). CAD cell footprint shown is an earlier plan (Figure from USACE 2001).

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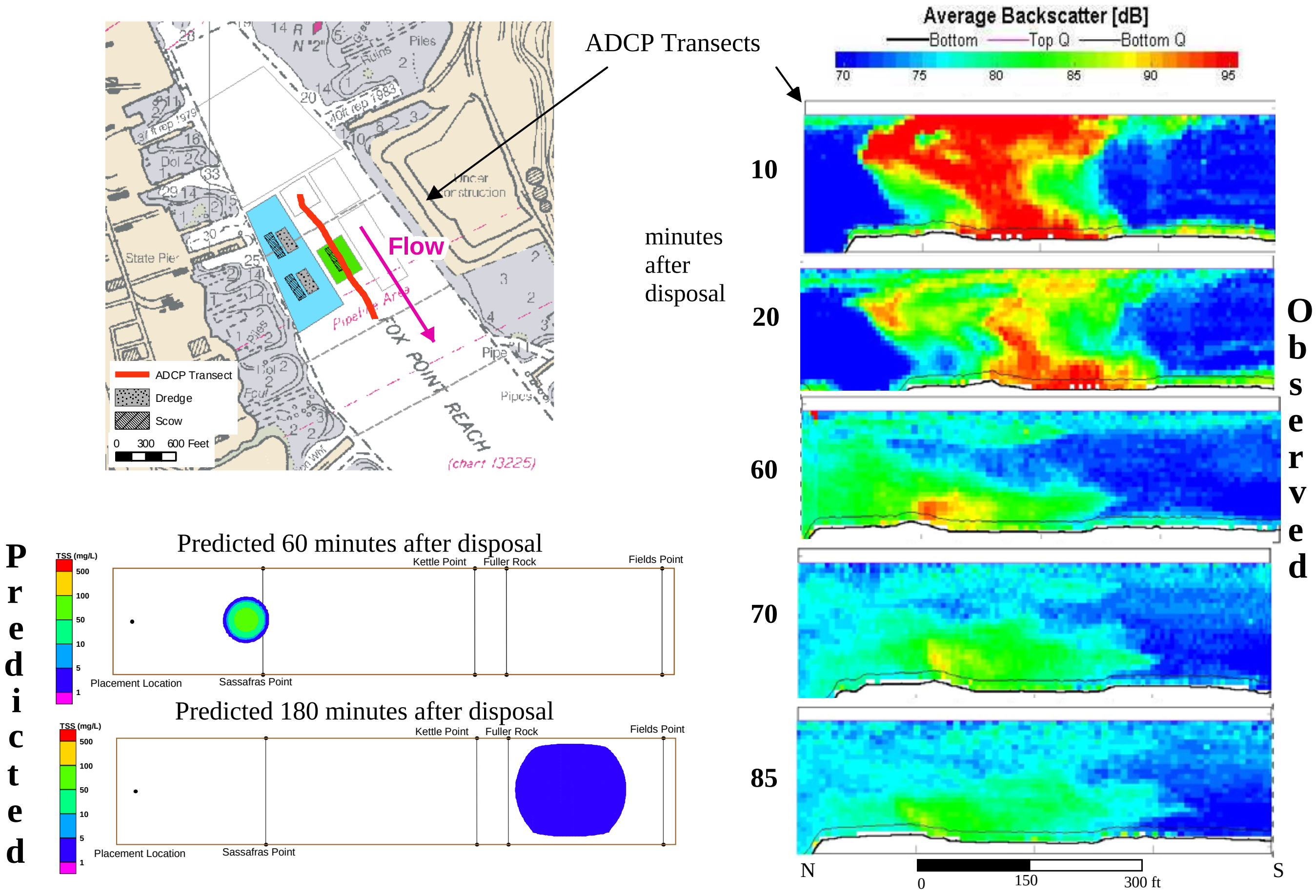

Figure 5. Comparison of predicted and observed TSS following disposal into a CAD cell. Map (upper left) shows location of ADCP transects. Model predictions (lower left) extend approximately 8500 ft and observed backscatter (right) extend approximately 700 ft from disposal location (Figure of model predictions from USACE 2001, App. P).

Reductions in dissolved oxygen concentrations resulting from disposal were predicted using two methods described by ERDC (USACE 2001). In the EIS, these estimates were applied to open water disposal but are compared to CAD cell disposal here for illustrative purposes. The first method uses the relationship between biological oxygen demand (BOD) and volatile solids concentrations to estimate reduction in dissolved oxygen. The second approach assumes that oxygen is a short-term phenomenon related to the chemical reaction of the most frequently encountered, readily oxidizable chemical compounds found in most marine and estuarine sediments (*i.e.*, ferrous iron and free sulfides). For the BOD method, BOD data from Haverstraw Bay on the Hudson River were used and were expected to be very conservative. Suspended solids concentration and residence time used in the calculation were conservative estimates from the STFATE modeling for open water disposal. For the second approach, ferrous iron and free sulfides data from an adjoining embayment (O'Sullivan et al. 1997) were used. The first approach yielded the largest reduction in dissolved oxygen: a 0.4 mg·l^{-1} reduction for a 3058.4 cubic meters (4000 cy) barge and a 0.6 mg·l^{-1} reduction for a 4587.6 cubic meter (6000 cy) barge. These reductions are small relative to the absolute values measured during the CAD cell disposal monitoring events (6 to 7 mg·l^{-1} near the surface to 3.5 to 4.5 mg·l^{-1} near the bottom of the water column for two events). Nonetheless, as anticipated, the predicted reductions were conservative relative to observed, since no change in DO following disposal was detected.

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Adaptive Approach to Monitoring

The disposal monitoring defined in the Water Quality Certification was extensive in both the scope of individual efforts as well as the number of required monitoring events. Given the thoroughness of the monitoring and short turnaround for completion of summary data reports, it was evident after several monitoring events that the predictive modeling was conservative, providing over-estimates of potential water column impacts under the specified disposal conditions. The monitoring program could have benefited from an adaptive approach rather than that stipulated in the Water Quality Certification. Such an approach could have assigned technical review of the data to an independent group charged with recommending modifications to the monitoring program. This adaptive approach could have reduced the overall cost of monitoring and/or allowed for re-evaluation of how to best use the monitoring resources. For example, as it became apparent that there was limited far-field transport of suspended solids following disposal into the CAD cells and that compliance with water quality standards was not an issue, the subsequent required monitoring could have been refocused to investigate plume dynamics in the near-field area. Such supplemental data could be helpful for refining modeling input parameters for future projects.

Disposal at RISDS

General Performance

The selection of RISDS as an open water disposal site took advantage of a natural depression on the seafloor to decrease the spread of material placed at this location. Parent material removed during the construction of the CAD cells was placed to form a berm to augment the capacity of the natural depression. Monitoring surveys performed during and following disposal at RISDS indicated that the majority of the material placed at the site remained within the site boundaries. It is recognized in the designation and management of open water disposal sites that the site boundary defines the location at the water's surface in which sediment disposal is permitted, and that during descent and the lateral bottom surge some dredged material may extend across the boundary on the seafloor.

Although oceanographic conditions were markedly different at RISDS compared to Providence Harbor (e.g., water depth, currents), the observed sediment plumes behaved similarly. TSS concentrations were highest at the bottom of the water column, and plumes dissipated relatively quickly. Greatest concentrations (up to 111 $mg \cdot l^{-1}$) were found 2.1 to 5.2 m (7 to 17 ft) above the seafloor. Plumes were detectable within the water column for the entire duration of the study (three to four hours). However, by the time the plumes exited RISDS (30 to 180 minutes post-disposal), TSS concentrations were generally less than two times ambient concentrations.

Comparison of Model Predictions and Monitoring

The STFATE model was used to predict TSS concentrations resulting from open water disposal at RISDS at various times, depths and distances from the disposal point (Appendix P, FEIS, USACE 2001). Field data, including bathymetry, current measurements, and sediment characterization, were collected to characterize the site and develop model input parameters. Variables that were analyzed included: 1) range of disposal scow sizes (dimensions were developed from actual scows available for use on the project); 2) current and wave conditions; 3) sediment characteristics; and 4) effects of overtopping.

The potential effects of elevated TSS concentrations due to dredging and disposal were assessed by comparing expected concentrations to normal background concentrations and typical episodic concentrations. Model predictions showed that TSS concentrations were expected to return to near-background levels within three to four hours after disposal (Table 4). For the largest scow modeled, the predicted plume was small relative to the disposal site boundary and generally remained within the boundary of the site (Figure 6).

Table 4. Model predicted maximum TSS concentrations at RISDS

Time (hr)	TSS ($mg \cdot l^{-1}$)
0.5	500
1	130
2	15
3	5
4	3

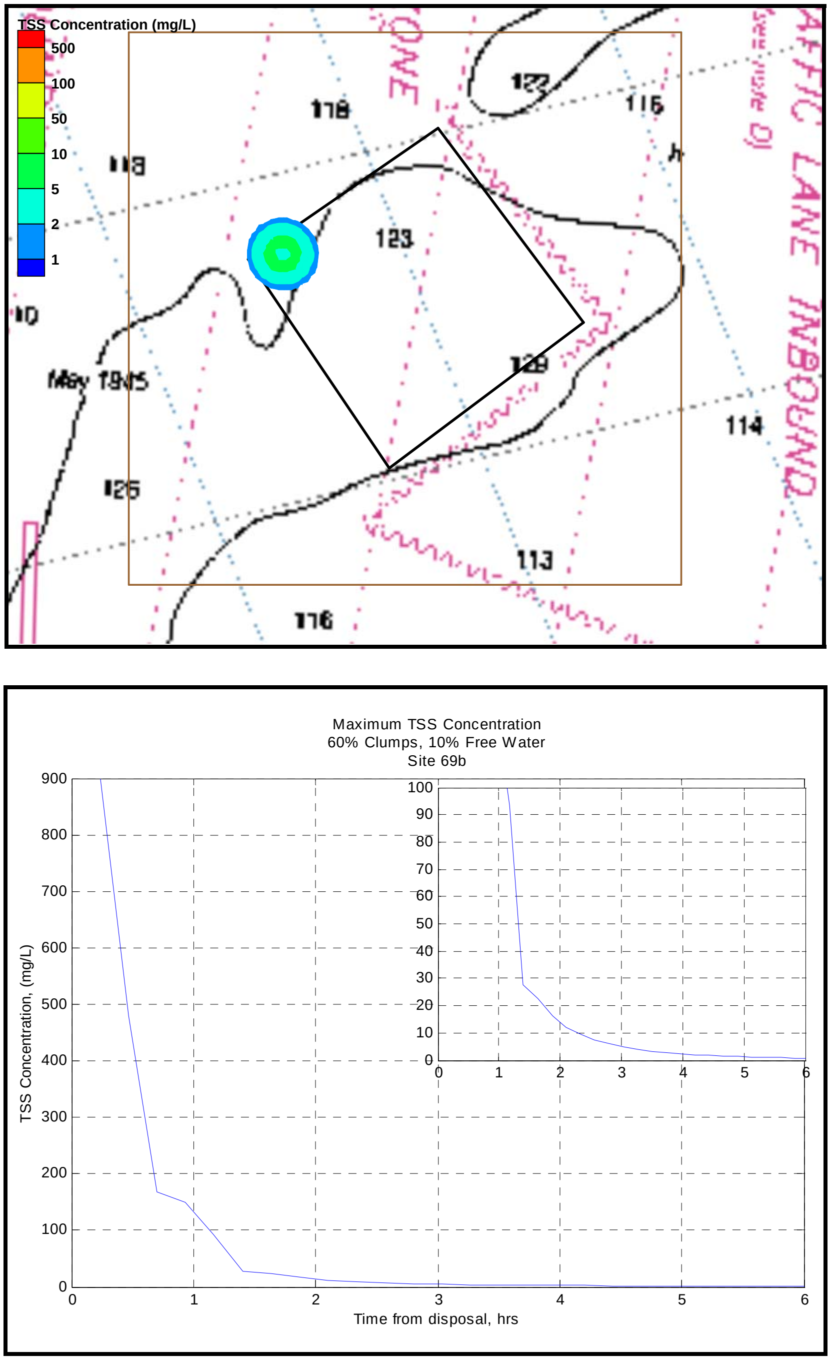

Figure 6. Predicted TSS at RISDS for 4587.6 cm (6000 cy) placement at t=4 hrs (upper figure) and maximum concentration over time (lower figure). Inset in lower figure is an enlargement of TSS concentrations over time from 0 to 100 (Figure from USACE 2001).

The STFATE model results for disposal at RISDS over-predicted TSS concentrations in the first one to two hours following disposal, when compared to observed concentrations of the three plumes that were monitored (Figure 7).

The TSS concentrations observed at or near the plume centroid during the first 90 minutes of each plume monitoring survey were approximately 10% of those predicted by STFATE. The dissimilarity between the model and survey results for the early stages of each sediment plume could be due to a mismatch between modeled and actual sediment properties or the inability to monitor the actual centroid of the plume immediately following disposal, where TSS levels would be highest. However, it may also be a reasonable representation of over-prediction by the model.

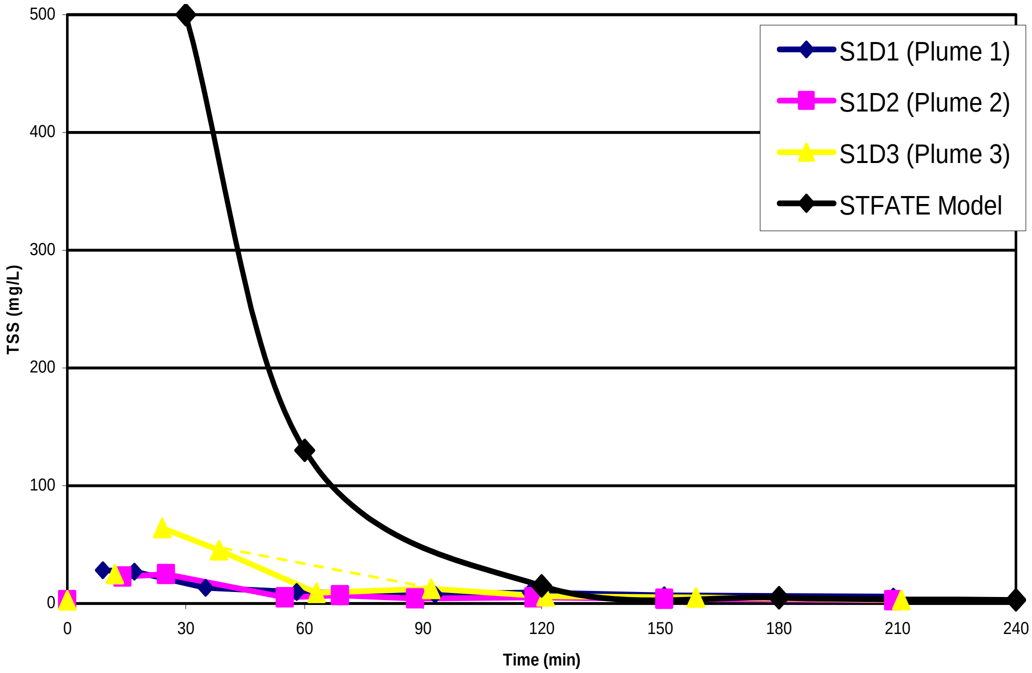

Figure 7 Comparison of predicted (STFATE model) and observed TSS concentrations for discrete water samples collected during CTD profiling operations for RISDS plume monitoring in comparison to TSS concentrations predicted for the disposal of 4587.6 cubic meter (6000 cy) of dredged material (Figure from SAIC 2005a).

Biological Impacts

A series of biological monitoring events were performed at the RISDS as part of the DAMOS Program designed to track disposal and benthic recovery at open water sites (SAIC 2004, ENSR 2007b, DAMOSVision 2007). The EIS evaluation predicted that following disposal RISDS would be rapidly recolonized by pioneering Stage I and II benthic organisms, primarily surface-dwelling tubicolous polychaetes and amphipods (USACE 2001). Over time, the site would advance to a more stable, head-down deposit-feeding community (i.e., Stage III). A survey of the artificial containment cell conducted six months following the last disposal event at the site confirmed the EIS predictions. The RISDS benthic community was comprised primarily of Stage II organisms, with some Stage III infauna. The infauna on the disposal mounds were represented by fewer species, fewer individuals and lower species diversity compared to the reference areas. However, the benthic community was typical of an area six months following disposal. Recovery is expected to continue until the benthic community within RISDS begins to resemble that found in the surrounding ambient sediments.

Analyses conducted for the EIS predicted that disposal at RISDS would have less negative impact on local lobster populations than if disposal occurred at the other sites considered (USACE 2001). It was predicted that the site would be of limited use to lobsters for at least several months following disposal until the sediments consolidated and the site was recolonized by benthic organisms. The lobster survey conducted seven to nine months post-disposal indicated that the local lobster population did not appear to be negatively affected relative to those of other areas of Rhode Island Sound. Relative abundance at RISDS compared to two nearby sites in Rhode Island Sound showed no evidence of disposal impacts. Statistical comparisons indicated no significant changes in lobster abundance or size at RISDS between 1999 and 2005 that were unusually strong or anomalous compared to the changes observed at the other two sites over the same time period. Thus, post-disposal monitoring indicated that the recovery of the local lobster population occurred in the timeframe predicted in the EIS. There was, however, an overall decrease in lobster abundance at all three sites from 1999 to 2005, consistent with a longer term trend of decreasing lobster abundance in southern New England.

Capping of CAD Cells

At the completion of the PRHMDP, capacity remained in the CAD cells for additional material not suitable for reuse or unconfined open water disposal. Therefore, the decision was made by the State not to cap the CAD cells at that time, but rather leave them open to receive additional material from future dredging projects. The CAD cells continue to consolidate at a rate faster than the normal shoaling rate for the area, as evidenced by recent surveys of the area. As of August 2007 the cells had an estimated capacity of approximately 305,840 cubic meters (400,000 cy). Ultimately, the cells are planned to be capped with suitable maintenance material from State and private projects as cell capacity is reached.

Continued monitoring of CAD cells conducted as part of the Boston Harbor Navigation Improvement Project provides insight into the longer term stability of CAD cells in a setting similar to Providence Harbor. In the Boston Harbor Project, nine cells were constructed beneath the navigation channel from 1997 to 2000. Studies during the project indicated that material within open cells remained in place during vessel passage over the cells (SAIC 2000). One entire cell and portions of the surface of several other cells remained uncapped following completion of the project. A follow up study in 2004 showed that the cells continued to be stable structures four to seven years following completion of disposal and capping operations (ENSR 2007a). Some additional consolidation of the material within the cells had taken place, resulting in the cell surface taking on the features of the original cell bottom topography. As expected, natural deposition was occurring over the cells, and little of the coarse-grained cap material was still apparent at the surface of the capped cells. Biologically, both the capped and uncapped cells were similar to the surrounding harbor bottom.

Similar processes are expected to occur for the PRHMDP CAD cells. As long-term consolidation of the disposed material progresses, the surface of the cells is expected to take on the topography of the original cell floor for each cell. This consolidation could allow for future disposal into PRHMDP cells. The surface of the cells (whether capped or uncapped) is expected to receive ongoing deposition and return to the ambient harbor bottom biological community.

Overall Project Public Perception

Despite many years of public debate concerning performance of this project, the PRHMDP was in the end perceived as a success by the agencies involved and by the general public (Lord 2005). Shipping was not affected during dredging, and construction generally proceeded without much attention. The public benefited not only from the restoration of two-way shipping traffic in the Upper Harbor, but from the opportunity for 27 non-Federal projects, including marinas and fuel terminals, to dispose of their dredged material in the CAD cells. Further, where Rhode Island previously had no open water dredged material disposal sites; two sites were established through PRHMDP for future use. RISDS was designated as a permanent disposal site for suitable material, and CAD cell capacity remains for non-Federal dredging projects with sediments unsuitable for RISDS.

The project took over 13 years to fully complete and involved a significant amount of coordination throughout the process. Prior to initiation of the Providence River and Harbor project there was little likelihood that any of the dozens of dredging projects that were in planning would have found suitable disposal options. Local maritime businesses realized they were in danger of being forced out of business and worked with their representatives to get the State’s dredging regulations changed. They also identified the need for long term disposal options for the State and realized that the State needed to take a more active roll in identifying potential sites. The State designated RICRMC as the lead agency for dredging and instead of just regulating the dredging they became active participants in identifying suitable disposal sites. The CAD site will remain open and has helped RICRMC meet short term disposal needs as they continue their efforts to locate other suitable sites within the State. A State dredging team has been activated that meets quarterly and facilitates coordination of proposed dredging projects in the State. This whole process showed that while a project can be shown to meet economic and environmental standards, if there is not the will to move forward politically the project will not likely succeed. Without the continued backing of the marine interests in the State of Rhode Island it’s unlikely the project would have moved forward.

CONCLUSIONS

From April 2003 to July 2005, a total of 4.43 million cubic meters (5.8 mcy) of material was dredged as part of the PRHMDP to restore navigation and create CAD cells. Dredged material suitable for offshore disposal was placed at the Rhode Island Sound Disposal Site (RISDS). Dredged material unsuitable for offshore disposal, because of contaminant-related toxicity concerns (comprising approximately 0.92 million cubic meters (1.2 mcy) of the total dredged), was placed into six CAD cells constructed beneath the Federal Channel at the head of the main channel in the Providence River.

Environmental concerns related to the dredging and particularly the disposal of dredged material extended the assessment of the project and delayed implementation for many years. However, through careful planning and execution, environmental impacts of this large project were either avoided or minimized, and it was considered successful by all metrics. Given the amount of pre-project assessment performed and the extensive monitoring conducted during the project, a number of lessons learned and conclusions can be drawn from the PRHMDP as summarized below:

- Sequencing – The sequencing of dredging operations allowed the project to proceed cost-effectively without interruption, and provided additional reassurance that environmental impacts would be minimized.
- Dredging – Water column monitoring performed during the dredging of maintenance material, as well as during dredging of native material during CAD cell construction, identified suspended solids plumes that dissipated rapidly with distance. The water column monitoring indicated that predictive modeling performed as part of the EIS (when adjusted to reflect actual operation) provided reasonable predictions of suspended solids in the vicinity of the operation. Biological monitoring performed during the dredging, while limited in scope, did not detect any significant impacts to hatching success of winter flounder eggs.
- Disposal into CAD Cells – Water column monitoring performed following disposal into the CAD cells demonstrated that the resulting suspended solids plumes were limited in both extent and duration. Collection of samples for laboratory analysis and toxicity testing revealed no water column impacts. Dissolved silver was not detected above the reporting limit in any samples. Only one sample exceeded the chronic/acute water quality criterion for dissolved copper, and this sample was collected at the up-current background location prior to the monitored disposal event. Similar to the dredging, the water column monitoring following disposal indicated that predictive modeling performed as part of the EIS provided reasonable, if not conservative estimates.
- Disposal at RISDS – Water column monitoring performed following disposal at RISDS, the open water disposal site, demonstrated that the suspended solids plumes predominantly remained within the boundaries of the site and that modeling predictions provided a conservative estimate of plume footprint and suspended solids concentrations. Biological monitoring performed within a year of completion of disposal at RISDS identified that the benthic community was recolonizing quickly and that lobster populations were not significantly impacted.
- Capping of CAD Cells – Given the lack of any significant water column impacts during disposal, the expected stability of the CAD cells, and the expected natural deposition of sediment over the disposed material, the PRHMDP CAD cells could remain uncapped, allowing the excess cell capacity to be preserved for future projects.
- Adaptive Management Approach to Environmental Monitoring – An extensive water column monitoring program was required for the PRHMDP around the dredging operations and CAD cell disposal given the significant concerns regarding disposal-related impacts. The monitoring was prescribed in detail within the Water Quality Certification. Following completion of the first several monitoring events, it became evident that there were no significant impacts related to the disposal. In the future, a Water Quality Certificate that provides some level of adaptive management to large environmental monitoring programs such as the one in the PRHMDP would allow for early confirmation of model predictions and a potential shifting of focus or scaling back of the monitoring that could provide more relevant field data and potentially a more cost effective program.

Despite many years of public debate concerning performance of this project, the PRHMDP was in the end perceived as a success by the agencies involved and by the general public (Lord 2005). The project provided a good example of multiple agencies coming together to solve a regional problem, with political, economic, technical, and environmental challenges. Shipping was not affected during dredging, and, with the exception of the unrelated fish kill in Greenwich Bay, the project proceeded without much attention (Lord 2005). The public benefited not only from the restoration of the authorized channel depth and two-way shipping traffic in the Upper Harbor, but from the opportunity for 27 non-Federal projects, including marinas and fuel terminals, to dispose of their dredged material in the CAD cells. Further, where Rhode Island previously had no open water dredged material disposal sites, two sites were established through PRHMDP for future use. RISDS was designated as a permanent disposal site for suitable material, and CAD cell capacity remains for non-Federal dredging projects with sediments unsuitable for RISDS.

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