RESUSPENSION MONITORING DURING REMEDIAL DREDGING IN ONE OF AMERICA'S MOST POLLUTED RIVERS

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ABSTRACT

In December 2005, a pilot study to evaluate remedial dredging of contaminated sediments from the Lower Passaic River in Newark, New Jersey was led by NJDOT along with the USACE and USEPA. The dredging pilot study was performed as part of the Lower Passaic River Restoration Project, which is being conducted under the Urban Rivers Restoration Initiative to develop a comprehensive plan to restore this 17-mile [27.3-kilometer] long, highly-degraded industrial waterway.

Using an 8-cy [6.1 m^3] Cable Arm® mechanical clamshell dredge bucket approximately 5,000 cubic yards (cy) [3,825 m^3] of contaminated sediment were dredged from a 1.5 acre [6,070 m^2] area in 10 to 15 feet [3.0 to 4.6 m] of water in the Harrison Reach just west of the New Jersey Turnpike Bridge over a five day period. One of the primary goals of this pilot study was to attempt 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. The comprehensive and elaborate resuspension monitoring program utilized a combination of six fixed moorings as well as shipboard monitoring using four boats.

Prior to execution of the study, a focused three-dimensional (3-D) hydrodynamic and sediment transport model using Computational Fluid Dynamics (CFD) was developed to determine the best 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 without engineering controls. Other aspects of the pilot study including dredging productivity and equipment performance are documented in a separate manuscript (Thompson et al., 2006).

This paper presents preliminary results of the resuspension monitoring measurements using the various instruments on the six moorings and four boats.

Keywords: contaminated sediments, estuarine dynamics, mechanical dredging, ADCP, LISST, TOPS

INTRODUCTION

An environmental dredging pilot study was conducted in the Lower Passaic River in Newark, New Jersey during the first week in December 2005 (Figure 1). The pilot study was performed as part of the Feasibility Study for the Lower Passaic Restoration Project. The U.S Environmental Protection Agency, Region 2 (EPA), the U.S. Army Corps of Engineers, New York District (USACE), and the New Jersey Department of Transportation, Office of Maritime Resources (NJDOT) formed a partnership with U.S. Fish and Wildlife Service (USFWS), National Oceanic Atmospheric Administration (NOAA) and New Jersey Department of 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-shared funding for the WRDA portion of the project. The Feasibility Study will address remediation and restoration of the 17-mile [27.3 km] tidally influenced Lower Passaic River and its surrounding watershed.

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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.

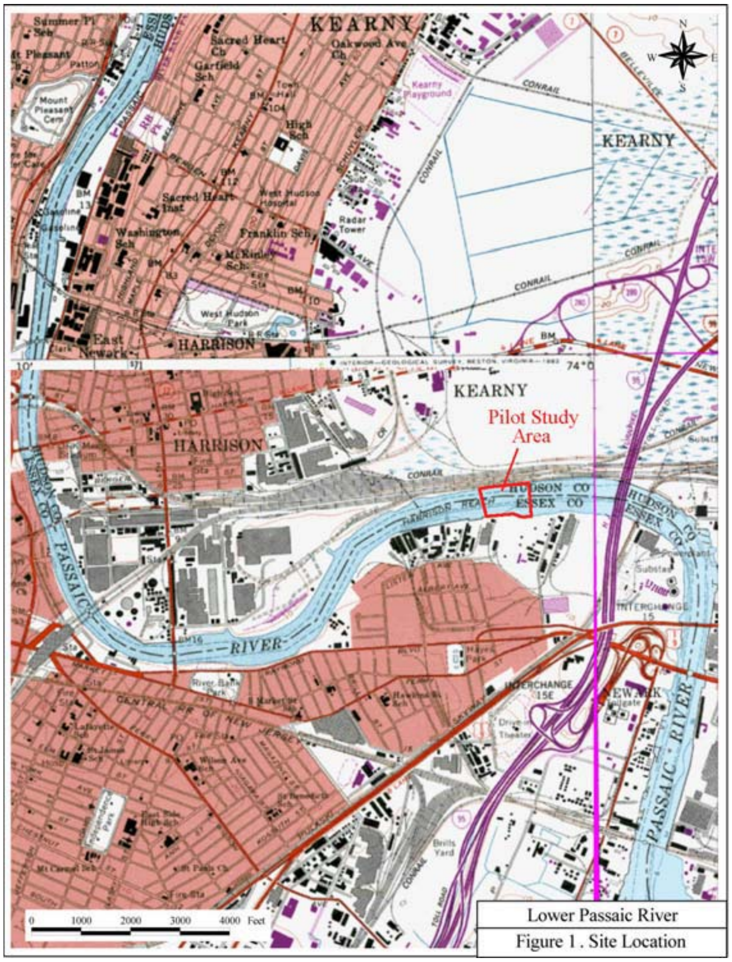


Figure 1. Map showing Harrison Reach of Lower Passaic River and vicinity.

Site Background

The Passaic River is the principal river in the Hackensack-Passaic Watershed a 935 square mile 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. Due to 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. 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 1-2 miles [1.6 – 3.2 km] 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 feet [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 portion of the Lower Passaic River sediment has been dewatered and 300 cy [230 m^3] of the dewatered material will undergo treatment with a thermo-chemical destruction process using a rotary kiln. Construction-grade cement will be produced during the treatment process, which could be used in the construction of sidewalks, parking lots, and driveways. The remaining sediment is being treated 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.

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. The monitoring program will help determine what kind of engineering controls would be required for a full-scale sediment removal action.
- Evaluate sediment decontamination and treatability. The pilot will evaluate the technical feasibility and economic viability of two decontamination technologies to treat contaminated Lower Passaic River sediments and determine whether a valuable product, such as manufactured soil or construction-grade cement, can be produced at full scale.

A comprehensive and elaborate 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. This paper presents preliminary results using the various instruments on the six moorings and four boats.

Hydrodynamic and Sediment Transport Modeling

Prior to execution of the study, a focused three dimensional hydrodynamic and sediment transport model using Computational Fluid Dynamics (CFD) modeling software Flow3D (http://www.flow3d.com/software/index.htm) was developed to determine the best 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 without engineering controls. 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 from pilot dredging. Each sediment class (i.e., sand, silt and clay) was modeled as a group with an average median particle diameter (D_{50}). This rate was then used as a source term in the Flow3D model which was used to simulate transport and settling of sediment. The dredging work 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. As a conservative approach from 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 would cause increased settling velocities of the silts and clays, thus increasing settling rate and decreasing the mass flux leaving the system.

Modeling Results

The model predictions indicated that the plume follows the path of deeper water conveyance (i.e., along the navigational channel closer to the northern bank). The plume is well defined during ebb tide; however, the plume is mixed after the flow reversal during flood tide. The plume progression characteristics were similar to those observed during the dye studies (September and October 2004) performed by Rutgers University. Both shipboard surveys and fixed moorings along four transects (two on either side of the dredging operation) were recommended for monitoring. 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 distance was indicated by Jay Cashman to be 400 ft [120 m] to allow movement and turning of the dredge, guide barge and scows. The two outer transects were positioned at a distance of approximately 1000 ft [300 m] that corresponds to the maximum distance where the coarse particles (i.e., sand) are expected to settle leaving only fines (i.e., silt and clay) to monitor. Assuming a one percent sediment release rate, the model predicted that dredging 5,000 cy [3,825 m^3] would result in a release of 55 tons [50 MT] of sediment. Sand is 16 percent of the 55 tons by weight, and it settles within approximately 500 ft [154 m] of release. Therefore, an estimated 46 tons [41.8 MT] of silt and clay would leave the study area assuming no flocculation. The estimated 46 tons of sediment released during pilot study dredging 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.

Resuspension Monitoring

Fixed Moorings

Figure 3 shows an aerial photograph of the pilot study area in the Harrison Reach with the six moorings. Four of the six moorings 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 follows the path of deeper water conveyance, the remaining two moorings were located in the deepest portion of the navigation channel at the same distance (at approximately 300 m) as the outermost centerline moorings (closer to the northern bank – one on either side of the dredging operation).

Each mooring, consisting of a float at the water surface and an anchor and a tripod frame suspended on a chain, was equipped with two Conductivity-Temperature-Depth (CTD) probes, two Optical Back Scatter (OBS) sensors, and an Acoustic Doppler Current Profiler (ADCP). In addition to the above instruments, the two centerline moorings closest to the targeted dredge prism (at approximately 120 m) were each equipped with a Laser In-Situ Scattering and Transmissometry (LISST) probe. The moorings monitored water column stratification and stability, particle concentration, and size distribution on a 24-hour-basis throughout the project. The mooring instruments are shown in Figure 4. Table 1 shows the measurements made by the instruments on each mooring.

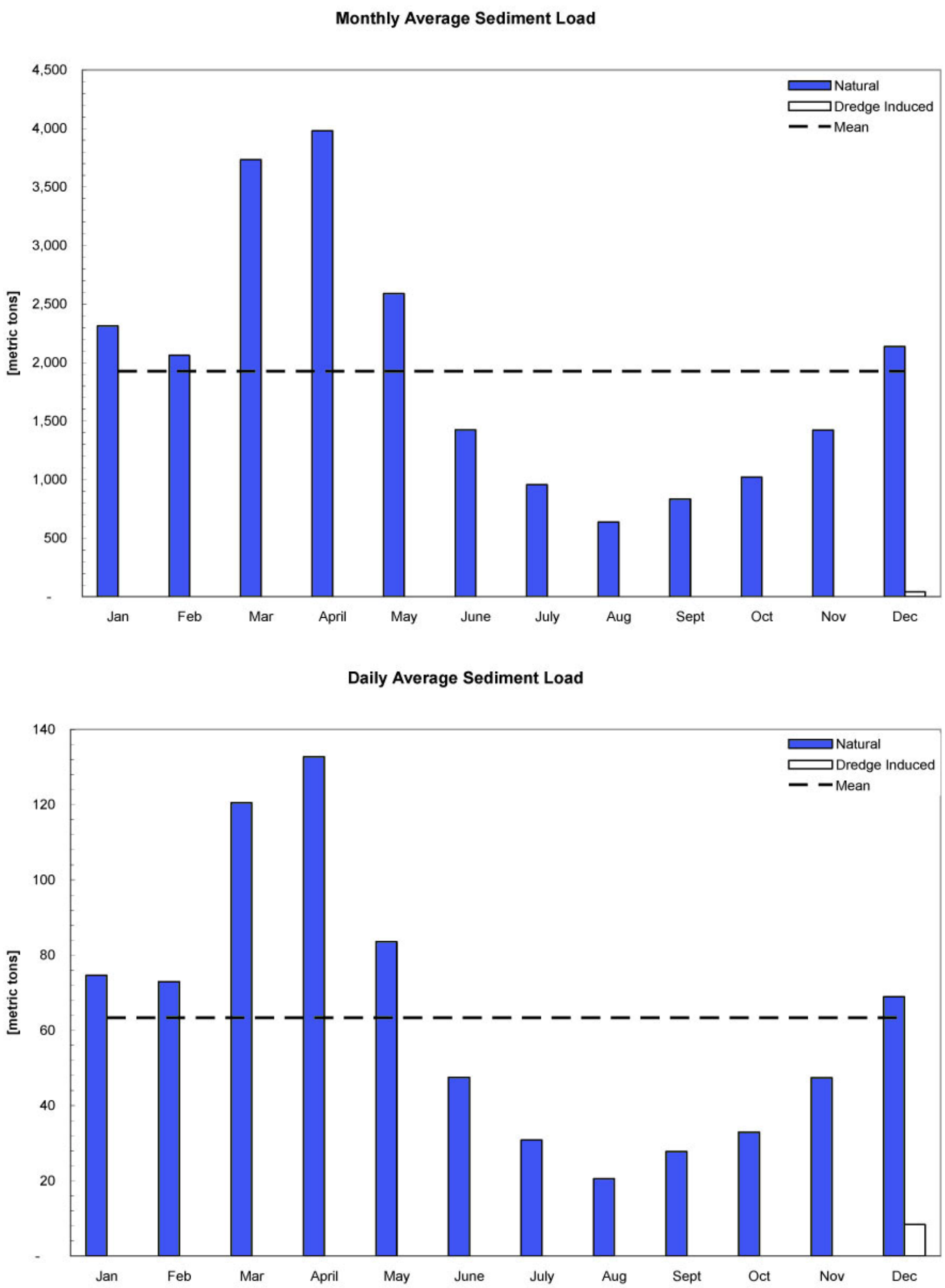


Figure 2. Monthly and daily average sediment load.

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

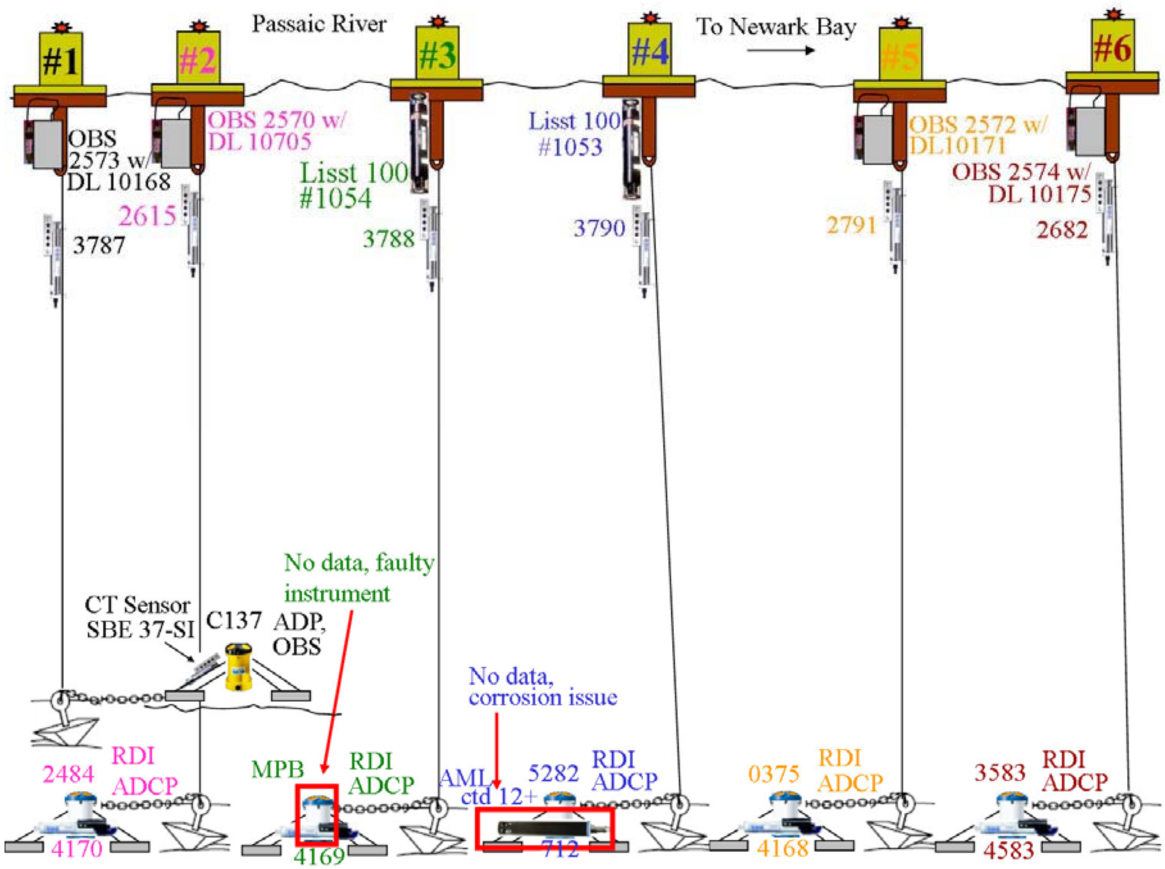


Figure 4. Six Moorings with instruments, floats, anchors, and tripod frames.

Table 1. Monitoring instruments for hydrodynamic data.

Mooring/Vessel	Instrument Location	Instrument Type	Measurements
Mooring 1	Bottom	ADP	Velocities (cm/s) Reflectivity Pressure (depth m)
		OBS with CT sensor	Turbidity (NTU) Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
	Top	OBS w DL	Turbidity (NTU)
		CTD	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
Mooring 2 & Mooring 5 & Mooring 6	Bottom	ADCP	Velocities (cm/s) Reflectivity Pressure (depth m)
		OBS	Turbidity (NTU)
		CTD	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
	Top	OBS w DL	Turbidity (NTU)
		CTD	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
Mooring 3 & Mooring 4	Bottom	ADCP*	Velocities (cm/s) Reflectivity Pressure (depth m)
		OBS	Turbidity (NTU)
		CTD	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
	Top	LISST	Volume Concentrations (ul/l) Pressure (depth m) Temperature (° C/F)
		CTD*	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
R/V Caleta	Variable	ADCP	Velocities (cm/s)
		CTD	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
		OBS	Turbidity (NTU)
R/V Julia Miller	Variable	LISST	Volume Concentrations (ul/l) Pressure (depth m) Temperature (° C/F)
		CTD	Conductivity (S/m) Salinity (PSU) Temperature (° C/F)
		OBS	Turbidity (NTU)

Top = meter below surface (mbs)
Bottom = meter above bottom (mab)
ADCP on Mooring 3 was a faulty instrument
CTD on Mooring 4 was a faulty instrument
Mooring ADCP velocities are along channel, cross-channel, and vertical and based on principal axis determined by direction of water flow
R/V Caleta ADCP velocities are east-west and north-south and based on an absolute coordinate system

Shipboard Survey Monitoring

Four boats were utilized to perform the shipboard surveys and sampling. Two of the four boats, each equipped with a global positioning system (GPS), a depth profiler, a Trace Organic Platform Sampler (TOPS) apparatus and two ISCO automatic samplers, performed continuous traverses perpendicular to the river flow at half-hour intervals along the outermost upriver and downriver moorings (see T-boats on Figure 5). They collected water samples for total suspended solids (TSS), particulate and dissolved organic carbon (POC and DOC), chloride/bromide, and for both filtered and unfiltered metals, low level mercury, dioxins/furans, PCB congeners, and pesticides analyses. The sediment load can be evaluated by comparing TSS and contaminant concentrations downstream to background TSS and contaminant concentrations measured upstream. A third boat, (the R/V Caleta) equipped with a CTD probe, an OBS sensor, and an ADCP, conducted sweeps across the near-field plume in a zigzag pattern crossing the plume approximately seven times in approximately one hour (see M boat on Figure 5). The fourth boat (the R/V Julia Miller) equipped with a CTD probe, a LISST probe, and an OBS sensor, ran along the centerline of the plume parallel to the flow (see L Boat on Figure 5). To a limited extent, this fourth boat also moved in a zigzag pattern to identify the edges of the plume. TSS samples were collected throughout the five-day study to calibrate the direct reading instruments. These two boats (L and M) also monitored upstream to measure background concentrations.

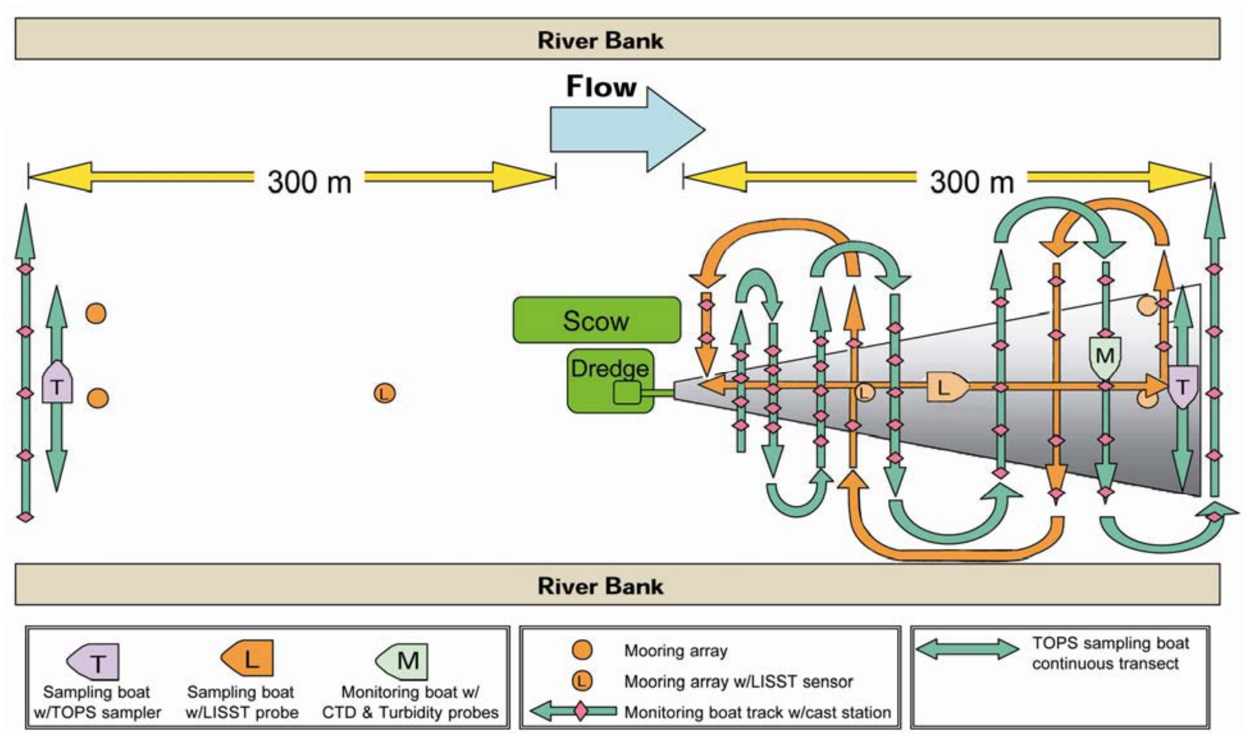


Figure 5. Monitoring mooring arrangement with monitoring boat track.

The dredging was performed by Jay Cashman on December 5 through 10, 2005. No dredging was performed on December 9, 2005 due to severe snowstorm with gale force winds. The TOPS boats performed pre-dredge background monitoring activities on December 1, 2005, and during dredging monitoring on December 5, 6, 7, 8, and 10, 2005. Only one TOPS boat was used to perform post-dredging monitoring on December 12, 2005. Along a transect defined by Moorings 1 and 2, the upriver TOPS boat (TU) performed continuous traverses perpendicular to the river flow at half-hour intervals. The downriver TOPS boat (TD) performed continuous traverses perpendicular to the river flow at half-hour intervals along a transect defined by Moorings 5 and 6. During the 'A' leg of the traverse from the south river bank to the north river bank the water intake lines were positioned one meter 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 one meter above the sediment bottom. Each TOPS boat had two ISCO automatic samplers that were utilized to collect samples for TSS, TOC, POC, and chloride/bromide analyses. A peristaltic pump on each TOPS boat was used to collect low level mercury and TAL metals samples. 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 for dioxins/furans (PCDDs/PCDFs), pesticides, and PCB congener analyses. 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. Figure 6 shows the freshwater discharge collected at the USGS gauge in Little Falls, New Jersey between November 20 and December 20, 2005.

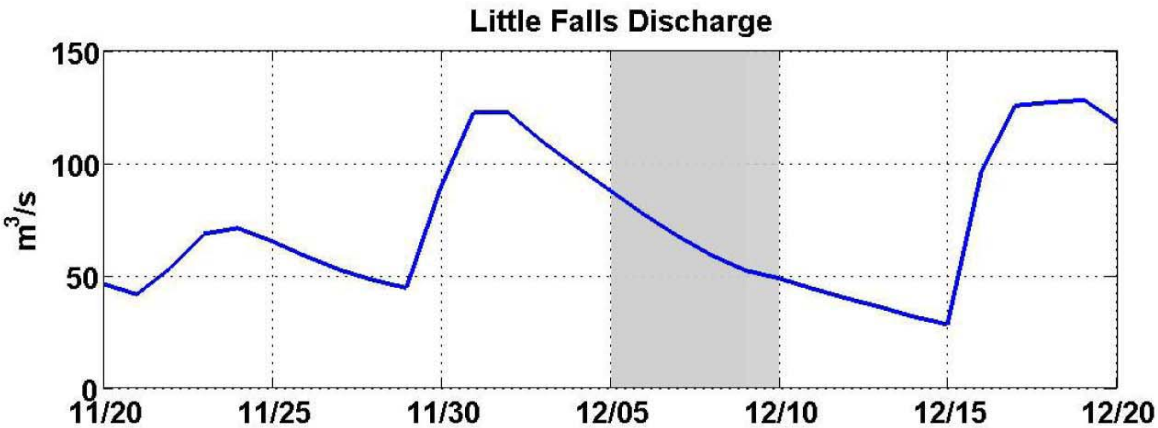


Figure 6. Freshwater discharge measured at the USGS gauge in Little Falls, New Jersey.

Preliminary Monitoring Results

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.

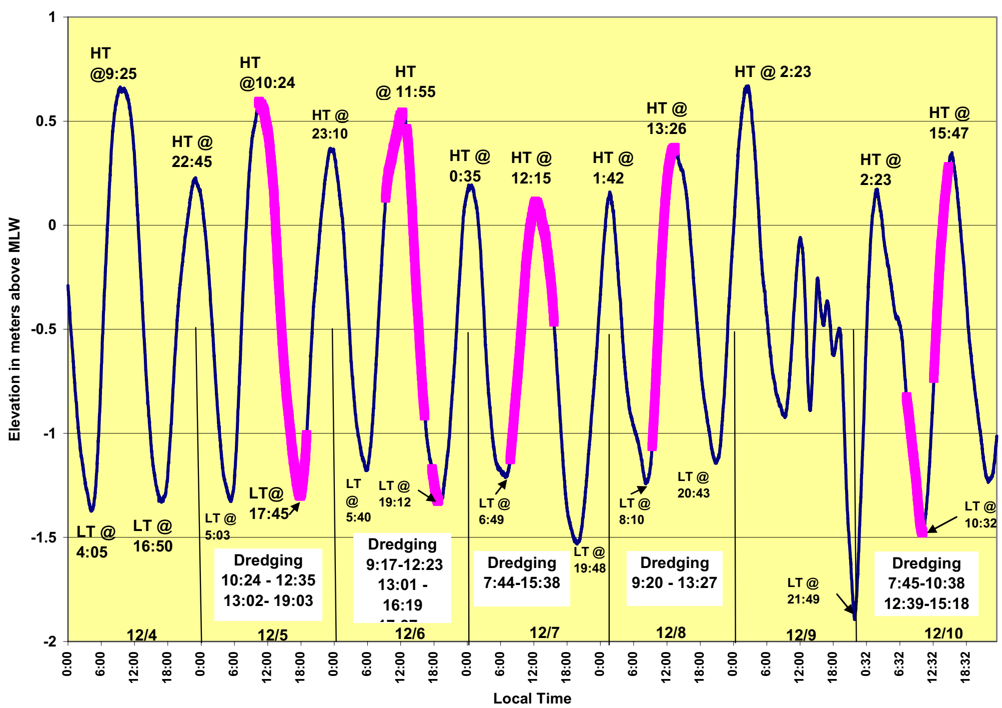


Figure 7. Water surface elevation measured at mooring 2.

Mooring 4 is located just downriver from the dredging area. Figure 8 shows the measurements recorded at Mooring 4 during the background monitoring period between December 1 and 3, 2005.

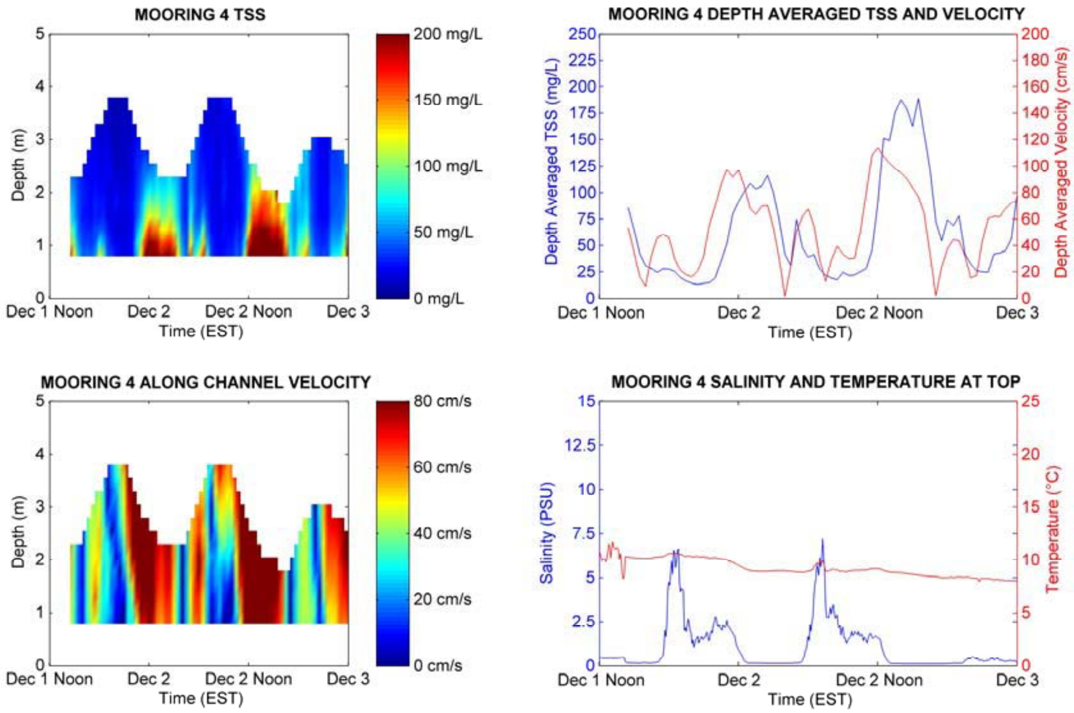


Figure 8. Background (pre-dredge) monitoring measurements at mooring 4.

The upper left panel shows the suspended solids measurements as they vary with depth and time between noon on December 1, 2005 (soon after the moorings were deployed) and midnight on December 2, 2005. The lower left panel in Figure 8 shows the along channel velocity as it varies with depth and time. As expected, during the ebb tides these velocities were the highest. The top right panel on Figure 8 shows a time series of depth averaged TSS and depth averaged velocity. The observations show the estuarine turbidity maxima. The lower right panel on Figure 8 shows the salinity and temperature as recorded by the top CTD. Due to instrument malfunction, the bottom CTD on Mooring 4 was not able to record any data.

Figure 9 shows similar measurements recorded at Mooring 4 (downriver from the dredging area) on the first two days of dredging, December 5 and 6, 2005. During these days, Jay Cashman dredged the 13 ft and 11ft cuts, respectively. More details pertaining to the dredge prism design, dredging productivity and equipment performance are presented in a separate manuscript (Thompson et al., 2006). The upper left panel on Figure 9 shows the suspended solids measurements as they vary with depth and time between midnight on December 4, 2005 and midnight on December 6, 2005. The lower left panel in Figure 9 shows the along channel velocity as it varies with depth and time. As expected, these velocities were the highest during the ebb tides. The top right panel on Figure 9 shows a time series of depth averaged TSS and depth averaged velocity. The observations show the estuarine turbidity maxima and indicate that the highest TSS recorded on these two days are comparable to those recorded during the pre-dredge monitoring on December 2, 2005 as shown in the top right panel on Figure 8. The corresponding highest depth averaged velocities recorded at Mooring 4 during December 5 and 6, 2005 as shown on Figure 9 are lower than the corresponding highest depth averaged velocities recorded at Mooring 4 on December 2, 2005. The lower right panel on Figure 9 shows the salinity and temperature as recorded by the top CTD. Although the salinity on December 5 and 6, 2005 is comparable to that observed on December 2, 2005, the surface temperature on December 5 and 6, 2005 is lower than that observed on December 2, 2005. As noted previously, no data was available for the bottom CTD on Mooring 4 due to instrument malfunction.

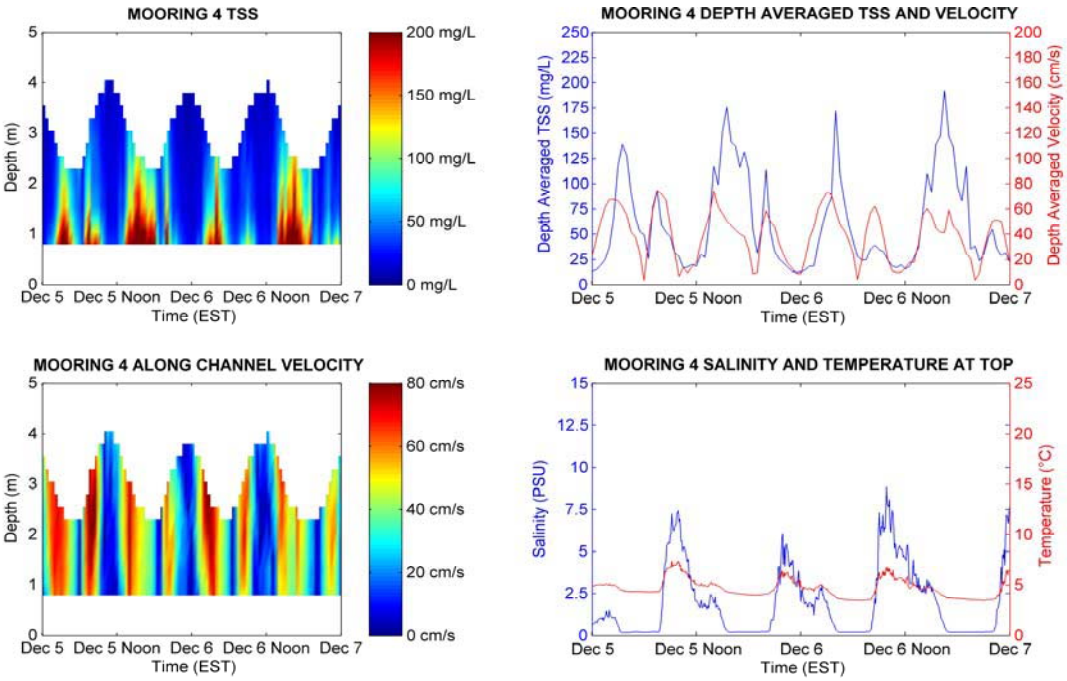


Figure 9. During dredging (first two days) monitoring measurements at mooring 4.

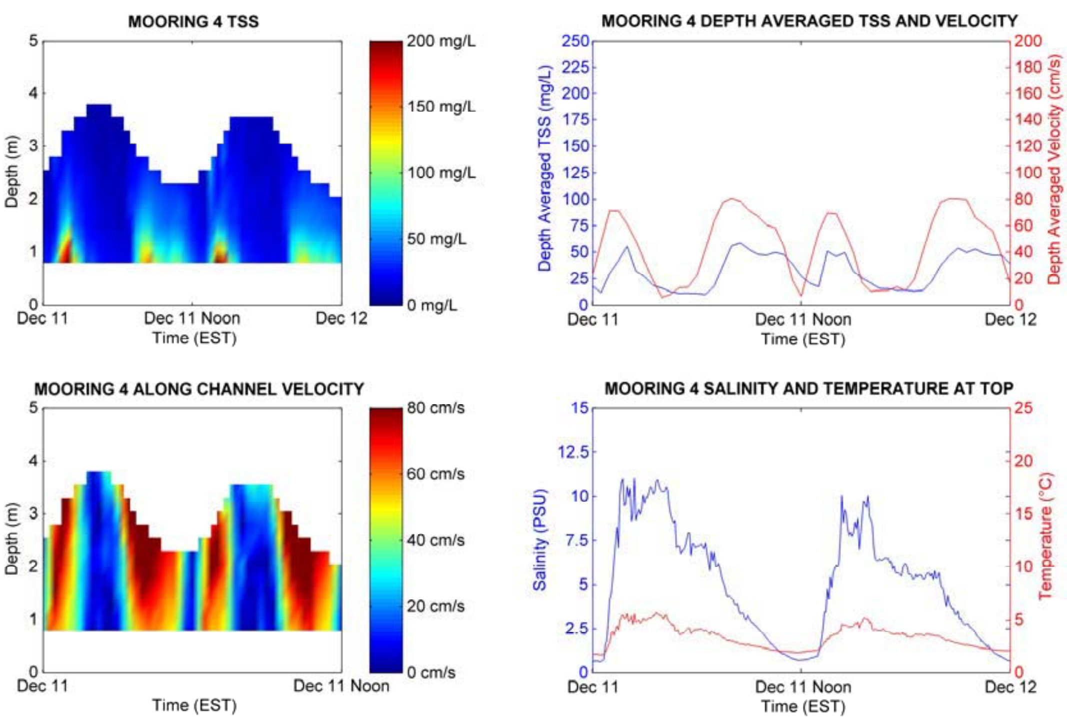


Figure 10. Post dredging monitoring measurements at mooring 4.

Figure 10 shows post-dredging measurements recorded at Mooring 4. The upper left panel shows the suspended solids measurements as they vary with depth and time on December 11, 2005. As with Figures 8 and 9, the lower left panel shows along channel velocity as it varies with depth and time. The top right panel shows depth averaged TSS and depth averaged velocity as a time series and the bottom right panel shows the surface salinity and temperature. The salinity on December 11, 2005 appears to be much higher than on previous days and the temperature is also the lowest as compared with Figures 8 and 9. This is probably due to the fact that the freshwater flow in the Lower Passaic River continued to drop between December 2 and 15, 2005 as shown on Figure 6. Therefore, the tidal energy was the dominating factor in the pilot study area.

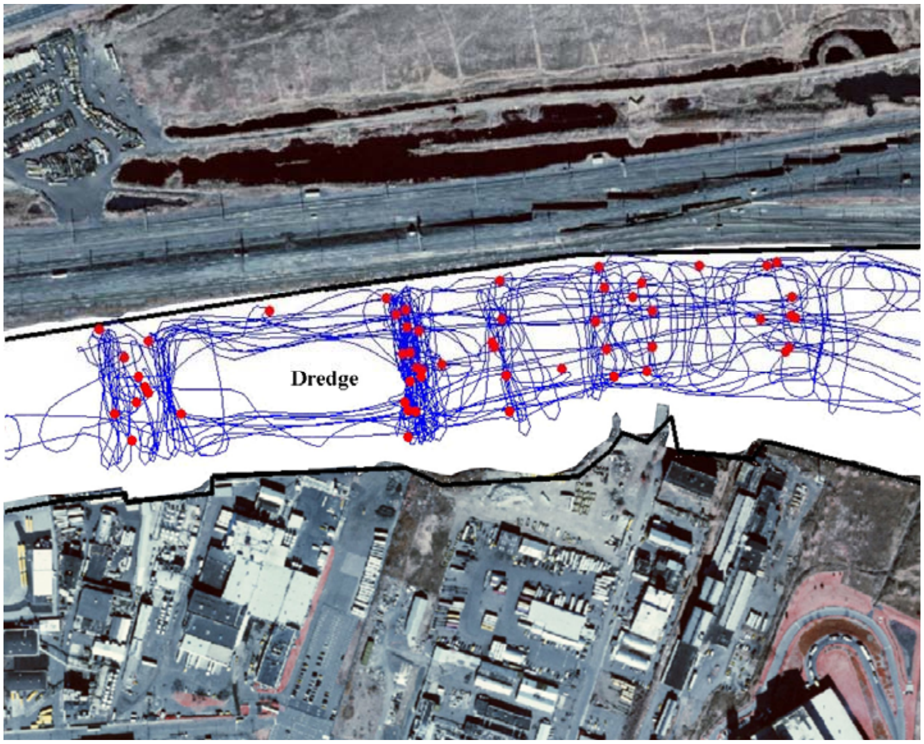


Figure 11. R/V Caleta December 5, 2005 ship tracks (blue lines) and CTD casts (red dots).

Figure 11 shows the ship tracks of the R/V Caleta (M boat) on the first day of dredging, December 5, 2005. As stated above, this boat was equipped with a GPS, an ADCP, and OBS sensor and a CTD probe. This boat conducted sweeps across the near-field plume in a zigzag pattern crossing the plume approximately seven times in approximately one hour. The open oval between the blue lines in the left portion of Figure 11 is the dredging area. The ADCP measurements were recorded continuously and at select intervals and locations a CTD cast was made to obtain a complete vertical profile of the water column. In addition, grab samples for TSS analyses were also collected. Approximately 100 grab samples for TSS analyses by the USEPA Region 2 DESA laboratory in Edison, New Jersey were collected from the M boat during the five days of dredging.

Figure 12 shows surface currents recorded in the pilot study area near maximum ebb tide conditions on December 5, 2005 along four tracks. The first track is along Mooring 3 and is upriver from the dredging area. Tracks 2, 3, and 4 moving west are downriver from the dredging area. Track 2 is just downriver from the dredging area and Track 4 is downriver well beyond Moorings 5 and 6. Track 3 is located just west of Moorings 5 and 6. Figure 13 shows vertical cross sections taken along these four tracks and presents TSS (white contour lines) and current velocity (black contour lines with values). The vertical axis on this four panel plot shows the depth and the horizontal axis shows the cross channel distance as measured from the southern bank of the river.

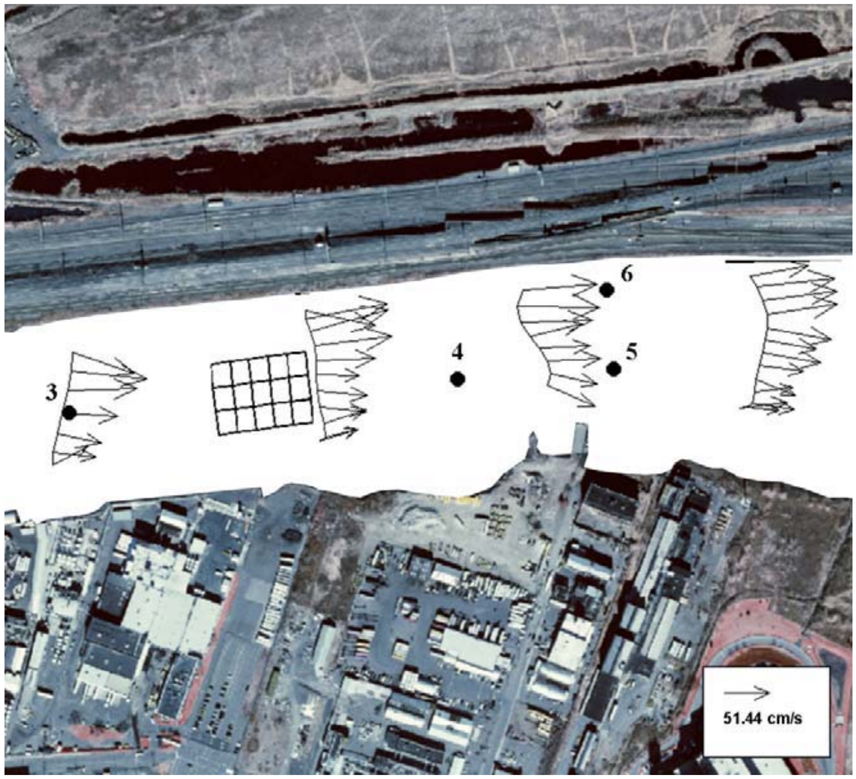


Figure 12. R/V Caleta December 5, 2005 surface currents near maximum ebb tide.

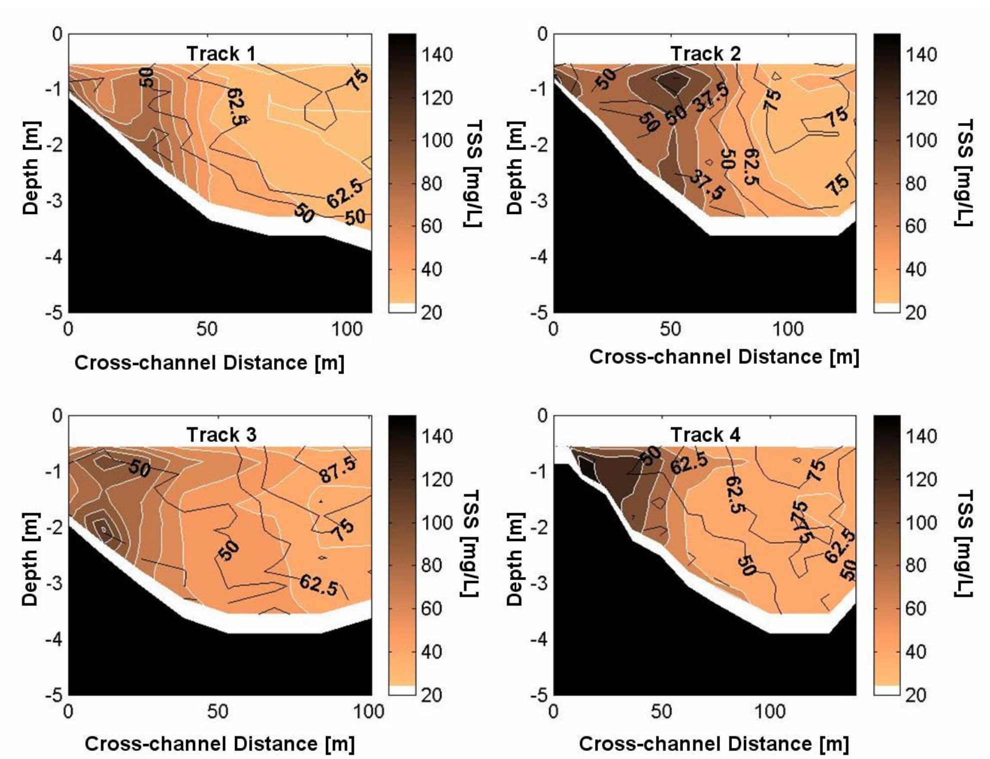


Figure 13. Cross sections along four tracks (shown in Figure 12).

Figure 14 shows the calibration of the R/V Caleta ADCP using the grab samples that were collected.

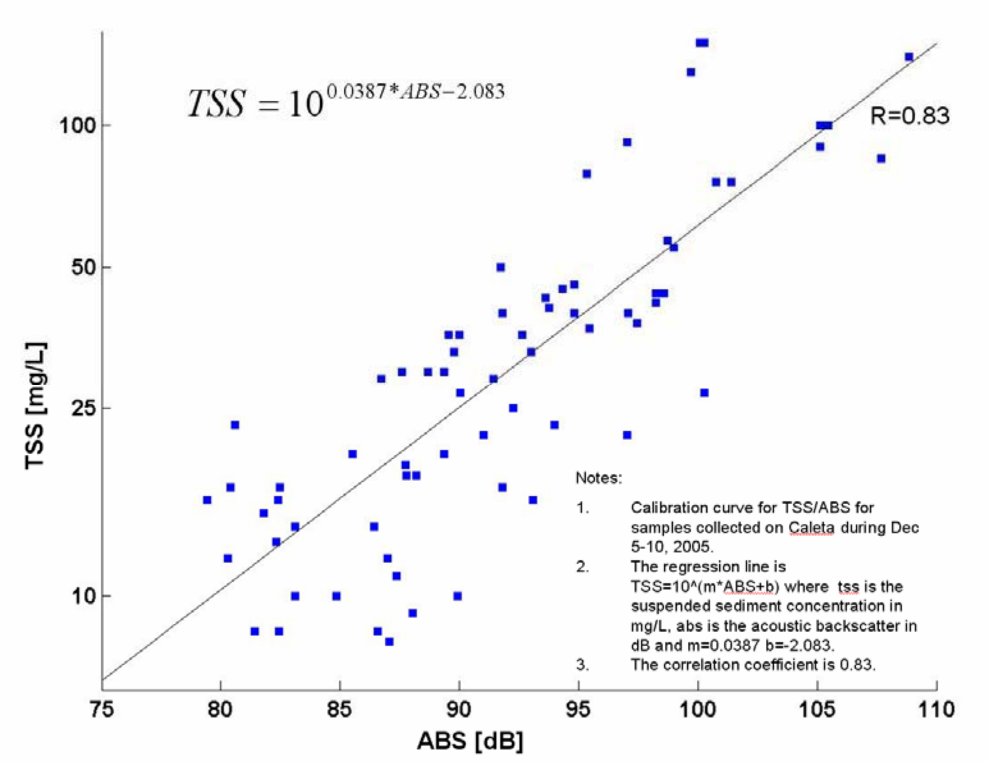


Figure 14. TSS calibration plot for the R/V Caleta ADCP measurements.

Using this calibration for the R/V Caleta ADCP, a similar calibration was performed for the ADCPs on Moorings 1, 2, 4, 5 and 6. As indicated on Table 1, the ADCP on Mooring 3 was faulty and therefore no data is available for that location.

Figure 15 shows a comparison of depth averaged TSS recorded on the first day of dredging December 5, 2005. The upper panel in Figure 15 shows a comparison between the TSS recorded at Mooring 1 (upriver deep channel) and Mooring 6 (downriver deep channel). The ADP at the bottom of Mooring 1 was a Sontek 1500 kHz instrument and the ADCP at the bottom of Mooring 6 was a RDI 600 kHz instrument. The lower panel in Figure 15 shows a similar comparison between the TSS recorded at Mooring 2 (upriver shallow centerline of dredge prism) and Mooring 6 (downriver shallow centerline of dredge prism). The ADCP at the bottom of Mooring 2 was a RDI 600 kHz instrument and the ADCP at the bottom of Mooring 5 was a RDI 1200 kHz instrument. The instruments on these moorings were recording measurements at different time intervals based on their memory and battery life and that is why the plots for Moorings 1 and 5 are relatively smooth and those for Moorings 2 and 6 appear to be more jagged.

The plots on both panels appear to indicate that it is not possible to attribute any differences in TSS measured at the corresponding upriver and downriver moorings to dredging because they are within the error of the measurement. This is not surprising and had in fact been predicted by the modeling because the sediment load that can be attributed to dredging is much smaller than the signal due to natural background conditions (see Figure 2). More analysis to examine the ADCP signals for the various ship tracks from the R/V Caleta for each day of dredging is still being performed.

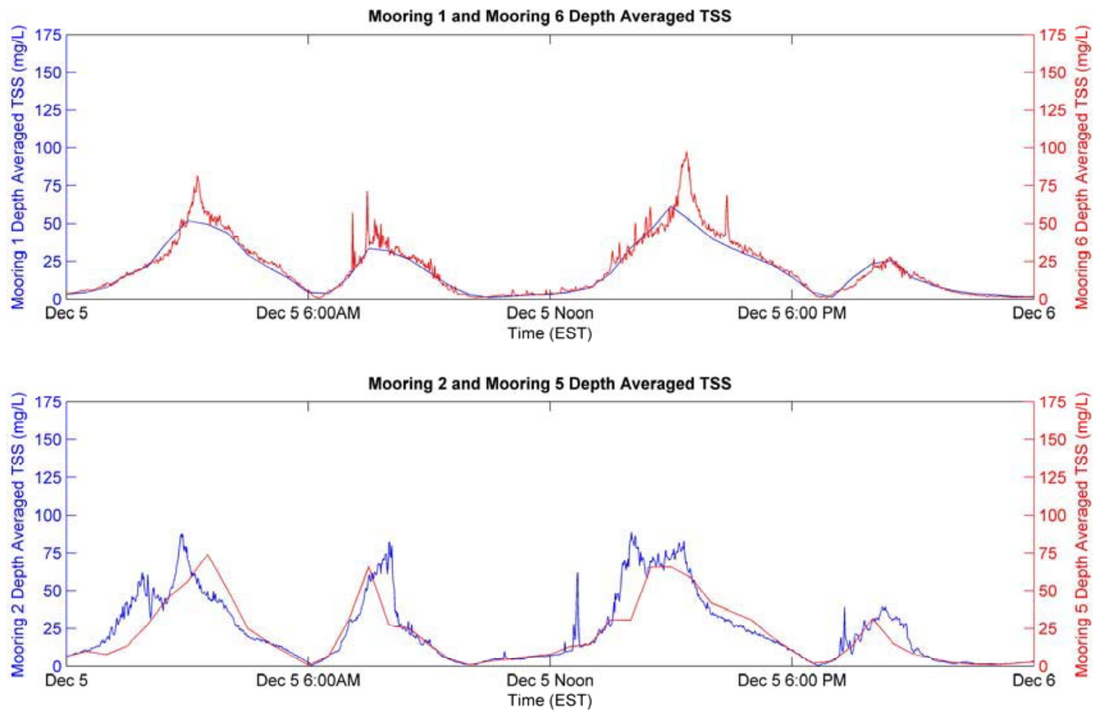


Figure 15. Comparison of depth averaged TSS at moorings 1 & 6 (top panel) and moorings 2 & 5 (bottom panel).

Harmonic Analysis

Using the shipboard data from the R/V Caleta, Professor Chant made estimates of the cross channel structure of the tidal and tidally averaged flow by performing a harmonic analysis of the ADCP data. This was done by defining 20-m grids along two river cross sections (one upriver and one downriver from the dredging area) and generating a time series of velocity measurements within each grid. Between December 5 and 10, 2005, each grid was visited approximately 50 to 100 times, thus providing essentially fixed point velocity measurements with a resolution of 20-m in the horizontal direction and 25-cm in the vertical direction. Each time series was then fit in a least squares sense to a mean flow plus a tidally fluctuating component:

$$u(x,z,t)=u_o(x,z) + U(x,z) * \sin(\omega t + \Theta_u)$$

$$v(x,z,t)=v_o(x,z) + V(x,z) * \sin(\omega t + \Theta_v)$$

where u and v are the east/west and north/south flows which are decomposed into their respective tidally mean currents, u_o and v_o and the tidally oscillating flow with amplitude U and V and phase Θ_u Θ_v. The spatial dimension is defined as x in the cross channel direction, z in the vertical t is time and ω is the frequency of the major semidiurnal tide (M2) with a period of 12.42 hours. Figure 16 shows the results of this analysis. The three panels in the left column in Figure 16 correspond to a cross section that is downriver from the dredging area and the three panels in the right column in Figure 16 correspond to a cross section that is upriver from the dredging area. The top panel in each column shows all the ship tracks from the R/V Caleta for all five days of dredging. The red dots show the locations of the CTD profiles and the thick light blue line shows the location of the grids used to generate the fixed point time series from the ADCP data. The middle panel in each column shows the along channel mean flow. The bottom panel in each column shows the amplitude of the along channel tidal current velocity. These were determined based on a principal component analysis of the results of the least squares fit.

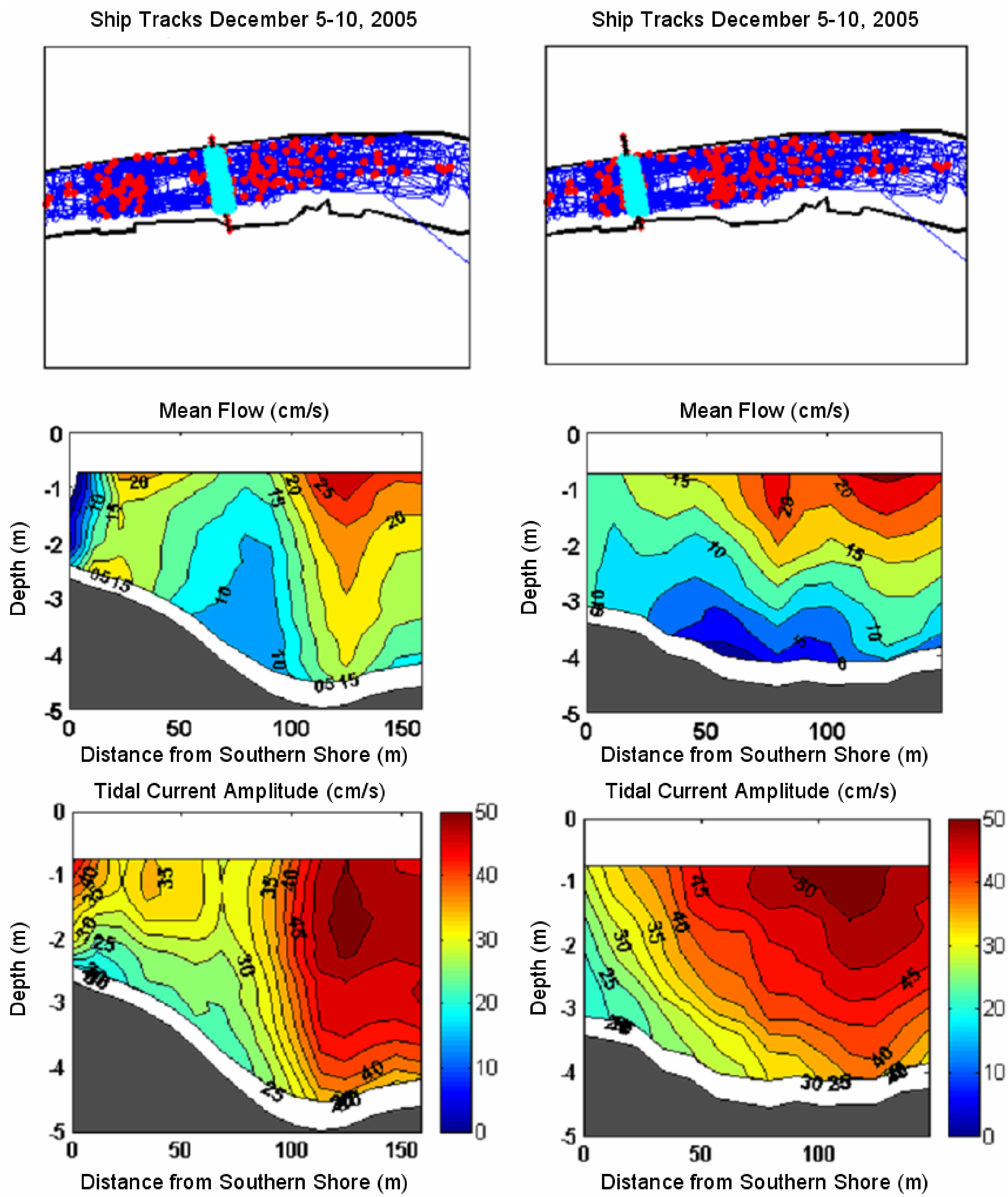


Figure 16. Results of harmonic analysis.

The middle panel in the right column (upriver cross section) shows a mean surface outflow of 20 to 30 cm/s that is concentrated in the northern half of the channel and near zero mean flows near the bed that are offset toward the southern side of the channel. This residual flow structure (or tidally averaged flow) is consistent with theoretical ideas of the interaction between tidal and residual flows downstream of a bend in the channel – as is the case here (Geyer, 1993; Chant 2002). In the absence of a channel bend we would expect the upper layer to flow seaward with a weak return flow at depth. However, inertia associated with the channel bend upriver from this section drives the upper layer outflow to the north side of the channel with a compensatory lower layer flow to the south. The amplitude of the tidal current (shown in the bottom right panel) along this cross section exhibits a similar structure with enhanced tidal current speeds of over 50 cm/s located at the surface on the north side of the channel with reduced velocities at the bottom on the southern side. Note that these tidal currents are superimposed on the mean flow. Thus during maximum ebb tide they are additive and the surface layer ebbs at 75 cm/s (1.5 knots), while during the flood they are opposed and surface flows peak at only 25 cm/sec (0.5 knots). Consequently, processes that are non-linear, such as flow curvature that involves centrifugal accelerations and are proportional to the square of the velocity, will be significantly more pronounced during the ebb. In the absence of flow curvature, the expected structure of the tidally varying flow would be enhanced tidal currents at the surface near the center of the channel and weaker tidal currents at depth. However, secondary flows associated with the channel bend drives the surface velocities to the north (outside of the bend) and the lower layer velocities to the south (inside of the bend).

In contrast, the cross-channel structure of the flow immediately downriver from the dredge area (left column) shows a completely different picture. Both the tidal mean flow and the tidally varying flow have maximum currents at the surface on both the north and the south side of the channel with a local minimum in between that appears to be centered around the location of the dredging operation. This suggests that rather than being associated with natural estuarine processes, this flow structure is due to the interaction between the flow field and the dredging operation. The perturbation of the flow is significant and results in a factor of two reduction in surface current during peak ebb and a significant change in its vertical structure. This significant perturbation could have a profound impact on the transport of sediments released by the dredge and likely, due to reduced velocities, limit the dispersion of sediments away from the dredging operation.

Selected Preliminary TOPS Boat Results

Figures 17 and 18 represent measurements recorded by the upriver TOPS boat (TU) and the downriver TOPS boat (TD) on the first two days of dredging – December 5 and 6, 2005, respectively. The upper panels on both figures show a time series for the water surface elevations, surface and bottom salinities recorded on these days at Mooring 2 between 7 am and 5 pm. The upper panels also show the time intervals when the upriver and down river integrated TOPS samples were collected and when dredging was performed. The lower panels on Figures 17 and 18 show the suspended sediment measurements made by the TU and TD boats on December 5 and 5, 2005, respectively for the shallow (A) and deep (B) legs of the transects. The 'A' leg of each transect represents measurements made one meter below the surface of the water and the 'B' leg of each transect represents measurements made one meter above the sediment bottom. The lower panels also show the time intervals when the upriver and down river integrated TOPS samples were collected and when dredging was performed.

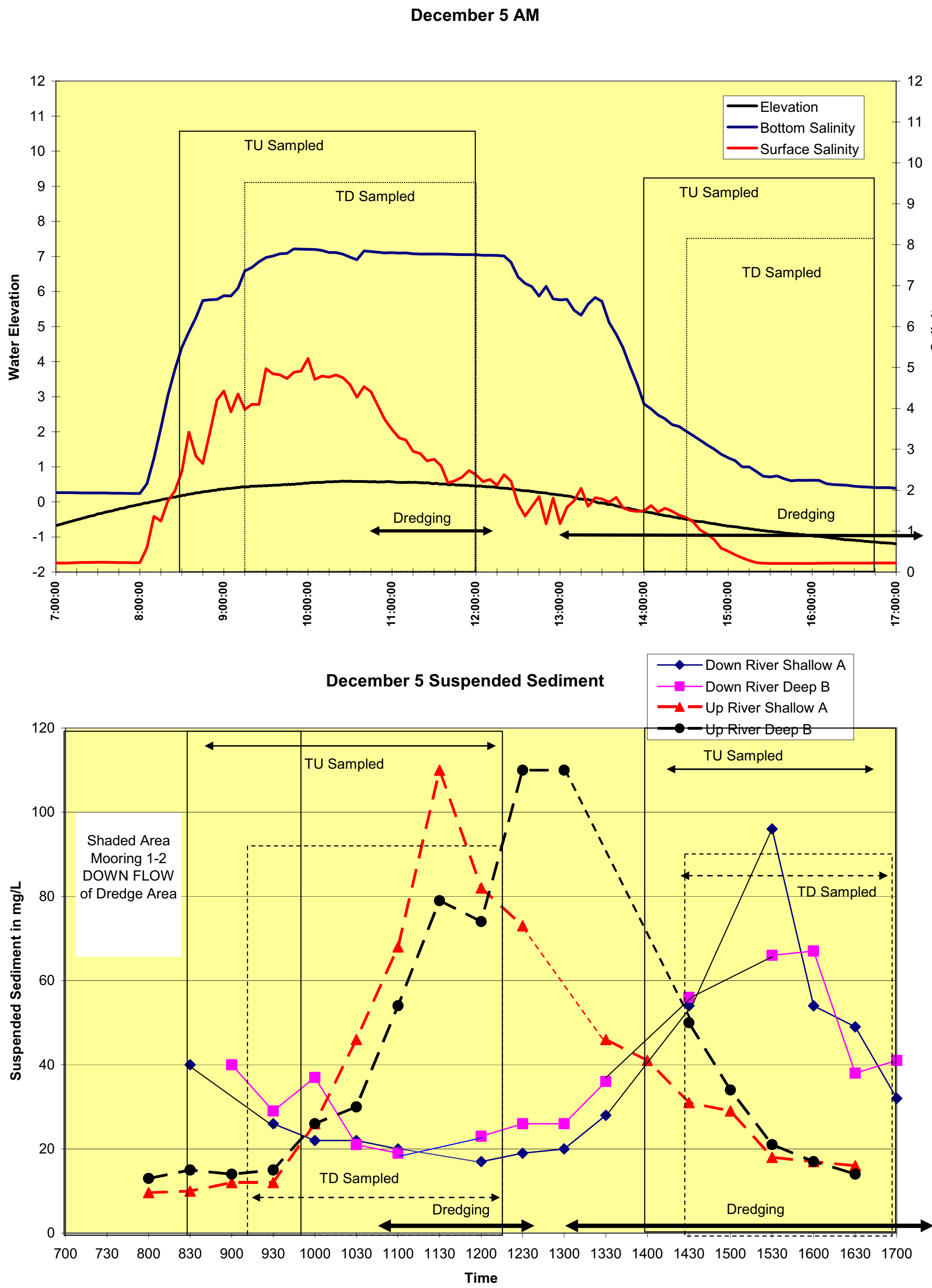
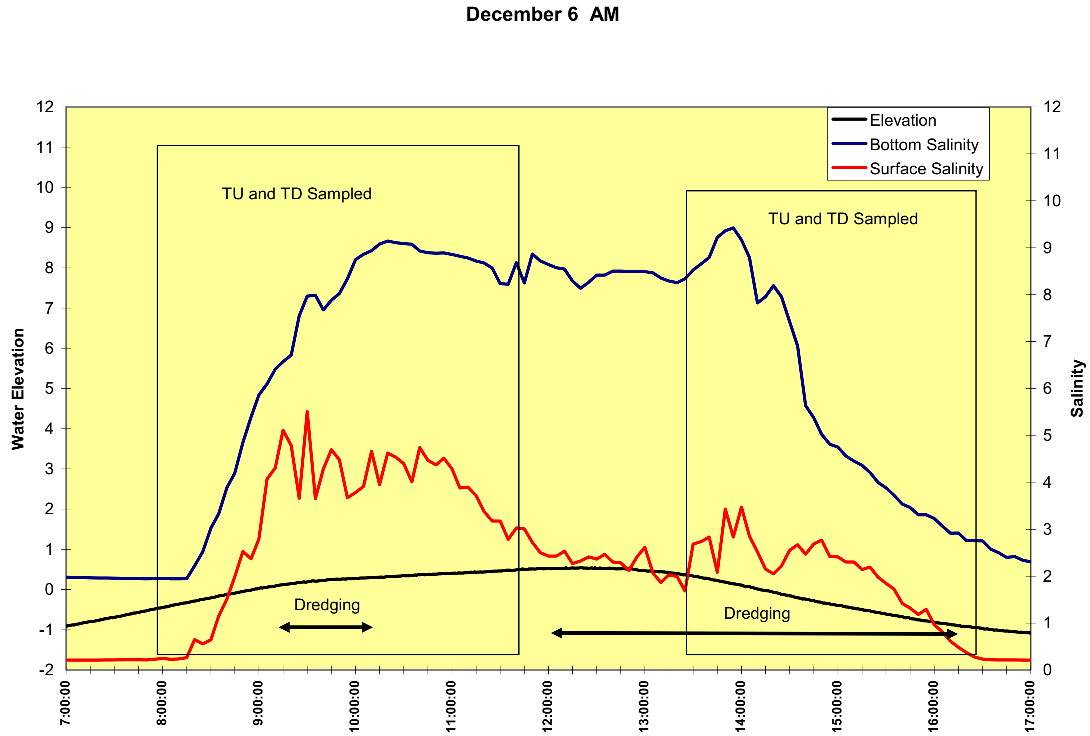


Figure 17. Measurements made by TOPS Boats on December 5, 2005.



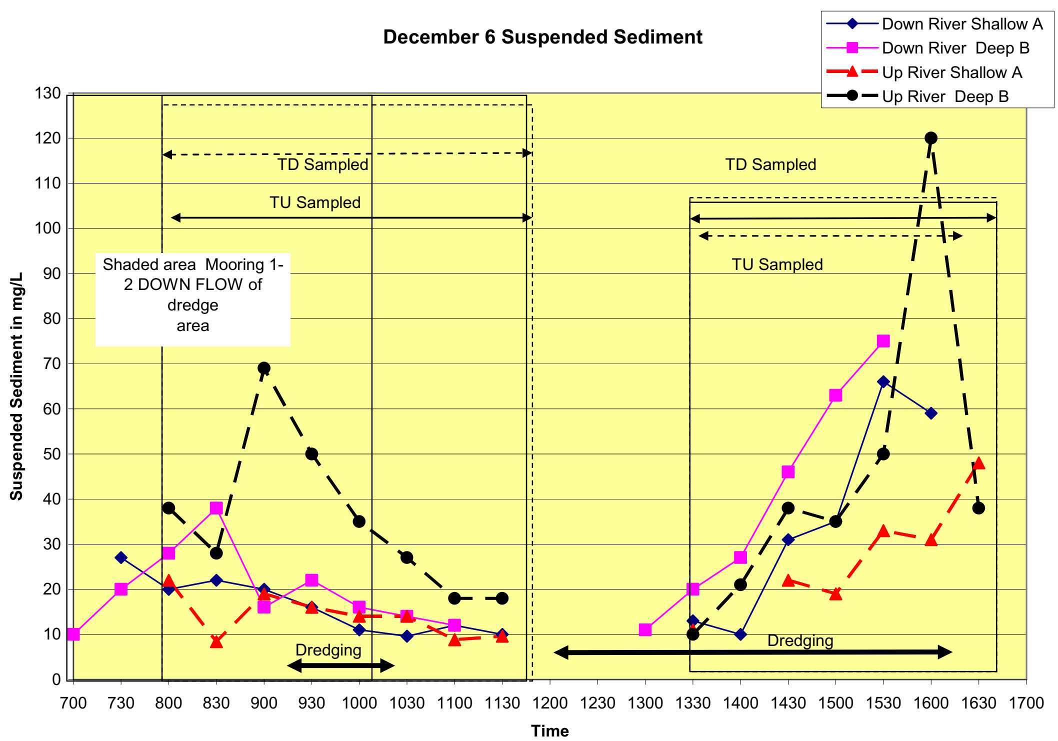


Figure 18. Measurements made by TOPS Boats on December 6, 2005.

CONCLUSIONS

At the present time a vast database of the hydrodynamic measurements recorded by the instruments on the six fixed moorings and the R/V Caleta and the R/V Julia Miller has been assembled. However, calibration of some instruments with analytical laboratory measurements is pending. In addition, a second database containing the analytical data collected by the two TOPS boats has also been assembled. Some of this analytical data is undergoing validatation by EPA. The movements of the dredge and associated equipment over each of the five days have been recorded. The Cable Arm Clam Vision files are also recorded for each bucket movement over the five days of dredging. A significant amount of data analysis is still pending and is expected to be completed by the time this manuscript will be presented at the WEDA TAMU XXVI conference.

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