ENVIRONMENTAL DREDGING PILOT STUDY IN THE LOWER PASSAIC RIVER: UPDATED RESULTS

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ABSTRACT

An environmental dredging pilot study was conducted in the Lower Passaic River in Newark, New Jersey in December 2005 led by NJDOT along with the USACE and USEPA. The pilot study was performed as part of the Feasibility Study for the Lower Passaic River Restoration Project (LPRRP), which is being conducted by the partner agencies - USEPA Region 2, USACE, NJDOT, USFWS, NOAA and NJDEP under joint CERCLA and WRDA authorities. The LPRRP is also being performed as a pilot program under the Urban Rivers Restoration Initiative to develop a comprehensive plan to restore this 17-mile long, highly-degraded industrial waterway.

Using an 6.1 m^3 [8- cubic yards (cy)] Cable Arm® mechanical clamshell dredge bucket approximately 3,173 m^3 [4,150 cy] of contaminated sediment were dredged from a 6,070 m^2 [1.5 acre] area in 3.0 to 4.6 m [10 to 15 feet] of water in the Harrison Reach just west of the New Jersey Turnpike Bridge over a five day period. The two primary goals of this pilot study were (1) to evaluate dredging productivity and equipment performance and (2) to measure the amount of sediment that is resuspended and subsequently transported downstream as a result of a dredging operation in the Passaic River estuary. A third goal of this pilot study was to evaluate the technical feasibility and economic viability of two full-scale decontamination technologies to treat the dredged Passaic River sediment.

A comprehensive and elaborate water quality monitoring program utilized a combination of six fixed moorings in conjunction with shipboard monitoring using four boats and associated instruments including Differential Global Positioning Systems (DGPS), Acoustic Doppler Current Profilers (ADCP), Laser In-Situ Scattering and Transmissometry (LISST) probes, Conductivity-Temperature-Depth (CTD) probes, Optical Back Scatter (OBS) sensors, Trace Organic Platform Samplers (TOPS) and Instrument Specialty Company (ISCO) samplers. Preliminary results from the pilot study were presented at the WEDA XXVI conference in San Diego (June 2006).

This paper presents updated results of the water quality monitoring measurements including a detailed characterization of the hydrodynamics of the estuarine system before, during, and after the dredging and the chemistry of the sediment released by the dredging operation in the suspended and dissolved phases. The paper also compares these results with predictive modeling that was performed prior to execution of the study using a focused three-dimensional (3-D) hydrodynamic and sediment transport model using Computational Fluid Dynamics (CFD).

Keywords: contaminated sediments, estuarine dynamics, resuspension monitoring, dredging productivity.

INTRODUCTION

In December 2005, an environmental dredging pilot study was conducted in the Lower Passaic River in Newark, New Jersey (Figure 1). The pilot study was performed as part of the Feasibility Study for the Lower Passaic River Restoration Project. The U.S Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE), and the New Jersey Department of Transportation (NJDOT) formed a partnership with U.S. Fish and Wildlife Service (USFWS), National Oceanic Atmospheric Administration (NOAA) and New Jersey Department of

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Environmental Protection (NJDEP) [Partner Agencies] to carry out the Lower Passaic River Restoration Project. The Lower Passaic River Restoration Project is also being performed as a pilot program under the Urban Rivers Restoration Initiative under joint Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Water Resource Development Act (WRDA) authorities. Funding for the remedial dredging pilot study was provided by the NJDOT as cost-sharing partner for the project. The Feasibility Study will address remediation and restoration of the 27.3-km [17-mile] tidally influenced Lower Passaic River and its surrounding watershed. The results of this study are also expected to be utilized in a Focused Feasibility Study (which is the subject of another paper in this session on the Lower Passaic River [Bossi et al.]) that identifies opportunities for Early Action to address threats to human health and the environment. The field implementation effort has also been summarized in the December 2005 issue of World Dredging Mining and Construction (Baron et al., 2005).

The dredging was performed by Jay Cashman Inc., with support from Cable Arm Inc. The Institute of Marine and Coastal Sciences at Rutgers University and the Water Resources Division of the United States Geological Survey (USGS) led the water quality monitoring program and were assisted by the consultant team from Earth Tech, Inc (NJDOT's prime consultant), Malcolm Pirnie, Inc., and Aqua Survey, Inc.

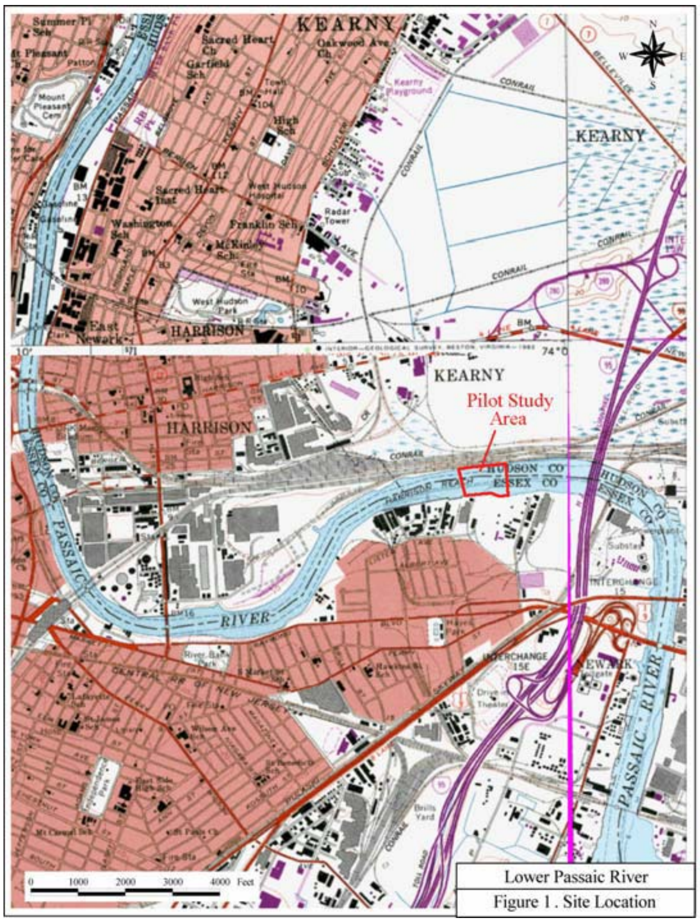


Figure 1. Map Showing Harrison Reach of Lower Passaic River and Vicinity Site Background.

The Passaic River is the principal river in the Passaic Watershed, a 2422 km2 [935 square miles] watershed located in northern New Jersey and southern New York states. The Lower Passaic River is considered to be the 17-mile tidally influenced portion of the river from the mouth of the confluence at Newark Bay up to the Dundee Dam in Clifton, New Jersey. Due to the urban history of the region and historical contaminant releases, the Lower Passaic River sediments are contaminated with dioxin, DDT, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), mercury, arsenic, lead, cadmium, and other organic and inorganic contaminants. Currently, there is a "do not eat" fish consumption advisory for all fish and shellfish in the Lower Passaic River, and the taking of blue crabs is prohibited. Fish consumption advisories in New Jersey are based on PCB, mercury and dioxin contamination; and NJDEP specifically notes the presence of high dioxin levels in blue crabs from the Passaic

River/Newark Bay area (NJDEP and NJDHSS, 2006). The upper 1.6 – 3.2 km [1-2 miles] of the river are dominated by freshwater inputs from flows over the Dundee Dam. At its confluence with Newark Bay, the river is brackish in nature, with typical bottom salinities of 14-23 parts per thousand. The Harrison Reach of the river, which extends approximately two miles from the NJ Turnpike Bridge to the Jackson Street Bridge that connects Harrison with Newark, was selected as the location for the pilot study (see Figure 1). For more detailed site background, see http://www.ourpassaic.org.

Pilot Study Overview

The dredging pilot study targeted approximately 5,000 cy [3,825 m^3] of sediment in the Federal Channel and adjacent areas. Dredging was performed over an approximately 1.5 acre [6,070 m^2] area to depths of approximately 3 ft [0.91 m]. The dredged material was transported to a near shore processing facility for treatment by two innovative decontamination technologies. These technologies are expected to process the dredged material into beneficial use end products. A large portion of the sediment was treated in early 2006 using a sediment washing process to produce a manufactured soil product. The decontaminated soil could be used in a number of land-based applications, such as upland remediation and landscaping. A portion of the Lower Passaic River sediment has been dewatered and undergone treatment with a thermo-chemical destruction process using a rotary kiln in January and February 2007. Construction-grade cement will be produced during the treatment process, which could be used in the construction of sidewalks, parking lots, and driveways. This aspect of the work is being conducted separately by NJDOT and USEPA under the New Jersey/New York Harbor Sediment Decontamination Technology Demonstration Program. The decontamination technology vendors will prepare separate reports that describe these efforts.

The major objectives of the pilot study included:

Evaluate dredging equipment performance. This includes productivity, precision (achieving targeted dredging depth and cut lines), turbidity levels, and operational controls.

Monitor sediment resuspension. This includes determining how much sediment is released from the dredging activity and where that sediment is transported.

Evaluate sediment decontamination and treatability.

An extensive resuspension monitoring program to attempt to measure the amount of sediment that is resuspended and subsequently transported downstream as a result of a dredging operation was utilized and consisted of a combination of six fixed moorings as well as shipboard monitoring using four boats. The pilot study will also help to identify the type of resuspension monitoring that may be required during a larger scale remedial dredging operation.

In preparation for the pilot study, the Partner Agencies conducted an extensive data collection effort. This included: an environmental dredging technology review (Earth Tech and Malcolm Pirnie, 2004); geophysical surveys (hydrographic surveys, a side-scan sonar survey, magnetometry and gradiometry surveys, and a sub-bottom profiling survey); sediment coring to characterize the chemical and geotechnical properties of the sediment (Earth Tech and Malcolm Pirnie, 2005a); hydrodynamic studies; and, predictive plume modeling (Earth Tech, 2005). For more detailed information on these studies and the pilot study project plans (Earth Tech and Malcolm Pirnie, 2005b), see **http://www.ourpassaic.org**. Preliminary results from the pilot study were presented at the WEDA XXVI conference in San Diego (June 2006). This paper presents updated results of the water quality monitoring measurements including a detailed characterization of the hydrodynamics of the estuarine system before, during, and after the dredging and the chemistry of the sediment released by the dredging operation in the suspended and dissolved phases. The paper also compares these results with predictive modeling that was performed prior to execution of the study using a focused three-dimensional (3-D) hydrodynamic and sediment transport model using Computational Fluid Dynamics (CFD).

Hydrodynamic and Sediment Transport Modeling

A focused three dimensional hydrodynamic and sediment transport model using CFD modeling software Flow3D (http://www.flow3d.com/software/index.htm) was developed to determine optimal locations for positioning of water column monitoring equipment, to estimate the mass flux of sediment leaving the study area, and to evaluate the impact of dredging on suspended sediment levels. The physical conditions present at the site that can influence the resuspension of sediments as a result of dredging activities are the meandering geometry, the tides, the dynamic salt wedge, the freshwater discharge, and sediment from the watershed transported by the river. The two main components that dominate the hydrodynamics at the Pilot Study site are tidal energy and freshwater discharge.

The DREDGE model (Hayes and Je, 2000) was used to calculate the source strength and to provide estimates of the sediment that would be released during dredging. Each sediment class (*i.e.*, sand, silt and clay) was modeled as a group with an average median particle diameter (D_{50}). These rates were then used as source terms in the Flow3D model which was used to simulate transport and settling of sediment. The dredging was assumed to occur for five days. The increase in sediment load was assumed to occur only during the 12-hour-per-day working period. Using a conservative approach, from a sediment transport perspective, effects of flocculation were not included and only the Stokes settling algorithm was used in the Flow3D model. By not including flocculation, the estimated mass flux leaving the system was conservative (biased high). Inclusion of flocculation could yield higher simulated settling velocities for the silts and clays, thus increasing settling rates and decreasing the estimate of the mass flux leaving the system.

Modeling Results

The model predicted that the suspended sediment plume would follow the path of deeper water conveyance (*i.e.*, along the navigational channel closer to the northern bank). The simulated plume is well-defined during ebb tide; but becomes mixed after the flow reversal during flood tide. The plume progression characteristics were similar to those observed during dye studies performed by Rutgers University in September and October 2004. Assuming a one-percent sediment release rate, the model predicted that dredging 3,825 m^3 [5,000 cy] would result in a release of 50 MT [55 tons] of sediment. Sand is 16 percent of the 50 MT [55 tons] by weight, and it settles within approximately 154 m [500 ft] of release. Therefore, an estimated 41.8 MT [46 tons] of silt and clay would leave the study area, assuming no flocculation; this corresponds to 0.2 percent of the natural annual sediment flux. Figure 2 shows the estimated sediment released from the Pilot Study dredging as compared to the monthly and daily average natural loads in the Lower Passaic River.

Based on the modeling exercise, both fixed moorings along four transects (two upriver and two downriver of the dredging operation) and shipboard surveys were specified for monitoring the hydrodynamics of the system during the dredging operation. The two inner transects (closest to the dredging operation) were positioned at a distance that corresponds to the minimum required distance for safe operation of the monitoring equipment. This minimum distance was specified by the dredging contractor (Cashman) to be 120 m [400 ft] from the dredge prism to allow movement and turning of the dredge, guide barge and scows. The two outer transects were positioned at a distance of approximately 300 m [1000 ft] from the dredge prism, which corresponds to the maximum extent of the area where the coarse particles (*i.e.*, sand) were expected to settle, leaving only fines (*i.e.*, silt and clay particles) to be monitored at those locations.

Resuspension Monitoring

Fixed Moorings

Figure 3 shows plots of the six mooring array overlaid on an aerial photograph of the pilot study area in the Harrison Reach. Four of the six moorings (Moorings 2, 3, 4, and 5) are located along the centerline of the targeted dredge prism (two upriver and two downriver of the dredging operation). Based on model predictions that the plume would follow the path of deeper water conveyance, the remaining two moorings (Moorings 1 and 6) were located in the deepest portion of the navigation channel along the outermost transects.

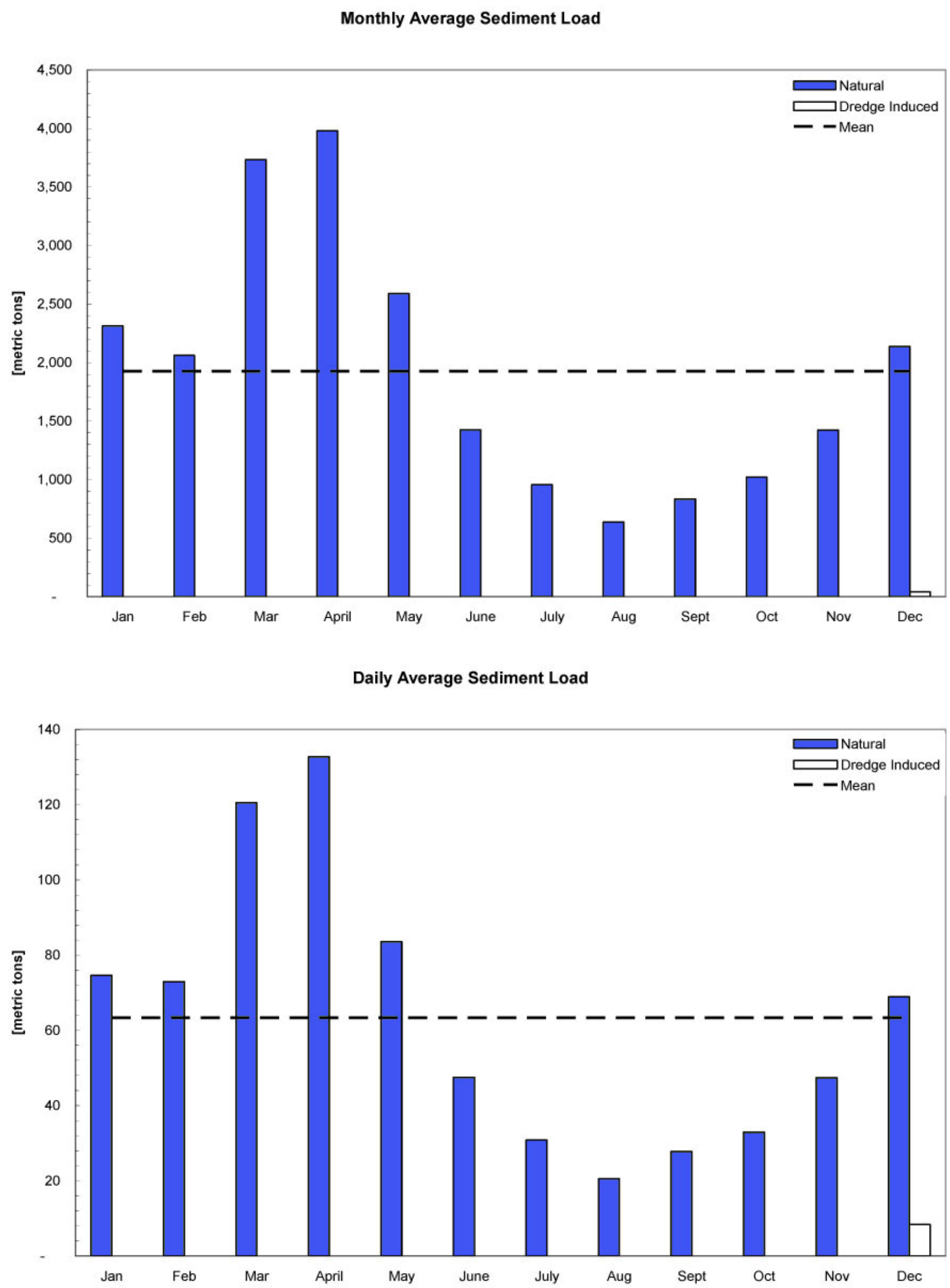


Figure 2. Monthly and daily average sediment load.

A mooring consisted of a float at the water surface and an anchor and a tripod frame suspended on a chain; the anchor and the tripod frame rested on the river bottom, while the float marked the mooring location at the surface. Each mooring was equipped with two Conductivity-Temperature-Depth (CTD) probes, two Optical Back Scatter (OBS) sensors, and an Acoustic Doppler Current Profiler (ADCP). In addition, the two centerline moorings closest to the targeted dredge prism (at approximately 120 m [394 ft], see Moorings M3 and M4 in Figure 3) were each equipped with a Laser In-Situ Scattering and Transmissometry (LISST) probe.

During an ebb tide, while the flow was toward Newark Bay, Moorings 1, 2, and 3 were on the upflow side of the dredging operation and Moorings 4, 5, and 6 were on the downflow side. During a flood tide, this relationship was reversed. The moorings monitored water column stratification and stability, particle concentration, and size distribution on a 24-hour basis throughout the project. The ADCP on Mooring 3 and the bottom CTD probe on Mooring 4 malfunctioned and no data was recovered from these instruments.

Figure 3. Aerial photograph of pilot study area showing fixed moorings.

Shipboard Survey Monitoring

Four boats were utilized to perform shipboard surveys and sampling. Two of these boats performed the hydrodynamics monitoring, while the remaining two boats were used for water quality monitoring. The first, the *R/V Caleta*, equipped with a GPS, a CTD probe, an OBS sensor, and an ADCP, conducted sweeps of the near-field plume in a zigzag pattern, crossing the plume approximately seven times in one hour (see boat M on Figure 4). The *R/V Caleta* was equipped with on-board laptop computers that allowed for the real time collection and display of the velocities, acoustic backscatter, salinity, pressure, and temperature over the depth of the water column. Approximately 100 samples for analysis of total suspended solids (TSS) were collected by the *R/V Caleta* throughout the five-day study to calibrate the direct reading instruments. Two different measurement techniques were utilized: a continuous monitoring technique using the towed ADCP sensor and a discrete water column profiling technique using the CTD and OBS. The second boat, the *R/V Julia Miller,* was equipped with a GPS, a CTD probe, a LISST probe, and an OBS sensor, as well as on-board laptop computers that allowed for the real time collection and display of the particle size distribution, turbidity, salinity, pressure, and temperature (see Boat L on Figure 4). Discrete measurements were recorded at selected locations and intervals with the LISST, OBS, and CTD to obtain a complete vertical profile of the water column. During most of its deployment, the *R/V Julia Miller* ran along the centerline of the plume parallel to the flow; but for a limited time, this boat also moved in a zigzag pattern to identify the edges of the plume. Both the *R/V Caleta* and *R/V Julia Miller* shifted their operation with the tides and also monitored upflow of the dredging operation to measure and record background conditions.

The *R/V Caleta* conducted daily shipboard surveys on December 5 through 8 and on December 10, during daylight hours. No surveys were performed on December 9, since there was no dredging due to a severe snowstorm with gale force winds. The *R/V Julia Miller* conducted daily shipboard surveys on December 5 through 8 during the daylight hours, but did not perform any surveys on December 10.

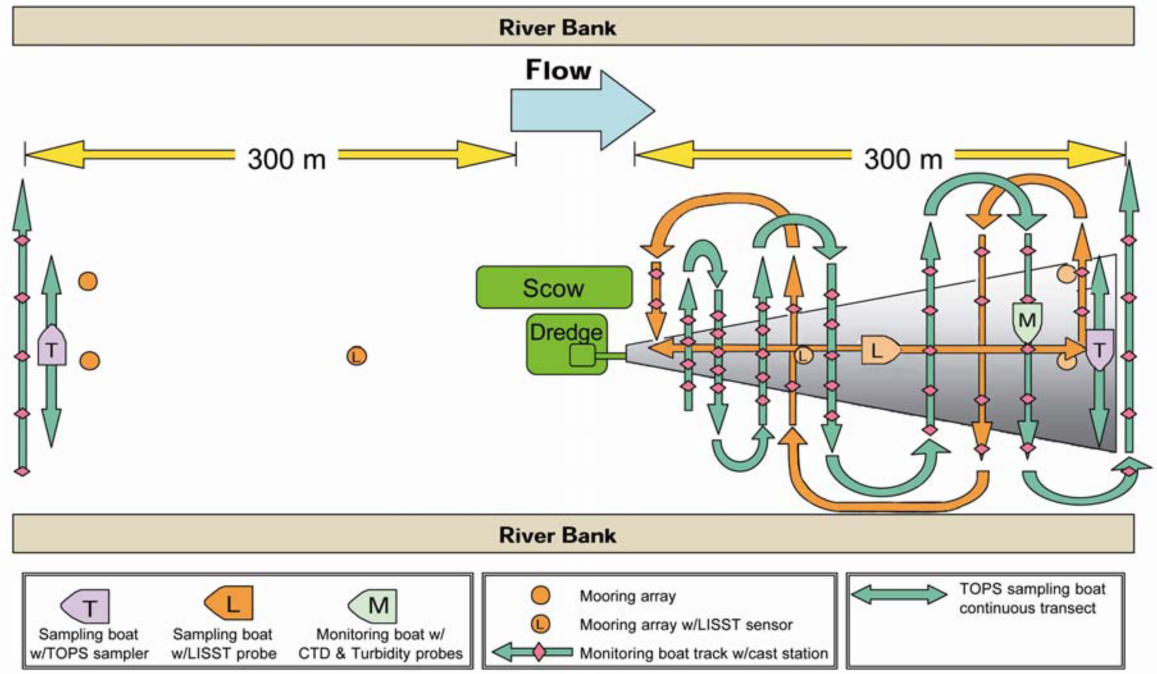


Figure 4. Monitoring mooring arrangement with monitoring boat track.

Two additional boats were utilized to perform water quality monitoring and sampling. Each boat was equipped with a GPS, a depth profiler, a peristaltic pump, a TOPS apparatus and two ISCO automatic samplers. The "Malcolm Pirnie" boat served as the upriver TOPS boat (TU) and performed continuous traverses along a transect coincident with the outermost upriver moorings (1 and 2). The *R/V Delaware*, served as the downriver TOPS boat (TD) and performed continuous traverses along a transect coincident with the outermost downriver moorings (5 and 6) (see boat icons labeled "T" on Figure 4). As described below, water samples were collected by these boats for analysis of TSS, particulate and dissolved organic carbon (POC and DOC), chloride/bromide, filtered and unfiltered metals, low-level mercury, dioxins/furans, PCB congeners, and pesticides. During an ebb tide, the sediment load can be evaluated by comparing TSS and contaminant concentrations measured downriver to background TSS and contaminant concentrations measured upriver. Similarly, during a flood tide, the sediment load can be evaluated by comparing TSS and contaminant concentrations measured upriver to background TSS and contaminant concentrations measured downriver.

The two TOPS boats performed monitoring activities to obtain pre-dredge background data on December 1, 2005, and during dredging on December 5, 6, 7, 8, and 10. Only one boat was used to perform post-dredging monitoring on December 12. Monitoring was performed continuously by both boats in round-trip traverses at half-hour intervals along the upriver and downriver transects perpendicular to the river flow. During the 'A' leg of the traverse from the south river bank to the north river bank, the water intake lines were positioned about 1 m [3.3 ft] below the water surface. During the 'B' leg of the traverse from the north river bank to the south river bank, the water intake lines were positioned about 1 m [3.3 ft] above the sediment bottom. No samples were collected near the edges of the river where water depths were less than 1.8 m [6 ft]. The raising and lowering of the water intake lines with a weighted fish was performed using a manually operated winch system custom-designed by the Water Resources Division of U.S. Geologic Survey (USGS) for each boat. The duration of each round trip traverse was kept as constant as possible at 10 to 12 minutes.

Each TOPS boat was also equipped with two ISCO automatic samplers that were utilized to collect samples for TSS, TOC, POC, and chloride/bromide analyses. During the 'A' leg of the traverse from the south river bank to the north river bank one sample was collected from the ISCO sampler for analysis of TSS and a second sample was collected for analysis of POC. This process was repeated during the 'B' leg. These samples provide the average cross-sectional suspended solids and POC content in the surface and bottom water. A peristaltic pump on each TOPS boat was used to collect samples for low level mercury analysis. The peristaltic pump was also used to collect composite samples for metals analysis. Samples were prepared by collecting approximately equal aliquots of river water into two sample bottles on each leg of the traverse. By splitting the pump outflow of this line, both unfiltered and filtered composite samples for metals analysis were collected. Although the TSS, TOC, POC, chloride/bromide, mercury and TAL metals samples were collected along each transect, the filtered and unfiltered metals and low level mercury samples were collected as half-day composites (composited from [nominally] seven traverses, at half-hour intervals, over a 3-hour period). In addition, for up to three hours prior to high or low tide, a concurrent composite (integrated) TOPS sample (consisting of six or seven traverses) was collected. The TOPS samples consisted of glass fiber filters (GFF) used to collect samples for suspended phase contaminants and XAD-2 resin cartridges for dissolved organics analysis.

The chemical samples, collected by identical TOPS samplers and pumping equipment in both the TU and TD boats, represent integrated composite samples that provide average contaminant concentrations on suspended sediment across the channel for the entire duration of sampling. The sediment-laden filters and the XAD-2 resin cartridges were sent for analysis of PCBs, dioxin-furans and organo-chlorine pesticides. Because the primary focus of the monitoring program was on particle-bound contaminants, only a limited number of resin cartridges from selected days were analyzed. As stated previously, the ISCO samples provide the average cross-sectional suspended solids and POC content in the surface and bottom water. Because they were collected concurrently with the TOPS composite sample, the ISCO samples also provide the means to calculate the mass of sediment captured on the TOPS filters - a required input for converting the results of the laboratory analyses (reported in mass per filter) into concentrations (e.g., mass per liter of river water).

During the pilot study, one integrated TOPS sample was collected from each TOPS boat (TU and TD) on December 1, 7, and 8, (during ebb or flood tide conditions), and two integrated TOPS samples were collected from each TOPS boat (TU and TD) on December 5, 6, and 10 (during both ebb and flood tide conditions). Only one TOPS boat positioned at the upriver location (near Moorings 1 and 2), was utilized for post-dredging monitoring (December 12), and only one sample was collected from that location during an ebb tide.

Figure 5 shows the freshwater discharge as recorded at the USGS gauge in Little Falls, New Jersey between November 20 and December 20, 2005. As stated previously, pre-dredge background monitoring for the pilot study was performed on December 1, 2005. Figure 5 shows that the freshwater discharge appears to peak at 122 m^3/s [4,308 ft^3/s] on that day. From that peak, the discharge appears to decrease monotonically to approximately 31 m^3/s [1,095 ft^3/s] on December 14, 2005. A precipitation event on December 15, 2005 produced a second peak in the discharge of 127 m^3/s [4,485 ft^3/s] on December 19, 2005. The dredging was performed between December 5 and December 10, 2005 and during this period the freshwater discharge appears to range from 89 m^3/s [3,143 ft^3/s] to just under 50 m^3/s [1,766 ft^3/s]. The mean annual freshwater discharge is approximately 32 m^3/s [1130 ft^3/s]. Therefore, it appears that the freshwater discharge at the start of dredging was significantly high (nearly three times the mean). A high freshwater discharge results in a higher sediment load being transported from the watershed.

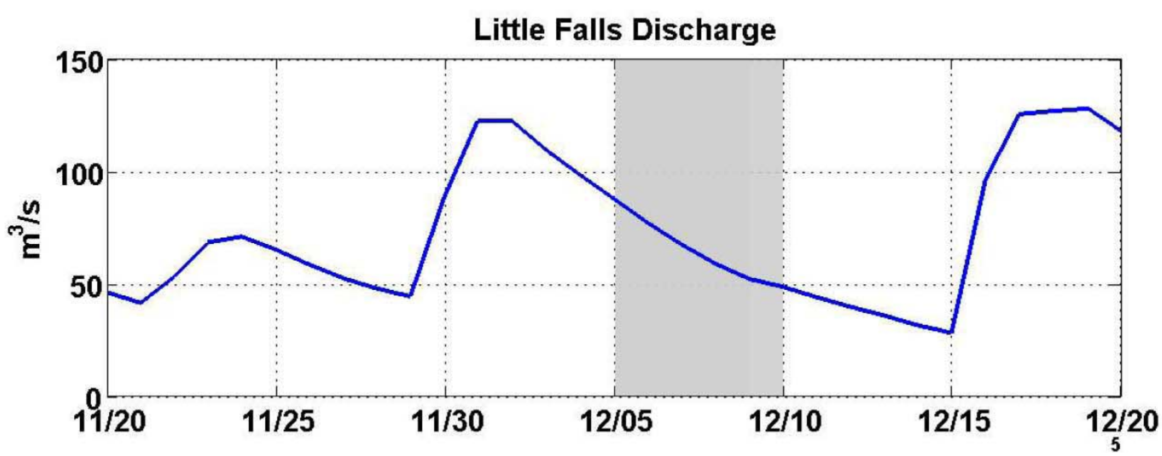


Figure 5. Freshwater discharge measured at the USGS gauge in Little Falls, New Jersey.

UPDATED RESULTS

The approximately 6,070 m^2 [1.5 acre] sampling grid (black rectangles – grids A1 through E3), daily areas dredged within the dredge cells and sediment core locations (green dots) are shown in Figure 6. Dredging was performed to depths of approximately 0.91 m [3 ft]. The inner rectangle (with a colored boundary) represents the three dredge cells. Grids A2, B2, C2, D2, and E2 correspond to the middle dredge cell at a target elevation of -13 ft referenced to Mean Low Water (MLW) and were dredged on December 5, 2005. Grids A3, B3, C3, D3, and E3 correspond to the southern dredge cell at a target elevation of -3 m [-11 ft] MLW and were dredged on December 6, 2005. Grids A1, B1, C1, D1, and E1 correspond to the northern dredge cell located at a target elevation of -5 m [-15 ft] MLW and were dredged on December 7, 8, and 10, 2005. This last cell was dredged at a slower rate so that the resuspension monitoring and TOPS boat sampling could be performed over several ebb and flood tide cycles.

Dredging Equipment Performance

Results pertaining to the dredging equipment performance including dredging productivity and accuracy were presented at the WEDA XXVI conference in San Diego (Thompson et al., 2006). Table 1 presents a summary of the quantities dredged during the project, the location of the dredging (e.g., which cut elevation), and the typical operational characteristics for that day's work. A total of 3,173 m^3 [4,150 cy] were dredged, with an average of 635 m^3 [830 cy] per day. The quantities presented are in-situ volumes and determined using the contractor's daily multi-beam bathymetric surveys.

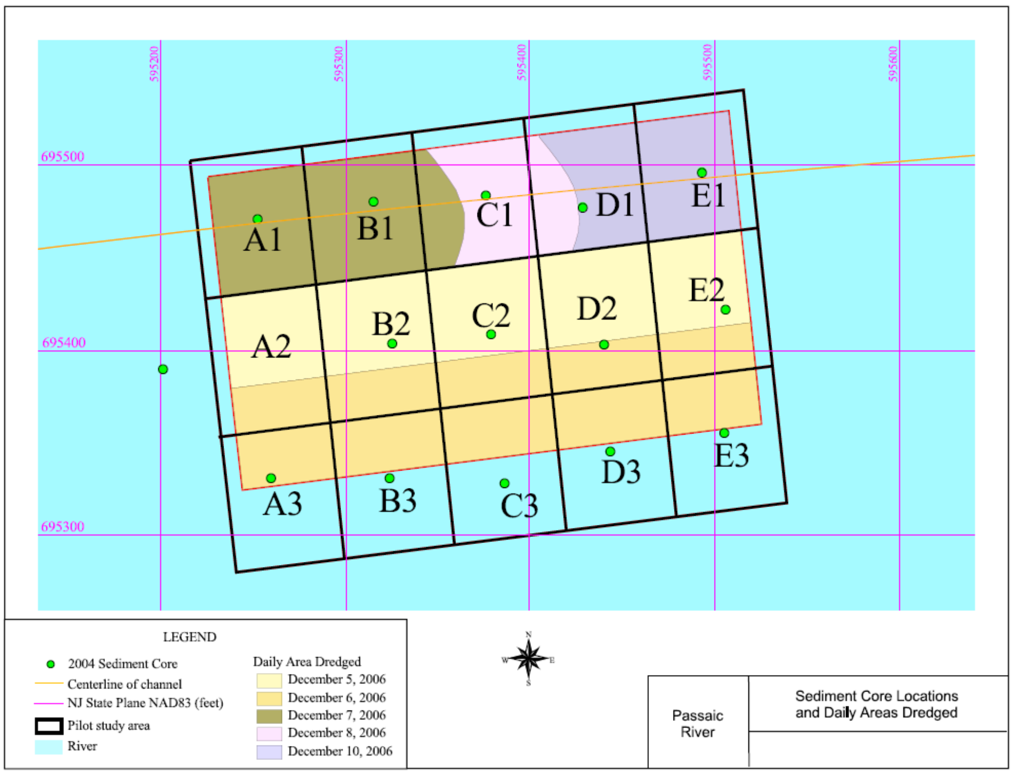


Figure 6. Daily areas dredged and sediment core locations.

The contractor's goal was to achieve a vertical accuracy of dredging of plus or minus six inches. An evaluation of the accuracy achieved was made by comparing the pre-dredging and daily post-dredging bathymetric survey data. A summary of the findings is presented in Table 2. 66 to 72% of the area was dredged within 15 cm [6 in] of the design elevation, 82% to 89% of the area was dredged within 23 cm [9 in] of the design elevation, and 92 to 94% of the area was dredged within 30 cm [12 in] of the design elevation. Overall, the days that the Cable Arm® sensors were functioning, demonstrate an improvement in dredging accuracy (increase of 7%) in order to achieve the targeted depth. The accuracy achieved was somewhat lower than anticipated during the design preparation.

Table 1. Dredging volume and work summary.

Date	Volume Dredged (cy)	Dredging Time (hours)	Location of Dredging	Operational Characteristics
Dec 5	942	7.25	-13' MLW Cut	Cable Arm sensors not working used bucket chain method, single lift per area, no extended equilibration time.
Dec 6	1367	6.6	-11' MLW Cut	Cable Arm sensors not working until 4:20 PM, used bucket chain method, single lift per area, no extended equilibration time.
Dec 7	834	7.17	-15' MLW Cut	2 lifts per area
Dec 8	486	5.58	-15' MLW Cut	2 lifts per area
Dec 9	No dredging due to weather			
Dec 10	522	5.25	-15' MLW Cut	2 lifts per area, extended bucket equilibration time
TOTAL	4,150	38.12		
AVERAGE	830 cy/day	6.27		

Table 2. Summary of dredging accuracy data.

Design Cut Depth (feet below MLW)	% of Area Within 6 inches		% of Area Within 9 inches		% of Area Within 12 inches	
	Without Cable Arm Sensor	With Cable Arm Sensor	Without Cable Arm Sensor	With Cable Arm Sensor	Without Cable Arm Sensor	With Cable Arm Sensor
11	60	69	74	81	84	90
13	65	--	85	--	95	--
15	--	79	--	90	--	95
TOTAL	66	72	82	89	92	94

Resuspension Monitoring by Fixed Moorings

Figure 7 shows the water surface elevation measured at Mooring 2 during the period from December 4 through 10, 2005. This figure also shows the periods during which dredging was being performed (magenta bands) along with the times for high and low tides. The storm event on December 9, 2005 is also readily observed on this plot. Data from the ADCPs and CTD probes mounted on the six moorings were presented at the WEDA XXVI conference in San Diego (Bilimoria et al., 2006). In addition to the data recorded by the ADCPs and CTD probes, the two innermost moorings (Moorings 3 and 4) closest to the dredge prism were each equipped with a LISST-100 Type C probe.

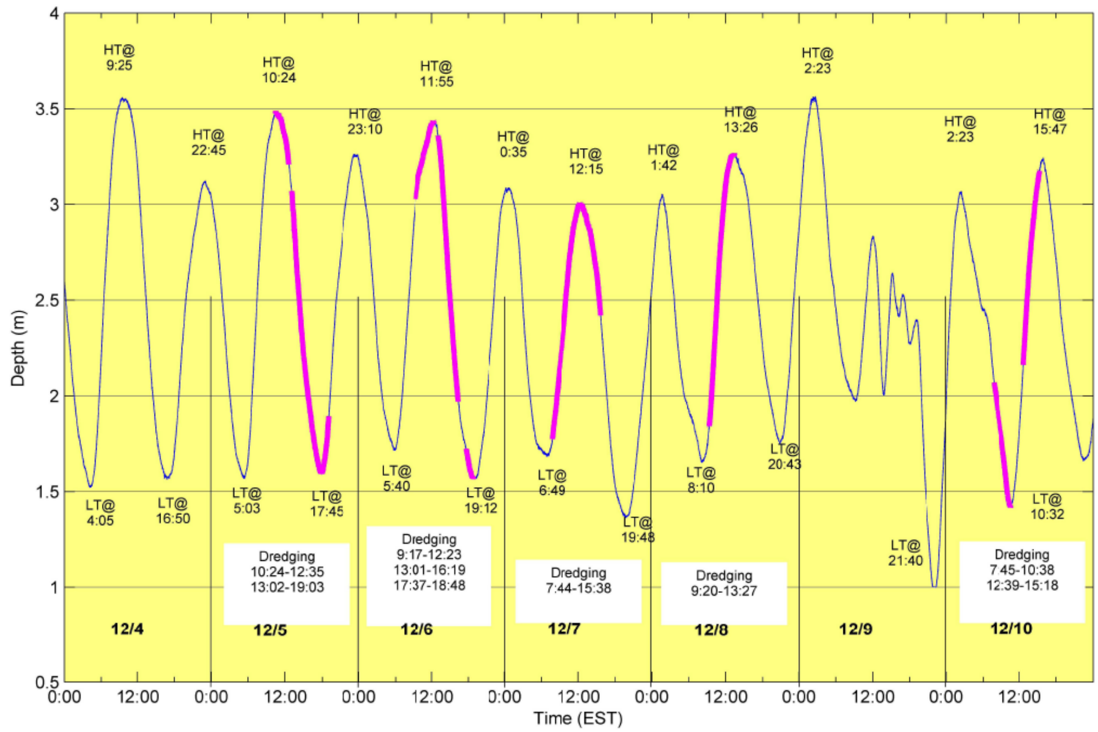
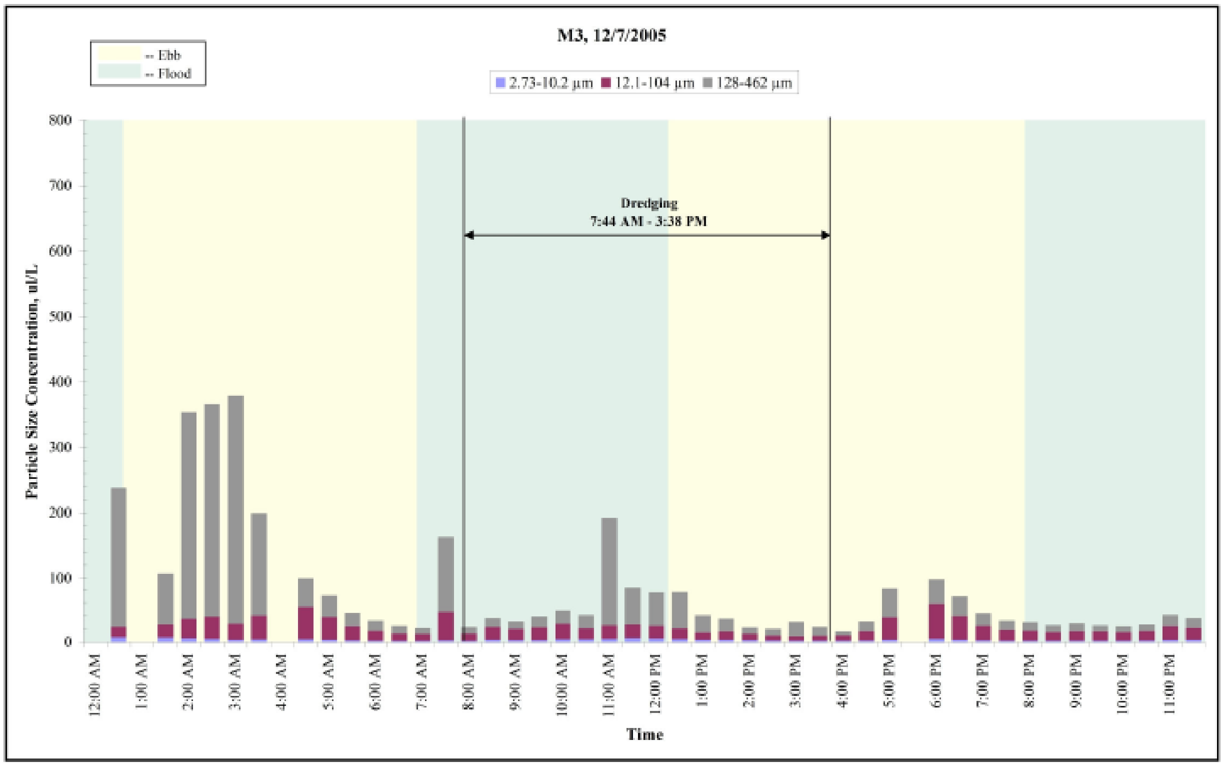


Figure 7. Water surface elevation measured at mooring 2.

These instruments are able to record volume concentrations of particles in 32 bin sizes between 2.5 and 500 microns. According to the manufacturer, Bin 1 corresponds to a median particle size of 2.73 microns and Bin 32 corresponds to a median particle size of 462 microns. The LISST probes on Mooring 3 and Mooring 4 were programmed to record data at 30 minute intervals.

Figure 8 presents the data recorded by the LISST probes on Mooring 3 and Mooring 4 on the third day of dredging, December 7, 2005. The data for each measurement were plotted in three order-of-magnitude ranges (< 10 microns, 10-100 microns, and >100 microns). The time intervals for the ebb and flood tides are also shown. Between 1:00 AM and 6:30 AM during the ebb tide, no dredging was performed. For the first part of the ebb tide between 1:00 AM and 4:30 AM, the particle size concentrations recorded by the LISST on Mooring 4 (downflow) are lower than those recorded by the LISST at Mooring 3 (upflow). For the second part of the ebb tide between 5:00 AM and 6:30 AM, the data recorded by the LISST probes at Mooring 3 and Mooring 4 are very similar. On December 7, 2005, the first part of the dredging was performed during a flood tide between 8:00 AM and 12:00 noon, when Mooring 3 was downflow of the dredging operation. Between 8:00 AM and 10:30 AM, the data recorded by the LISST probes at Mooring 3 and Mooring 4 are very similar. The second part of the dredging was performed during an ebb tide between 12:30 PM and 3:30 PM, when Mooring 4 was downflow of the dredging operation. The particle size concentrations recorded on Mooring 4 during this time interval appear to be slightly higher than those recorded at Mooring 3, especially for the particles > 100 microns. After the dredging ceased for the day, the data recorded by the LISST probes at Mooring 3 and Mooring 4 are very similar for the remainder of that day.

The data recorded by the LISST probes on Mooring 3 and Mooring 4 during the post-dredging monitoring period representing background conditions on December 11, 2005 are shown on Figure 9. The dredge and associated equipment had been demobilized on December 10, 2005. During the early morning flood tide between midnight on December 10 and 4:30 AM on December 11, as well as during the ebb tide between 5:00 AM and 10:00 AM, the particle size concentration patterns recorded by the LISST probes on Mooring 3 and Mooring 4 are dissimilar. For the remainder of that day, the data recorded by the LISST probes on Mooring 3 and Mooring 4 are for the most part, similar.



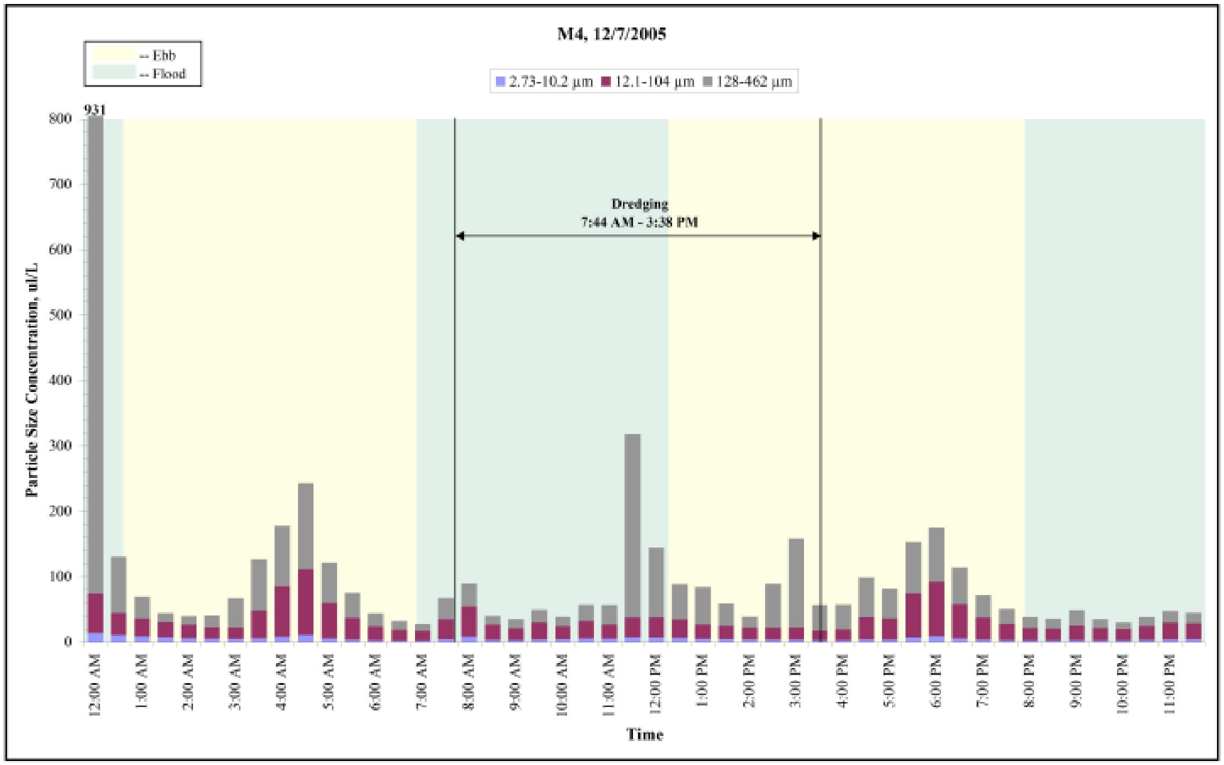
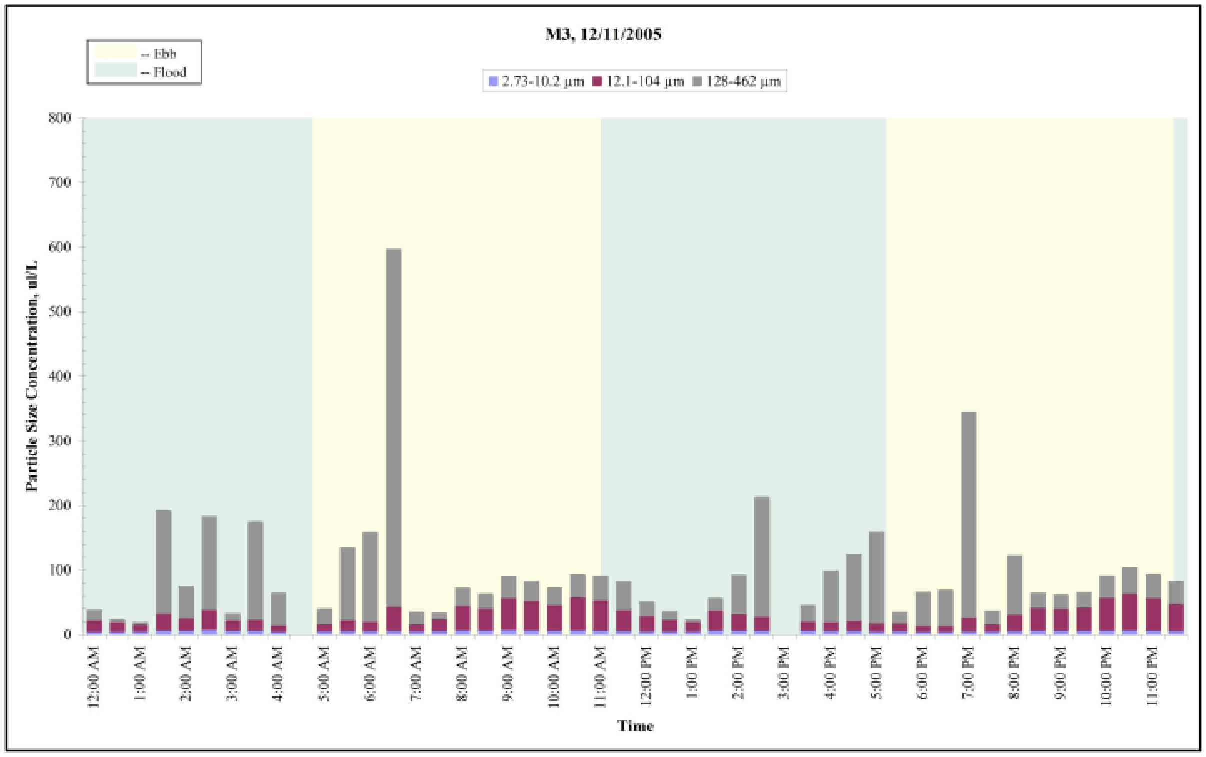


Figure 8. LISST data for moorings 3 and 4 on December 7, 2005.



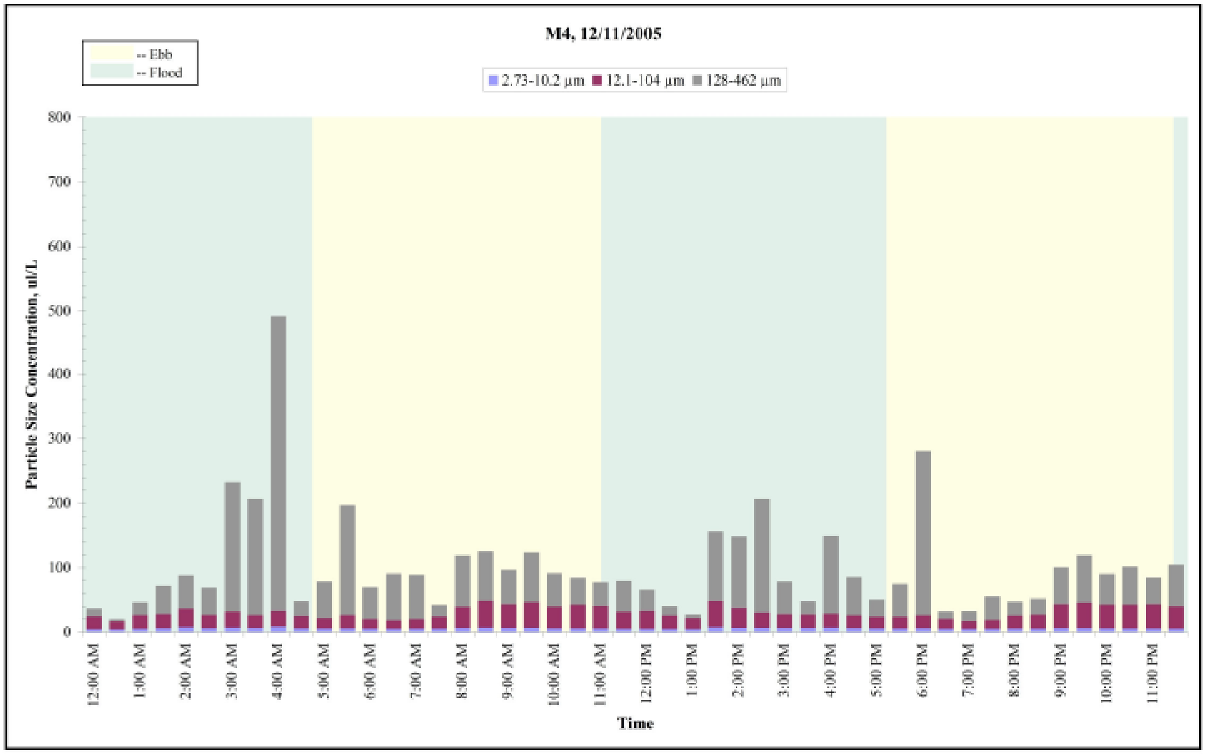


Figure 9. LISST data for Mmoorings 3 and 4 on December 11, 2005.

Resuspension Monitoring by Shipboard Surveys

Figure 10 presents the along-channel velocities that were recorded in three passes of the *R/V Caleta* while it was downriver of, and moving away from, the dredging operation on December 6 between 1615 and 1645 hours EST. The first panel of the figure shows the locations of the moorings, the position of the dredge within the dredge prism, and the ship tracks for the three passes of the boat, while it was just downriver of the dredge prism, superimposed on an aerial photograph of the pilot study area. The three lower panels show vertical cross-sections of the velocities recorded by the ADCP in each of the three passes. The first pass is from the south to the north just downriver of the dredge prism, the second pass is from the north to the south downriver of Mooring 4, and the third pass is from the south to the north just upriver of Moorings 5 and 6. The plot shows very high velocities in the northern half of the river at all depths due to the strong ebb tide. The dredging activity concurrent with the monitoring shown in this figure was being performed in Cell D3 (see Figure 6) under ebb tide conditions.

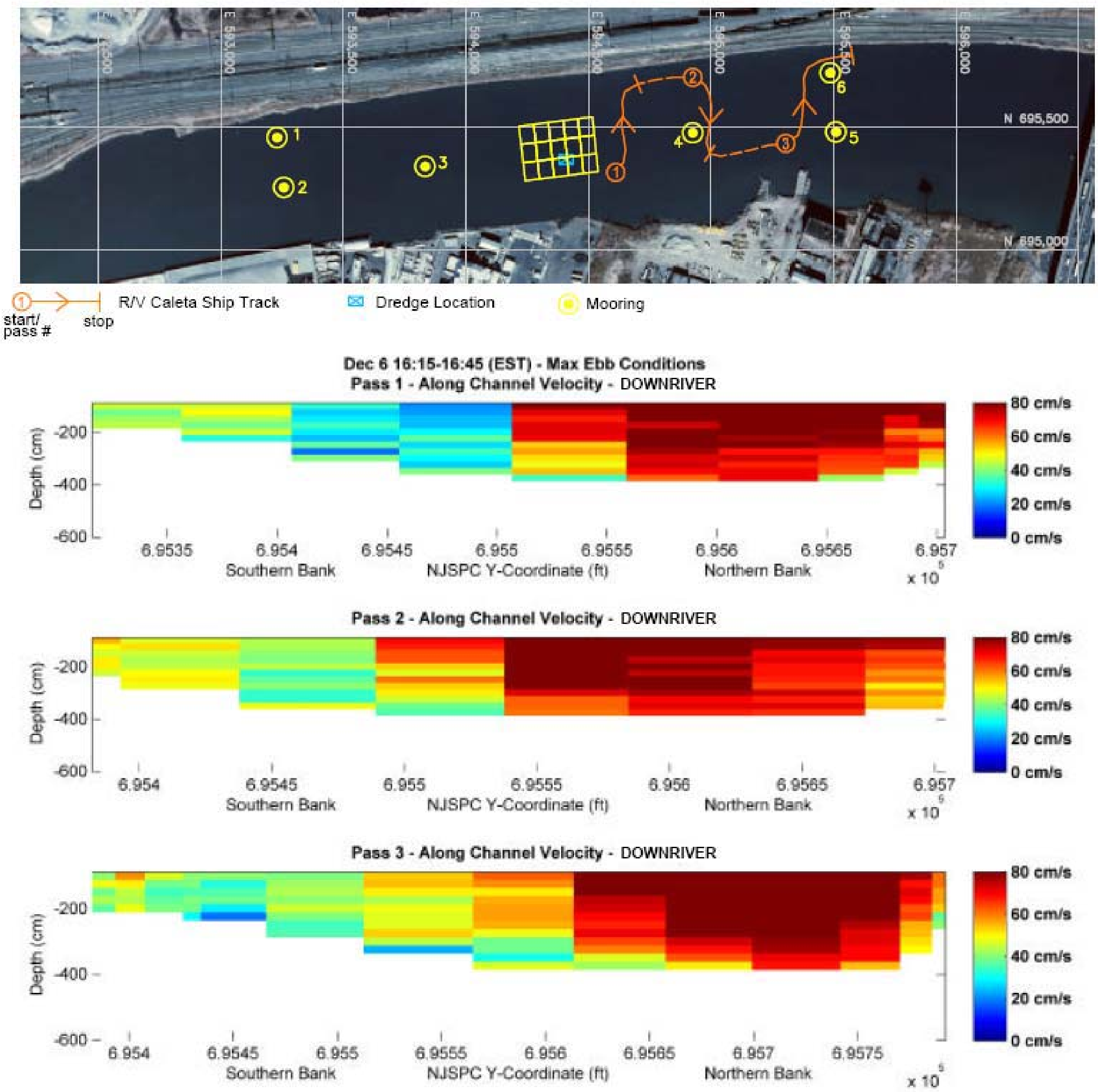


Figure 10. R/V Caleta shiptrack and velocity cross-sections for December 6, 2005 1615-1645 hours EST.

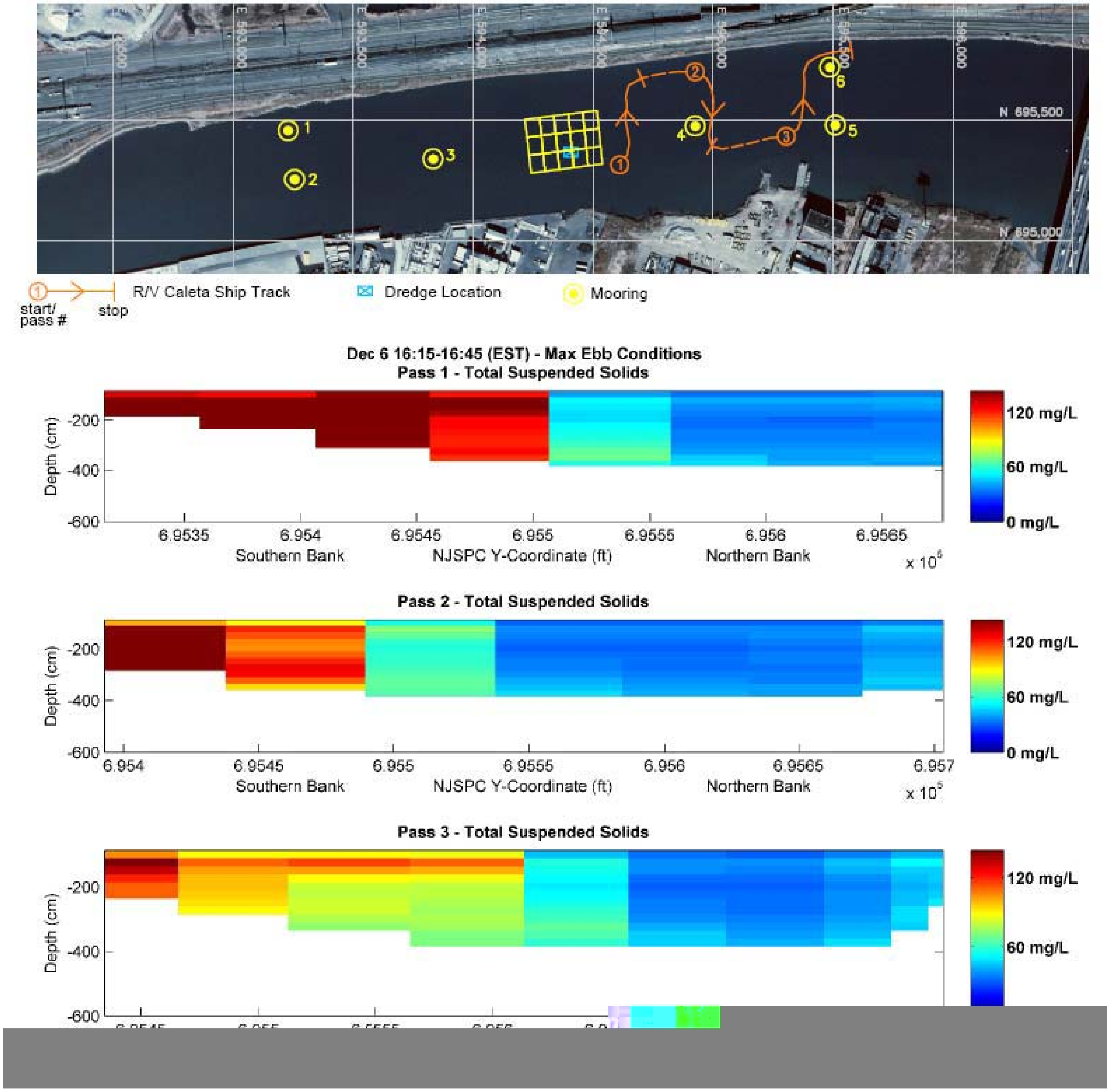


Figure 11. R/V Caleta shiptrack and TSS cross-sections for December 6, 2005 1615-1645 hours EST.

Figure 11 is a similar plot showing the TSS values calculated from reflectivity measurements recorded by the ADCP for the same time period and locations as the velocities described above for Figure 10. The three lower panels in Figure 11 show vertical cross-sections of the calculated TSS values in each of the three passes. The plot shows very high TSS along the southern half of the river that progressively decreases from Pass 1 to Pass 3 as the boat moves further away from the dredging operation.

Figure 12 is a four-panel plot that shows the ship track of the *R/V Caleta* on December 6, 2005 at 0930 hours EST and the data recorded by the ADCP in a single cross channel pass. The first panel is an aerial photograph of the pilot study area showing the locations of the moorings, the position of the dredge within the dredge prism, and the ship track for the *R/V Caleta* from north to south, while it was upriver of the dredging operation between the dredge and Mooring 3. The second and third panels show the along channel velocities and the TSS recorded by the ADCP. The fourth panel shows the calculated TSS flux for this pass. For this plot, the dredging was being performed in Cell A3 (see Figure 6) under flood tide conditions.

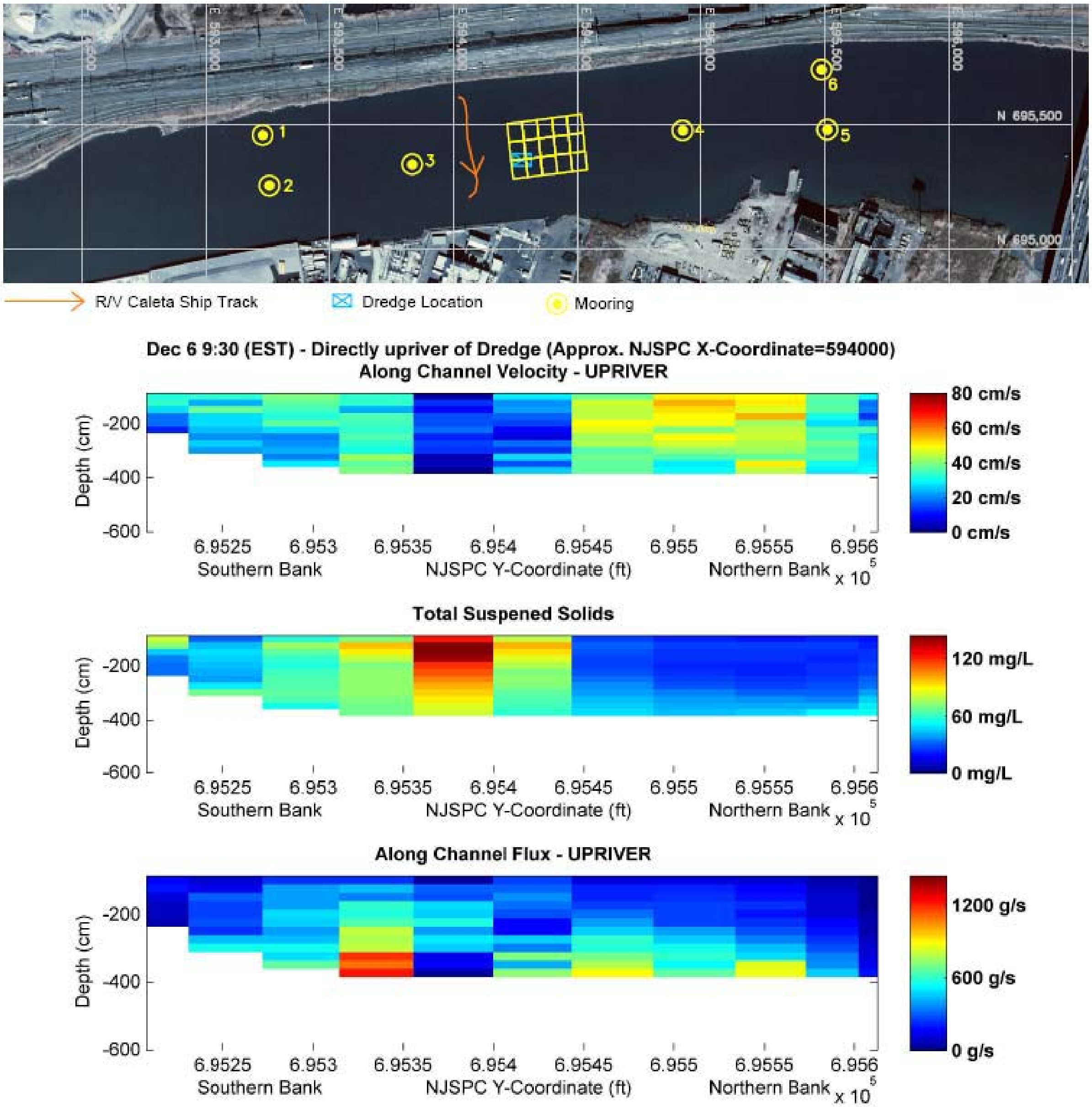


Figure 12. R/V Caleta shiptrack and velocity-TSS-flux cross-sections for December 6, 2005 0930 hours EST under flood tide conditions.

Figure 13 is a three-panel plot that shows the locations of some of the casts made by the *R/V Julia Miller* on December 8, 2005 on the upriver and downriver side of the dredging operation between 1030 hours and 1140 hours EST. The upper panel is an aerial photograph of the pilot study area showing the locations of the moorings, the position of the dredge within the dredge prism, and the locations of the six casts made by the *R/V Julia Miller*. The bottom left panel shows the average concentrations of the suspended sediment particles and their corresponding bin sizes recorded by the LISST for the three casts on the upriver side between Mooring 3 and the dredge prism between 1120 and 1140 hours EST. The bottom right panel shows the average concentrations of the suspended sediment particles and their corresponding bin sizes recorded by the LISST for the three casts on the downriver side near Mooring 4 between 1030 and 1050 hours EST. For this plot, dredging was being performed in Cell C1 (see Figure 6) under flood tide conditions. The observations show that there is an increase in concentration on the upriver side (downflow of the dredging operation) for the larger flocculated particles (bins 24 through 32) corresponding to median particle sizes of 128 to 462 microns which could be attributed to the dredging operation and/or the movement of the salt wedge.

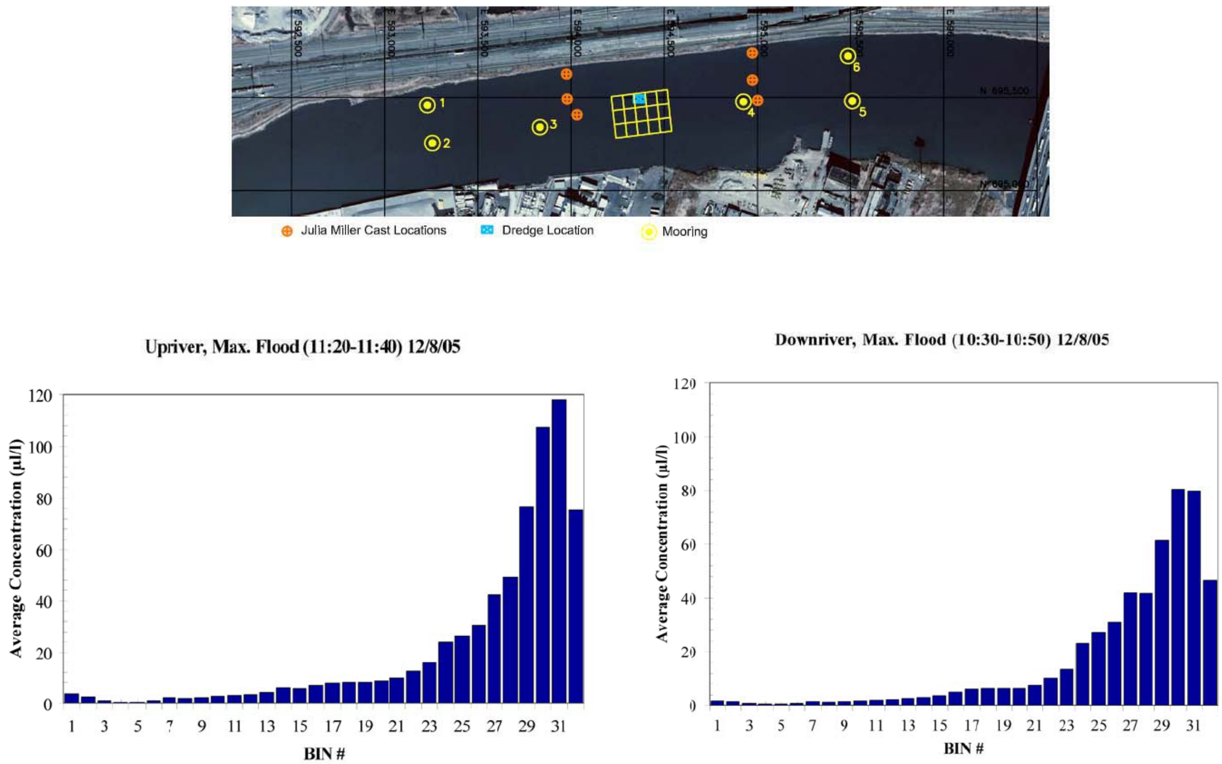


Figure 13. R/V Julia Miller ship location and LISST data concentrations by bin size for December 8, 2005.

Figure 14 is another three-panel plot that shows the locations of the six casts made by the *R/V Julia Miller* on December 8, 2005 on the upriver and downriver side of the dredging operation between 1036 hours and 1134 hours EST. The upper panel is an aerial photograph of the pilot study area showing the locations of the moorings, the position of the dredge within the dredge prism, and the locations of the six casts made by the *R/V Julia Miller*. The bottom left panel shows the particle size concentrations for each measurement grouped into three order of magnitude ranges (< 10 microns, 10-100 microns, and > 100 microns) and plotted for each of the three casts recorded by the LISST at 1130 hours, 1132 hours, and 1133 hours EST on the upriver side. The bottom right panel shows the particle size concentrations for each measurement grouped into three order of magnitude ranges (< 10 microns, 10-100 microns, and > 100 microns) and plotted for each of the three casts recorded by the LISST at 1036 hours, 1038 hours and 1040 hours EST on the downriver side. For this plot, dredging was being performed in Cell C1 (see Figure 6) under flood tide conditions.

One method of evaluating the sediment released by the dredging operation is to make a comparison between the TSS flux at the outermost upriver and downriver moorings during maximum ebb and maximum flood conditions. Therefore, a nominal 3-hour time interval was selected that corresponded with the highest velocities recorded by the ADCPs at Moorings 1 and 2 (upriver) and Moorings 5 and 6 (downriver) on December 5, 6, 7, and 8, 2005.

The average and maximum suspended sediment fluxes that were computed for the maximum ebb conditions (December 5 and 6, 2005) and maximum flood conditions (December 7 and 8, 2005) are presented on Table 3. On this table, the transect along the line formed by Moorings 1 and 2 is identified as Transect A (upriver) and the transect along the line formed by Moorings 5 and 6 is identified as Transect F (downriver). Table 3 also presents average discharge as recorded by the ADCPs and the total suspended sediment mass and total volume of river water crossing Transects A and F in this nominal 3-hour time window.

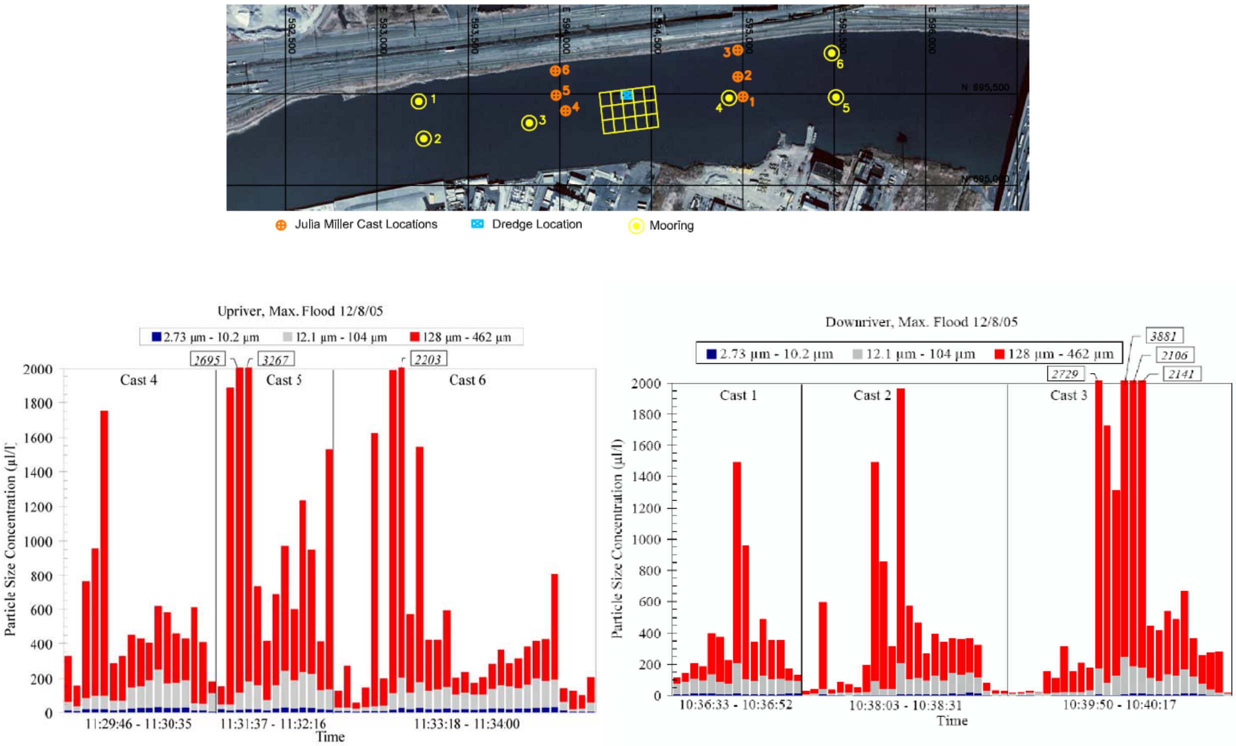


Figure 14. R/V Julia Miller ship location and LISST data particle size concentrations for December 8, 2005.

Table 3. Suspended sediment flux under maximum ebb and maximum flood conditions.

Max Ebb Conditions

December 5, 2005	Average Sediment Flux (kg/s)	Total Sediment Mass (kg)	Max. Sediment Flux (kg/s)	% Δ Sediment Flux (Transect A->F)	Average Flow Rate (cubic meters/s)	Total Water Volume (cubic meters)	% Δ Water Flow (Transect A->F)
Transect A (Mooring 1 and 2)	12.7	137,306	16.1	11%	228	2,467,639	4%
Transect F (Mooring 5 and 6)	14.1	152,783	16.6		239	2,575,909	

December 6, 2005	Average Sediment Flux (kg/s)	Total Sediment Mass (kg)	Max. Sediment Flux (kg/s)	% Δ Sediment Flux (Transect A->F)	Average Flow Rate (cubic meters/s)	Total Water Volume (cubic meters)	% Δ Water Flow (Transect A->F)
Transect A (Mooring 1 and 2)	11.9	128,342	13.2	12%	223	2,406,987	-10%
Transect F (Mooring 5 and 6)	13.3	143,686	16.6		202	2,176,732	

Max Flood Conditions

December 7, 2005	Average Sediment Flux (kg/s)	Total Sediment Mass (kg)	Max. Sediment Flux (kg/s)	% Δ Sediment Flux (Transect F->A)	Average Flow Rate (cubic meters/s)	Total Water Volume (cubic meters)	% Δ Water Flow (Transect F->A)
Transect A (Mooring 1 and 2)	-2.2	-24,255	-3.2	0%	-105	-1,133,072	-1%
Transect F (Mooring 5 and 6)	-2.2	-24,257	-3.3		-106	-1,140,547	

December 8, 2005**	Average Sediment Flux (kg/s)	Total Sediment Mass (kg)	Max. Sediment Flux (kg/s)	% Δ Sediment Flux (Transect F->A)	Average Flow Rate (cubic meters/s)	Total Water Volume (cubic meters)	% Δ Water Flow (Transect F->A)
Transect A (Mooring 1 and 2)	-6.4	-57,614	-8.7	-13%	-204	-1,837,415	7%
Transect F (Mooring 5 and 6)	-7.4	-66,267	-11.9		-192	-1,723,748	

*** Data for Dec 8, 2005 is over a 2.5 hour time period in comparison to the 3 hour time periods used for Dec 5th, 6th, and 7th.*

Table 3 shows suspended sediment flux and the water flow rate at Transects A and F on December 5, 2005 between 1300 hours and 1630 hours EST (maximum ebb conditions). At Transect A, the average and maximum sediment fluxes were 12.7 kg [28 lb] per second and 16.1 kg [35 lb] per second, respectively. At Transect F, the average and maximum sediment fluxes were 14.1 kg [31 lb] per second and 16.6 kg [37 lb] per second, respectively. As the water flowed from upriver to downriver during this time period, there was a net average gain of 1.5 kg [3 lb] per second which potentially could be attributed to the dredging operation and/or the movement of the salt wedge, although this average gain is within the range of the measurement error.

Similarly, Table 3 shows suspended sediment flux and the water flow rate at Transects A and F on December 7, 2005 between 0830 hours and 1200 hours EST (maximum flood conditions). At Transect A, the average and maximum sediment fluxes were 2.2 kg [5 lb] per second and 3.2 kg [7 lb] per second, respectively. At Transect F, the average and maximum sediment fluxes were 2.2 kg [5 lb] per second and 3.3 kg [5 lb] per second, respectively. As the water flowed from downriver to upriver during this time period, there was no net change in the calculated sediment flux as recorded by the ADCPs.

Similar comparisons were also performed for the background monitoring period on December 3, 2005, when no dredging equipment had been brought to the pilot study area. Figure 15 shows suspended sediment flux and the water flow rate at Transects A and F on December 3, 2005 between 1100 hours and 1430 hours EST (maximum ebb conditions). At Transect A, the average and maximum sediment fluxes were 35.2 kg [78 lb] per second and 49.8 kg [110 lb] per second, respectively. At Transect F, the average and maximum sediment fluxes were 34.4 kg [76 lb] per second and 44.7 kg [99 lb] per second, respectively. As previously noted, the freshwater discharge on this day was very high. As the water flowed from upriver to downriver during this time period, there was an apparent net average loss of 0.8 kg [2 lb] per second in the calculated sediment flux as recorded by the ADCPs. This is within the range of measurement error.

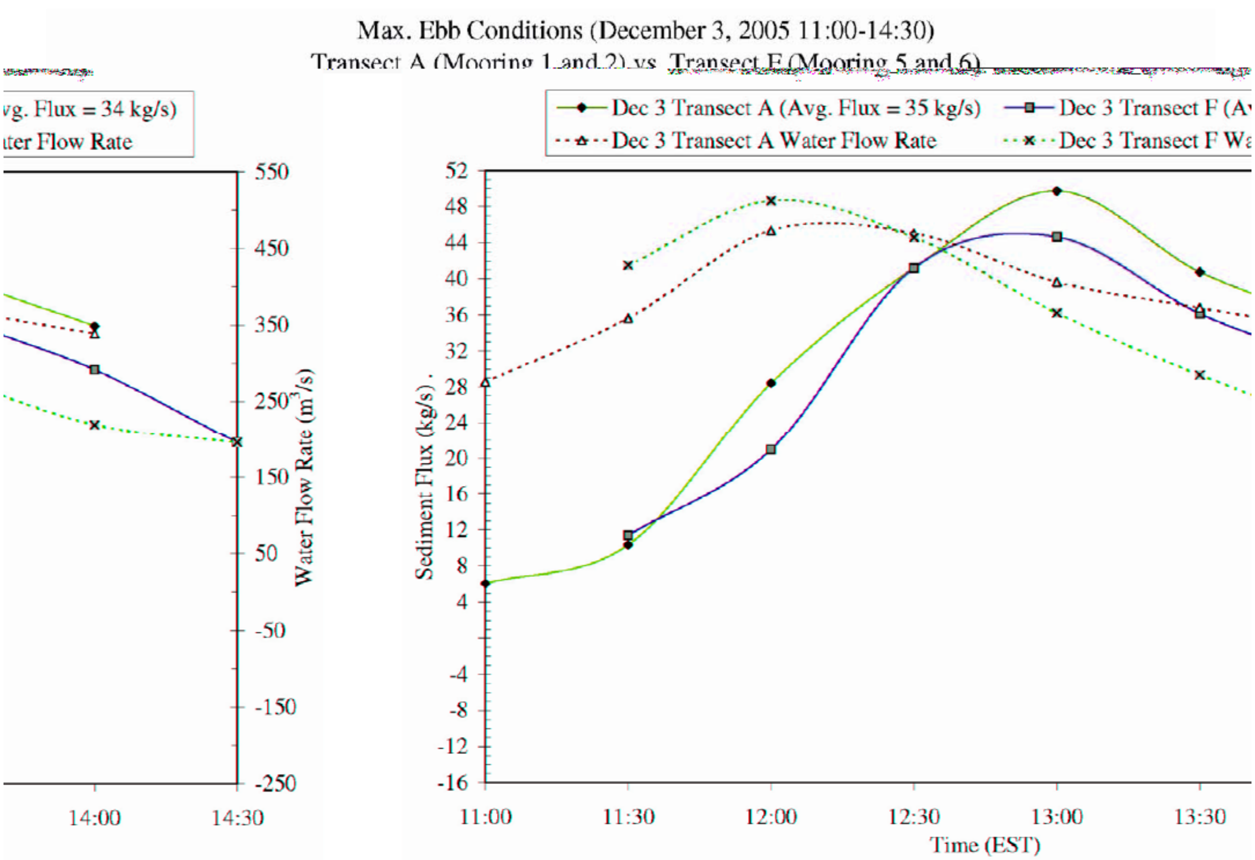


Figure 15. Suspended sediment flux under maximum ebb conditions on December 3, 2005.

Figure 16 shows suspended sediment flux and the water flow rate at Transects A and F on December 3, 2005 between 0500 hours and 0830 hours EST (maximum flood conditions). At Transect A, the average and maximum sediment fluxes were 6.7 kg [15 lb] per second and 12.2 kg [27 lb] per second, respectively. At Transect F, the average and maximum sediment fluxes were 8.0 kg [18 lb] per second and 15.6 kg [34 lb] per second, respectively. As the water flowed from downriver to upriver during this time period, there was an apparent net average loss of 1.3 kg [3 lb] per second in the calculated sediment flux as recorded by the ADCPs during the background monitoring period. This is within the range of measurement error.

Therefore, a comparison of the TSS flux at the outermost upriver and downriver moorings during maximum ebb and maximum flood conditions (as illustrated above for the background monitoring period and many days during dredging) appears to indicate that it is not possible to identify any sediment released by the dredging operation at this distance (approximately 305 m [1000 ft]).

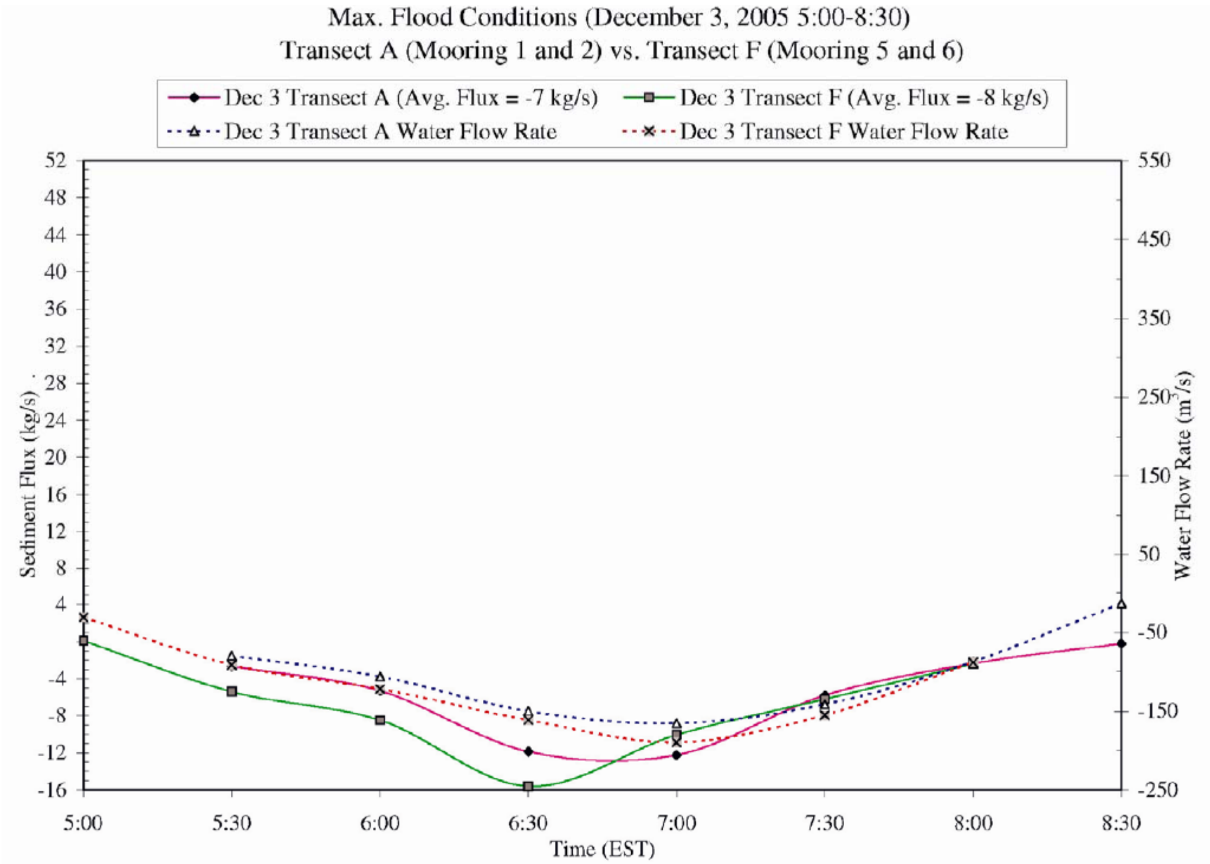


Figure 16. Suspended sediment flux under maximum flood conditions on December 3, 2005.

CONCLUSIONS

Using a 6.1 m^3 [8-cy] Cable Arm® mechanical clamshell dredge bucket, a total of 3,173 m^3 [4,150 cy] were dredged, with an average productivity of 635 m^3/day [830 cy/day]. The average working day was 10 hours and the average dredging time was 6.4 hours yielding an average up-time of 64 percent. 66 to 72% of the area was dredged within 15 cm [6 in] of the design elevation, 82% to 89% of the area was dredged within 23 cm [9 in] of the design elevation, and 92 to 94% of the area was dredged within 30 cm [12 in] of the design elevation. Overall, the days that the Cable Arm® sensors were functioning, demonstrate an improvement in dredging accuracy (increase of 7%) in order to achieve the targeted depth. Considering that the dredging equipment was mobilized to the Pilot Study Area on a Sunday afternoon and dredging began in full swing on Monday morning with no shake-down time, this was an excellent performance.

The measurements recorded by the ADCP on the *R/V Caleta* have shown that a signal from the dredging operation can be detected closer to the dredge prism and that this signal becomes weaker as one moves further away. The measurements recorded by the LISST on the *R/V Julia Miller* have also indicated that the signal from the dredging operation is detected closer to the dredging operation. The LISST measurements also show that the suspended sediment appears to be transported as relatively larger flocculated silt particles.

The observed results show that the two main components that dominate the hydrodynamics at the pilot study area are tidal energy and freshwater discharge. As indicated by the hydrodynamic and sediment transport modeling, in December 2005 when the freshwater discharge was nearly three times the mean, the signal from the dredging operation was small in relation to the background suspended sediment load in the Lower Passaic River and was masked by the movement of salt wedge. Therefore, any observable effects of the full-scale dredging operation were primarily limited to the vicinity of the inner moorings (3 and 4) and were not detectable at the outer upriver (1 and 2) and downriver (5 and 6) moorings.

Water quality data collected by the TOPS boats (not presented here due to space considerations) have shown that contaminant transport is primarily in the suspended phase and not via the dissolved phase. In addition, the concentrations of the chemicals of concern measured in the suspended phase are within the range of those measured at the sediment surface in the vicinity of the pilot study dredge prism.

A Preliminary Draft of the Pilot Study Report has been prepared and is undergoing internal review by the Partner Agencies prior to being released. Additional data analysis is still pending and is expected to be completed by the time this manuscript will be presented at the WODCON XVIII conference.

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ACKNOWLEDGEMENTS

This pilot study was conducted by a coordinated technical team composed of experts from multiple agencies, organizations, universities and consulting firms. The pilot was led and primarily funded by NJDOT– the Local Sponsor for the overall Feasibility Study. The dredging was performed by Jay Cashman Inc., with support from Cable Arm Inc. The USACE provided the base of operations via the *SUV* Hudson, field personnel, and dredging construction oversight. USEPA provided analytical services for water quality samples and critical partnership for the decontamination pilot. USFWS provided the shuttle vessel and field staff, and US Geologic Survey (USGS) and Rutgers University led the water quality monitoring program. The consultant team included Earth Tech, Inc (NJDOT's prime consultant) and Malcolm Pirnie, Inc., firms that provided the basis for the design, project specifications, and implementation of the program including dredging construction oversight with the multi-agency partnership. Aqua Survey, Inc. also conducted many of preparatory surveys and provided vessels and field personnel for pilot planning and implementation. NJDEP, Office of Dredging and Sediment Technology provided technical assistance and permits including the Federal Consistency Determination and Water Quality Certificate. Dr. Donald Hayes from the University of Utah and Dr. Michael Palermo of Mike Palermo Consulting were key advisors to the development of the Environmental Dredging Pilot. The Passaic Valley Sewerage Commissioners (PVSC) provided the dock for launching all the sampling boats. Along with Lisa Baron (NJDOT), Peter Weppler (USACE) and Alice Yeh (USEPA) also provided essential support for the pilot study and the overall Feasibility Study.