

**Hydrodynamic Conditions and Sediment Release Rates
during the Lower Passaic River Environmental
Dredging Pilot - December 2005.**

Robert J Chant

Rutgers University

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1 Abstract

Data obtained from shipboard observations and moored platforms were used to characterize hydrodynamic conditions and sediment release rates during the dredging activities associated with the Lower Passaic River Environmental Dredging Pilot that took place December 5 -10, 2006. A 6 element mooring array was deployed between December 1-12, Each mooring contained a bottom mounted profiling Doppler current meter, surface and bottom conductivity and temperature (CT) sensors and surface and bottom optical backscatter sensors (OBS). In addition, two of the moorings included a Laser In Situ Scattering Transmissometry (LISST-100) which were deployed approximately 1 meter below the surface. Shipboard measurements utilized two vessels and included Acoustic Doppler Current Profiling (ADCP) measurements and profiling with a Conductivity, Temperature, Depth (CTD) probe, an OBS and LISST package. Acoustic and optical backscatter measurements were calibrated against total suspended sediment (TSS) measurements.

A high discharge event prior to the dredging pilot coupled with the tidal motion drove the Passaic's salt wedge and associated turbidity maximum across the study site during each flood and ebb tide. The high-suspended load associated with the passage of the turbidity maximum past the study site hindered efforts to estimate sediment release rates from the dredging operation utilizing the moored data. However, the dredge plume was evident in the shipboard ADCP data in the immediate vicinity of the dredging operation. While there was a tendency to observe higher sediment flux downstream of the dredge during the majority of shipboard surveys, this was not significant at the 95 percent confidence limits. Uncertainty in the estimate is based on both a "noisy" environment

associated with the naturally variable TSS levels and by the intermittent nature of the release. However, on approximately $\frac{1}{4}$ of the surveys there was clear evidence of a release and was indicated by high levels of TSS that resided in the upper water column immediately downstream of the dredge. Analysis of these sections indicated a release of 1.5 % with a standard deviation of 0.7%. Finally, shipboard ADCP data indicated that the dredge structure and equipment significantly modifies the flow field, and thus transport processes, immediately downstream of the dredging operation.

2. Introduction

This report describes methodology and results of hydrodynamic and suspended sediment observations collected in December 2005 within the Harrison Reach of the Passaic River (Figure 1). The major objective of these measurements was to provide data to estimate the quantity of sediment released during the Lower Passaic River Environmental Dredging Pilot Study that took place December 5-10, 2005. Included in this component of this field effort was the deployment and recovery of six moorings in the Harrison reach. The mooring array consisted of six elements with each element containing an ADCP and surface and bottom Conductivity/Temperature (CT) sensors from which time series of salinity were obtained. Each mooring also included a surface and bottom OBS. Two of the moorings (M3 & M4) included a LISST-100, which provided estimates of the particle size distribution. Both LISST's collected data every $\frac{1}{2}$ hour over the duration of the deployment and provided estimates of particle size distribution in logarithmically spaced bins ranging from 2-500 μm . Finally, moorings M2 and M6 contained bottom mounted paroscientific pressure sensors with sufficient accuracy to measure the time-varying pressure gradient across this array.

All moorings contained an upward looking ADCP meter. These instruments provided a continuous record of current velocity and estimates of total suspended sediment. The estimate for total suspended sediment required calibration of each instrument against either direct or indirect estimates of TSS. Note that each instrument will have a different calibration curve, due to a number of issues such as different manufacturers and different acoustic frequencies. Mooring 1 used a 1500 kHz Sontek Acoustic Doppler Profiler, moorings 2-5 contained a 1200 kHz RD Instrument (RDI)

ADCP and mooring 6 used a 600 kHz ADCP. Moorings 1-5 were programmed to obtained current measurements with 25 cm resolution in the vertical. Mooring 6, due to the lower frequency of the Doppler, collected data at 50 cm resolution. Mooring 2 was equipped with 2 Gigabytes of memory and collected data at nearly 1 Hz throughout the deployment, while the other current meters were programmed to record the mean velocity profile every $\frac{1}{2}$ hour based on a 10 minute burst at 1 Hz. The heads of the Dopplers were located approximately 50 cm above the bottom of the river. In addition a blanking distance of 15 cm was used for the higher frequency ADCP's (the 4 RDI 1200 kHz Dopplers and the Sontek 1500 kHz Doppler) while the 600 kHz Doppler had a blanking distance of 25 cm. Thus, for the higher frequency Dopplers, the first measurement is at 65 cm above the bed, while for the 600 kHz Doppler the first bin is 75 cm above the bed. Furthermore, interference of the acoustic signal with the sea surface precludes Dopplers from making measurements in the upper 10% of the water column. Thus for a nominal depth of 5 meters, velocity measurements are available from 75 cm (for the higher frequency Dopplers) to 4.5 meters above the bed.

The mooring arrays were deployed on December 1, 2005 and recovered on December 12, 2005. The Doppler current profiler at M3 recorded acoustic backscatter but did not collect velocity information. All the other Doppler current meters recorded both velocity and backscatter data for the entire deployment.

The shipboard surveys included two boats: the *R/V Caleta* and the *Julia Miller*. The *R/V Caleta* was equipped with a 1200 kHz RDI ADCP that was programmed to collect a velocity profile at approximately 1 Hz with 25 cm resolution. The *R/V Caleta* also included an Ocean Sensor (OS-200) CTD probe equipped with an OBS and operated

at approximately 6 Hz. The *Julia Miller* was equipped with an OS-200 CTD probe and a LISST-100 to provide profiles of salinity and particle size distribution during the dredging operation. In addition to collecting velocity data, the ADCPs also recorded acoustic backscatter intensity that can be correlated with suspended sediment concentration. To calibrate both the OBS and ADCP backscatter data for TSS estimates, approximately 100- 0.5 liter pumped water samples were taken during the December 2005 event. These samples were filtered by USGS and provided the TSS measurements required to calibrate the acoustic and optical sensors.

Figure 2 shows the results of the calibration between the acoustic backscatter from the *R/V Caleta*'s ADCP and the TSS measurements. Note the TSS is plotted logarithmically against the acoustic backscatter because the acoustic backscatter is recorded in decibels, which by definition is logarithmic. While there is scatter in the regression, a good correlation was found with a correlation coefficient ($r=0.83$). With this calibration, we then estimated suspended sediment concentration with the shipboard ADCP backscatter as:

$$\text{TSS}=10^{0.0387*\text{abs}-2.083} \quad (1)$$

where abs is the acoustic backscatter measurement obtained by the ADCP. Because the flux estimates in this report are based on the shipboard data, also provided are the estimates of errors based on the fit. The error estimates are based on testing the goodness of fit using the standard error and follows the methodology described in Emery and Thomson, 1998. Based on a 95% confidence limit, the slope of the regression is between 0.0281-0.0493 and is depicted by the dashed lines on Figure 2. Note that this error analysis results in increased errors when suspended sediment levels are well above or

well below average. Furthermore, since the release of sediments is likely to be associated with a high-suspended level event, the error analysis will result in large uncertainty during these times.

The moored ADCP's were calibrated by obtaining a regression between the shipboard ADCP's acoustic backscatter and the acoustic backscatter from the moored data. The data from the moored record were compared to the shipboard acoustic backscatter data when the vessels GPS fix reached within 10 meters of the mooring. In general, there was a good correlation between the shipboard and moored ADCP backscatter. Regression coefficients between the vessel and moored Doppler were 0.90, 0.83, 0.95, 0.95 and 0.88 at sites 1, 2, 4, 5 & 6 respectively. Based on these regressions TSS at each of the mooring locations was estimated as

$$TSS_{site\ 1}=10^{0.0387*(abs-1.3)/0.7)-2.083} \quad (2a)$$

$$TSS_{site\ 2}=10^{0.0387*(abs-0.65)/1.03)-2.083} \quad (2b)$$

$$TSS_{site\ 4}=10^{0.0387*(abs-3.78)/0.95)-2.083} \quad (2c)$$

$$TSS_{site\ 5}=10^{0.0387*(abs-9.47)/0.90)-2.083} \quad (2d)$$

$$TSS_{site\ 6}=10^{0.0387*(abs-16.92)/0.93)-2.083} \quad (2e)$$

Note that the regression varies between instruments because both of the different frequencies that the Doppler's operated in (1500 kHz at site 1, 1200 kHz at sites 2-5 and 600 kHz at site6) and due to the variability of individual acoustic transducers in each instrument. This variability, for example, requires that an ADCP be re-calibrated if it is sent back to the factory for repair. However, since calibration of each instrument

occurred in the field over the course of the experiment, the variable acoustic backscatter response of each instrument has been taken into account.

The OBS was also calibrated against the TSS measurements and results are shown in Figure 3 ($R=0.73$). During the course of the event, we calibrated both the OBS sensors that were on the *R/V Caleta* (red dots on Figure 3) and the OBS on the Julia Miller (Blue dots on Figure 3). The regression between the OBS and TSS yielded:

$$\text{TSS} = 2.1 \text{ FTU} - 0.83 \quad (3)$$

Where FTU is the Formazin Turbidity Unit reported by the OBS. This calibration was then applied to the moored OBS sensors to provide fixed-point time series of TSS.

3. Estuarine conditions during Dredging Operations:

River discharge measured at the USGS gauge at Little Falls and sea level measured by the NOAA station at Bergen Point are plotted in Figure 4. Also shown in Figure 4 (in red), is the pressure record obtained from the mooring deployment at M2. Prior to the dredging operation, the Passaic River discharge peaked on December 1-2 at approximately $100 \text{ m}^3/\text{s}$. Following this peak, the flow rate decreased monotonically to $25 \text{ m}^3/\text{s}$ by December 14. A rain event on December 15 produced another discharge event that peaked on December 19 around $100 \text{ m}^3/\text{s}$ (not shown). The sea level record shows both variability associated with the spring/neap cycle and strong variability associated with meteorological forcing. Tidal range peaked just prior to the dredging operation and decreased during the week. A strong wind event on December 9 drove sea level

downward and knocked the top off of the evening high tide, producing the lowest sea level over this record during the following low tide (Figure 4). Later in this report, the effects of this event on suspended sediment concentration will be shown.

The high river discharge produced a salt-wedge type estuary that extended only a few miles into the Passaic River (Figure 5). At the end of flood on December 6, the head of the salt-wedge was 2 miles upstream of the dredging operation. Tidal currents in the Passaic average around 50 cm/s and thus, the tidal excursion (the distance that a parcel of water would travel during the ebb or flood tide) in the Passaic is approximately 6-7 km or about 4 miles. Thus, the salt wedge, which lies 2 miles upstream of the Harrison Reach at the end of flood will reside 2 miles downstream of the Harrison reach at the end of ebb. Suspended sediment loads are low during the transect shown in Figure 5, with maximum values of 35 mg/l in the lower layer near the Harrison Reach (~River Mile 3), because the transect was taken during slack water. During the dredging operation, the salt wedge passed the field site twice each tidal cycle. The passage of the front is evident in the moored data (Figures 6a-c). For example, Figure 6a shows conditions on December 6, the date of the salt section shown in Figure 5. During the morning flood (just after 8 EST), frontal passage past the mooring is evident as salinity rises rapidly at both surface and bottom sensors. TSS levels are elevated in the unstratified waters ahead of the front. Later during the flood, strong salinity stratification develops and TSS drops dramatically. Note that the salt section shown in Figure 6 was taken around 12 EST when currents and TSS levels were low. The front passes the mooring again during the ebb and TSS levels at the mooring are once again elevated. During the ebb tide, surface and bottom salinities are near zero and TSS level remain high. This pattern is essentially repeated throughout

the week, although there is a general rise in salinity due to the declining river discharge. By December 10, near bottom salinity is nearly 12 psu at the end of flood. There is also a tendency for TSS levels to decrease from the December 5 to the 9, however the storm event beginning around noon on December 9 appeared to increase background TSS loads for the rest of the Environmental Dredging Pilot Study. Note that the enhanced TSS levels apparent at the surface on December 7 and 8 are artifacts associated with interference of the Doppler's acoustic beams with the river's sea-surface.

4. Sediment flux estimates from moored data

Estimates of the suspended sediment flux were made with the moored data. The objective of these estimates was to assess if the mooring array could detect increased sediment loadings during the dredging operations. Sediment flux estimates were made using data collected at Mooring Site M2 and M4. Ideally, M3 and M4 would have been used as they are the closest moorings to the dredge, however the ADCP at location M3 did not record velocity data and thus sediment flux estimates could not be made there. While more detailed estimates of sediment flux could have been made by combining data from M1 and M2, M2 was chosen because its cross-stream position was similar to M4 thus making the comparison more meaningful. With the ADCP data sediment flux estimates (F_{TSS}) were made as:

$$F_{TSS}(t) = \int_0^{\eta} u \text{ TSS } w \, dz \quad (4)$$

Where:

u = along channel velocity;

TSS= suspended sediment estimate made with moored ADCP backscatter data;

W= depth dependent channel width;

t= time; and

z= vertical coordinate.

The integral is taken from the surface ($z=\eta$) to the bottom ($z=0$). Near bottom and surface estimates were made by linear extrapolation of the suspended sediment and velocity profiles. While we could have also extrapolated the profiles with a log-layer for velocity and Rouse profile for sediment, the highly stratified conditions that prevailed during this experiment tended to produce near bottom velocity profiles that were more often linear than logarithmic in nature.

Figure 7 shows the results of this calculation, along with estimates of the depth averaged velocity and depth averaged suspended sediment concentration derived from the moored ADCP backscatter. Depth averaged velocities are maximum during the ebb when tidal currents augment river flows. Depth averaged ebb velocities exceed 75 cm/s prior to the dredging operation and reduce to just above 50 cm/s approaching neap tides on December 9. However, both flood and ebb currents increase in response to the storm event on December 9. Maximum flooding currents exceed 60 cm/s occurring during the spring tide around December 3 and again during the storm event on the 10th.

Depth averaged TSS estimates shows variability consistent with the flow velocities. As expected, the TSS estimates are enhanced during peak current. In the early part of the record, depth averaged TSS estimates generally exceeded 100 mg/l throughout much of the ebb. TSS levels drop following the December 5 and while they do at times

exceed 100 mg/l during peak ebb on December 6 and 7, levels drop below 50 mg/l throughout the tidal cycle on December 8 and 9. During the dredging operation on December 5th and 6th, which occurred primarily during the ebb and shown as grey background on Figure 7), TSS estimates at the downstream site M4 are higher than at the upstream site M2, suggestive of the release of sediments during the dredging operation. However, the storm event on December 9 increased TSS levels to 100-200 mg/l.

The lower panel in Figure 7 shows estimates of sediment flux as calculated by equation 4. In general, these estimates of sediment flux are relatively close, with the mean flux from M2 equal to 1.13 kg/s, while that at site M4, were equal to 1.26 kg/s. There is evidence of enhanced sediment flux during the ebbs on December 5 and 6 at site M4 relative to site M2 during the dredging operation. On December 5, the mean flux across M2 was 3.6 kg/s while it was 5.1 kg/s across M4. Similarly on the December 6, the mean flux past M2 was 3.0 kg/s and 4.7 kg/s past M4. While this suggests a release rate of 1.5-1.7 kg/s, we note that enhanced sediment fluxes past M4 were also evident on December 3 and 4 and prior to when the dredging operation began. Shipboard surveys (shown next) show significant lateral variability in TSS concentration and current speed. It is likely that this lateral variability confounds short-term estimates made with the moored instruments. Subsequently, results from the moored data are inconclusive in regards to estimating the release rate of sediments from the dredging operation.

LISST data from the moorings also show systematic variability over the tidal cycle, but no discernible signal associated with dredging. Figure 8 shows the particle size distribution (PSD) from the LISST at site M4 as a function of salinity stratification. Here, strong stratification is defined as surface to bottom salinity differences greater than 5 psu.

Moderate stratification is defined for salinity differences between 3-5 psu, weak stratification 1-3 psu and no stratification defined for surface to bottom salinity differences less than 1 psu. While the river is stratified, the LISST shows that the total volume of particles increases with bin size up to the largest bin size reported by the LISST (500 μm). Previously published data with digital floc camera from the Passaic River (Mikkleson et al., 2005) reported that the median particle size observed in the Passaic was greater than 500 μm , and this is consistent with PSD shown during stratified conditions. However, as stratification weakens, there is a clear tendency for the particle size to decrease. When the river becomes unstratified, the median particle size around the 100 μm . This suggests that particles primarily travel as flocs during stratified conditions and may be broken into smaller particles during times of weaker stratification and greater turbulence. Alternatively, this may reflect the resuspension of 200-300 size particle during enhanced turbulent events associated with the unstratified conditions.

The analysis of the particle size distribution also utilized the LISST profiling data taken from the *Julia Miller*. In general, there was no clear evidence of a change of particle size distribution in the dredge plume. Like the moored data, the natural variability in particle size distribution likely obscured this signal. However, on December 6, there is one event that showed a change in PSD between the upstream and downstream sides of the dredge. At 14:45, there was a large release of sediments from the dredging operation (this is discussed in the next section). During this time, LISST profiles were taken upstream and downstream of the dredge (Figure 9) and there is a clear change in the depth averaged particle size distribution during this time. Upstream of the dredging operation the volume of particles increases with LISST bin—suggesting that the mean

particle size is larger than 500 μm . In contrast, downstream of the dredge there is a clear increase in the volume of particles in the 200-300 μm range. While this change in particle size concentration also occurs as the river destratifies during the ebb (Figure 8), the moored LISST data shows PSD increasing monotonically with bin number (such as in the upstream sample) during this time period. Therefore, this tentatively suggests that the dredging operation results in the release of particles in the 200-300 μm range.

5. Sediment release rates from shipboard Surveys

With the shipboard surveys we resolved lateral variability in both TSS and velocity structure. Figures 10-1 through 10-42 each show 3-4 cross-channel sections of velocity and suspended sediment in the vicinity of the dredging operation. These Figures represent all of the shipboard surveys from which estimates of suspended sediment fluxes were made. With these sections, lateral variability is resolved and the transport of suspended sediment past each section was calculated in two ways. In the first method, we estimate release of sediments by the dredging operation by the difference in the total suspended sediment transport upstream and downstream of the dredge. Here the total suspended sediment transport across a section is:

$$\text{TSS}_{\text{flux}} = \int_a^b \int_0^{\eta} (\bar{\mathbf{u}} \bullet \mathbf{n}) \text{TSS} \, dz \, dy. \quad (5)$$

Where:

quantity $\bar{\mathbf{u}} \bullet \mathbf{n}$ = velocity normal to the transect;

y = cross channel coordinate;

a and b = ends of the transects.

Other terms are the same as described in equation 4.

The second method only estimates release from those surveys that observed a definitive release of sediments from the dredging operation. These surveys are characterized by high-suspended sediments in the upper half of the water column. The release of suspended sediments is then estimated as indicated by equation 5 except the integral is only taken across a portion of the channel that is determined by the width of the dredged plume. An appealing aspect of the latter method to estimate sediment flux is that since the transect downstream of the dredge occurred within 10's of meters of the dredge, we only expect to observe sediments released from the dredge immediately downstream of the dredge and not to the north or south of the dredge. Thus, this method focuses the analysis on this region, while the other analysis may be contaminated by increased suspended loads that often appear on the south side of the channel, which is likely a major source of "error" in the estimate of the release.

Thus for completion, we include the sediment release rates from the entire cross-sections in Section 5.1. However, we express caution that this analysis is contaminated by errors associated with natural variability in sediment concentrations on either flank of the channel where we do not expect the dredge plume to reside—particularly on the northern flank of the channel. The analysis in Section 5.2 is more focused on the dredge plume and thus, should reduce errors associated with natural sediment variability away from the region where we expect the dredge plume to reside.

5.1 Sediment release estimates from entire cross-sections

The data used to estimate sediment release rates using the entire cross section are shown in Figures 10-1 through 10-42. In these figures, a map depicts the location of the transects along with vectors showing the current velocity and the location of the dredge. The transects are color coded with transect 1-4 colored black, red green and blue respectively. The second panel in the upper left shows the suspended sediment transport per unit width, which is the result of the vertical integral in equation 5, for each section. The lower 4 panels depict the along-channel velocity and estimates of TSS based on the shipboard ADCP data for each section. In the lower left of each panel, the total sediment flux (results of equation 5) and the time are reported. Note that this estimate of TSS flux is based on the solid line shown in Figure 2. For example, Figure 10-6 shows a series of transects during the ebb on December 5 between 13:47-13:57. The panel showing the section across Track 2 shows clear evidence of suspended sediment release from the dredge (Track 2). Here, the estimated TSS levels are elevated in the upper water column and this is in contrast to the natural tendency for suspended sediment to increase towards the bottom. In addition, the flux of suspended sediment in the vicinity of the dredge (between 30-50 meters) is elevated from the upstream section. Sediment flux at Cross-Section 1 is 5.4 kg/s, while for Cross-Section 2 immediately downstream of the dredging operation it is 7.8 kg/s. While Cross-Section 3 shows a reduction in TSS flux note that this section is shorter (less than 100m) and missed sediment fluxes on the flank. Cross-Section 4, which ran across the entire channel, TSS flux was back up at 7.0 kg/s.

Also, note that the dredge equipment also affects the flow structure. In Cross-Section 1, upstream of the dredge, the velocity is strongest on the northern side of the

channel and decreases monotonically to the south. In contrast, immediately downstream of the dredging operation at Cross-Section 2 there is a minimum in current velocity in the vicinity of the dredge. During strong currents, this pattern was frequently observed, such as in Figure 10-3, where currents are greater than 50 cm/s on the flanks of the channel in Cross-Section 2 but less than 25 cm/s in the vicinity of the dredge.

Table 1 compiles the estimates of the TSS flux from sections taken immediately upstream and downstream of the dredge (such as the upstream Track 1 and the downstream Track 2 in Figure 10-6). The range in the flux estimates represent the 95% confidence limits on the regression shown in Figure 2. Upstream and downstream are defined by the current flow, so that the upstream estimate is to the east of the dredge during the flood and to the west of the dredge during ebb. During slack water, upstream is poorly defined and thus TSS flux estimates are not compared. The 5th column reports the change in TSS flux between these two sections, and a positive number indicates a release of sediments by the dredging operation.

Table 2 relates these release rates to dredge production rates. During these 5 days (December 5-8, 10), the dredging production was approximately 135 yd³/hour, 215 yd³/hour, 115 yd³/hour, 90yd³ /hour, and 100 yd³/hour respectively. The estimate of the percentage of this dredged sediment that was released is listed in Table 2. This estimate assumes a mean sediment density of 1300 kg/m³ that is based on analysis sediment cores collected July 2004 within the Dredging Pilot Study Area (TAMS/ET and Malcolm Pirnie, Inc., 2005).

Only on December 5, is there a clear tendency to observe a statistically significant (based on a 95% confidence limit on the regression) increase in the estimate of sediment

flux downstream of the dredge relative to the upstream estimate. Based on the ranges observed, the release rate is 3-9%. However, note that this estimate is skewed by the large release observed during the 14:25-15:02 survey and that this time corresponds with a rapid increase in TSS associated with the passage of the turbidity maximum (Figure 6a). Removing this data point from the time series reduces the release rate to 2-5%. In Section 5.2, we focus on the region where the release is evident and neglect the increase in TSS flux on the sides of the channel. On December 8, there was also a tendency for the estimates of sediment flux to be higher downstream of the dredge, suggestive that between 2-5% of the dredged sediment was released to the water column. However, like December 5, this estimate was somewhat skewed by a high release estimate during a single survey between 11:32-11:53. Similarly, on December 6, the upper range of the release rate (4%) is also skewed by a single event between 14:02 and 14:26. Note also that during these releases the large error bounds associated with the 95% confidence limits are large because suspended sediment concentrations are well above average and the uncertainty in the error estimate increases with increasing suspended sediment concentration.

In summary, on three of the days the release was not significantly different than zero, while on the dates that the lower error bound was significantly different from zero, the mean release rates are skewed by a few observations showing significant release. This likely occurs because of the release of sediments from the dredging operation, like the dredging operation itself, is an intermittent process and only likely to be observed a fraction of the time.

5.1 Sediment release estimates from observations of dredge plume.

In this section, the analysis focuses on times that a plume is evident downstream of the dredge in the shipboard ADCP data. This analysis is motivated by the reality that the release of sediments from the dredging operation is likely to be an intermittent process and thus, a meaningful estimate of the release of sediments should focus only on times when a signal is detected. The detection of a release event is determined by the structure of the TSS field downstream of the dredge. In particular, a release event is defined as occurring in sections where our estimates of TSS are elevated in the upper water column immediately downstream of the dredge. This method also focuses the analysis only on the region where TSS levels are elevated thus reducing errors associated with suspended sediment variability immediately away from the dredge.

During the pilot study, there were a total of 29 surveys upstream and downstream of the dredge. During eight, or 29%, of these surveys there was clear evidence of release. These eight surveys are listed in Table 3 and depicted in Figures 11-1 through 11-8 in a similar presentation as Figure 10. In all eight of the surveys, there was an increase in the sediment flux downstream of the dredge indicating that this method captured the release. In these figures, only the two transects, one immediately upstream and one immediately downstream of the dredge are shown. In the upper right panel, the sediment transport per unit width is drawn for these two transect and the region where the dredge release occurred is colored in grey. The rate of release is estimated across grey area shown in the figure, which represents the width of the sediment plume.

Of the 29 hydrodynamic cross sections identified for this analysis, eight cross sections report a detectable plume of resuspended solids from dredging operations. The

remaining 21 cross sections do not present evidence of a plume. When solely considering these eight detectable cross sections, a release rate (or net solids flux) can be calculated, assuming that the instantaneous release rate represents an on-going source of solids. Following this assumption, Table 2 presents the range of possible release rates and the corresponding range of release rates reported as a percentage of solids dredged. In this analysis, the full length of the cross sections was evaluated; however, since the cross-section lengths in the upriver and downriver pair varied, a certain degree of uncertainty is associated with the release rate calculation.

To minimize the uncertainty presented in Table 2, adjusted release rates were calculated and presented in Table 3. First, resuspension plumes tend to be sporadic and follow the cycle times rather than representing an on-going source. This sporadic release of resuspended solids is supported by the consideration of all 29 cross sections and accounting for the 21 cross sections with no identifiable plume. Secondly, to minimize uncertainty and error, cross sections lengths from the upriver and downriver pair need to be equal. Consequently, the release rates presented in Table 3 are adjusted to consider the time that the resuspension plume was not present in the water column and corrected so that comparable plume widths are compared.

Adjusted release rates in Table 3 represent the percentage estimated by dividing the release rate by the mean production for the day and multiplying this ratio by the fraction of the time that a dredge plume (0.29). The mean release rate during the week was 1.5 percent with a standard deviation of 0.7 percent. Prior to this Pilot dredging operation, there was general agreement that the release rate would be approximately 1 percent—and this is consistent with this analysis.

Conclusions

Analysis of shipboard and moored data were used to characterize the spatial and temporal structure of currents, salinity and suspended sediment during the Lower Passaic River Environmental Dredging Pilot Study, December 5-10, 2005. Prior to the dredging operation, a large discharge event of approximately $100 \text{ m}^3/\text{s}$ drove the estuarine salt wedge into the vicinity of the dredging operation. High turbidity associated with this salt wedge obscured efforts to estimate sediment release rates from the dredging operation with the moored data. However, the dredge plume was evident in the shipboard ADCP data. Two methods were used to estimate the rate of release utilizing the shipboard data. The first method estimated suspended sediment fluxes upstream and downstream of the dredging operation by integrating the shipboard estimates of TSS and velocity across the entire channel. On only two of the five days, were there statistically significant sediment releases. On days that there were significant releases, the individual release rate survey calculations fell in the range of 2-5%. However, the error analysis used in this method did not attempt to limit errors associated with both a noisy environment or the noisy “signal” associated with the intermittency of the release of sediments by the dredging operation. Thus, these results should be viewed with caution.

The second method acknowledged that the release of sediments is in fact an intermittent process and focused the analysis on times and locations that a clear sediment plume was observed. Over the course of the week, eight of the 29 surveys identified in this analysis indicated the presence of a sediment plume from the dredge. The plume was only clearly defined within the immediate vicinity of the dredge, and was typically

obscured by the natural suspended load beyond 100 meters downstream of the dredge. In all of these eight sections, there was an increase in the suspended sediment flux downstream of the dredging operation and results to within one standard deviation suggests that between 0.8 – 2.2 percent of the total mass dredged is released into the water column during the dredging operation and becomes part of the active sediment pool in the river.

Finally, it is noted that the estimate of the sediment release rate during dredging operations that are reported here are essentially identical to those reported in the main body of this document and calculated by Malcolm Pirnie Inc. While these two estimates used the same data sets to estimate the release rate, the analysis occurred independently. In summary, both estimates yielded a sediment release rate in the near field of approximately 1 percent for environmental dredging operations. Higher release rates were observed during start-up and due to storms, but are not considered characteristic of likely long-term dredging operations.

Table 1: TSS flux estimates from Caleta

Date Time	e	TSS _{flux} upstream (kg/s)	TSS _{flux} downstream (kg/s)	Change in TSS _{flux} (kg/s)	Comment
Dec 5	9:10-9:38	1.2-1.4	3.8-3.9	2.4 - 2.7	Not yet dredging. Change in TSS flux likely due to drop in current speed
Dec 5	10:50-11:15	0.5-0.7	0.8 -0.9	0.1 - 0.4	Weak current.
Dec 5	12:13-12:46	0.9-1.3	1.3-1.7	0.0 - 0.8	High TSS on track 3 but not track 2
Dec 5	12:49-13:04	1.1-1.6	2.4-2.7	0.8 - 1.6	Clear evidence of release and reduction of current along track 3
Dec 5	13:31-13:46	4.1-4.6	6.7-7.4	2.3 - 3.3	Strong ebb.
Dec 5	13:47-13:57	4.9-6.1	7.2-8.6	1.1 - 3.7	Strong ebb.
Dec 5	14:25-15:02	5.4 -7.2	10-16	2.8 - 10.4	Max Ebb- Turbidity Maximum in study region
Dec 6	9:53-10:00	2.1-2.3	1.3-1.4	-1.0 - -0.7	Track 1 upstream Averaged of track 2&3 Downstream. Near slack upstream and downstream poorly defined
Dec 6	13:11-13:25	0.5-.75	1.5-1.6	0.75 - 1.1	Averaged from two upstream and downstream sections. Weak ebb
Dec 6	14:02-14:26	1.5-1.8	6.8-10	5.0 - 8.5	Strong ebb. Large release signal
Dec 6	14:51-14:53	5.5-5.8	4.7-6.8	-1.1 - 1.3	Higher TSS flux downstream in Cross-Section 4
Dec 6	15:31-15:36	6.6-8.3	5.4-8.4	-2.9 – 1.8	Strong ebb.
Dec 7	9:08-9:26	1.0-1.4	1.2-1.5	-0.2 - 0.5	Weak flood.
Dec 7	9:39-10:00	1.4-1.7	1.5-1.6	-0.2 - 0.2	Flood
Dec 7	10:33-11:09	1.8-1.9	2.2-2.4	0.3 - 0.6	Flood
Dec 7	12:39-13:05	0.3-0.5	0.3-0.8	-0.2 - 0.5	Near slack upstream/downstream poorly defined
Dec 7	13:16-13:40	0.6-0.9	1.0-1.2	-0.1 - 0.6	Clear plume in track 1
Dec 7	14:31-14:50	1.3-1.7	1.8-2.3	0.1 - 1.0	Ebb. Clear surface plume in track 2
Dec 7	15:55-16:01	2.1-2.7	2.8-2.9	0.1 - 0.8	Average of two upstream and downstream tracks
Dec 7	16:10-16:17	3.3-3.4	3.7-3.8	-0.3 - 0.5	Choose tracks 1 & 4 because 2&3 are short
Dec 8	10:03-10:15	2.1-2.2	3.0-3.2	0.8 - 1.1	Flood
Dec 8	11:35-11:53	3.6-4.9	5.4-6.8	0.5 - 3.2	release apparent in track 2
Dec 8	12:52-13:07	0.2-0.3	0.7.-0.9	0.4 - 0.7	Near slack
Dec 8	14:37-14:44	0.5-0.6	0.7-0.9	0.1 – 0.4	Weak ebb
Dec 10	8:43-9:02	3.7-3.9	3.2-3.4	-0.7- -0.4	Strong ebb

Dec 10	9:21-9:49	3.3-3.6	2.7-3.0	-0.7 - -0.3	
Dec 10	12:47-13:02	4.9-5.9	7.9-9.5	2.0-4.6	GPS error on <i>R/V Caleta</i> . Peak flood. Track 1 is upstream of dredge while track 2 is downstream.
Dec 10	13:38-13:55	8.6-11	7.9-11	-3.1 - 2.4	Clear plume signal in TSS field in track 2 but track is short.

**Table 2: Range of Potential Daily Release Rates Assuming that Instantaneous Release Rate Represents an On-going Source of Solids
(Cross section lengths not corrected.)**

Date	Production Rate (yd ³ /hour)	Production Rate (kg/s)	Release Rate (kg/s)	Release Rate (%)
Dec 5	135	37	1.2-3.4	2-5 ¹
Dec 6	215	58	0.15-2.5	0-4 ²
Dec 7	115	31	0	0-2
Dec 8	90	25	0.4-1.4	2-5 ³
Dec 10	100	27	0-1.4	0-5

¹ Dec 5: Does not include estimate on 12/5 14:25-15:02

² Dec 6: high end of range (4%) skewed high due to single survey between 14:02 and 14:26.

³ Dec 8: high end of range (5%) skewed high due to a single survey between 11:32 – 11:53.

**Table 3: Adjusted Release Rate Accounting for the Sporadic Nature of the Resuspension Plume and Cross Section Corrected for Plume Width.
(Estimate of release from sections with obvious sediment plume downstream of dredge).**

DATE	TIME	RELEASE RATE	%
12/5	13:47	0.9 kg/s	0.7
12/5	14:25	2.0 kg/s	1.5
12/6	14:02	4.3 kg/s	2.0
12/6	14:51	1.8 kg/s	0.9
12/7	16:10	1.5 kg/s	1.3
12/8	11:41	1.0 kg/s	1.1
12/10	12:47	2.1 kg/s	2.1
12/10	13:38	2.7 kg/s	2.9

** Note that the percentage is based on daily mean production times the fraction of time that the dredge plume was observed in the shipboard observations. See text for this discussion.

References

- Emery, and W. J. A. R. E. Thomson. 1998. Data analysis methods in physical oceanography. Pergamon.
- Mikkelsen O. A., P. S. Hill, T. G. Milligan, R. J. Chant, 2005, In situ particle size distributions and volume concentrations from a LISST-100 laser particle sizer and a digital floc camera. *Continental Shelf Research* vol 25 1959-197
- EarthTech/TAMS and Malcolm Pirnie, Inc., 2005. Data Summary and Evaluation Report. Prepared for New Jersey Department of Transportation.

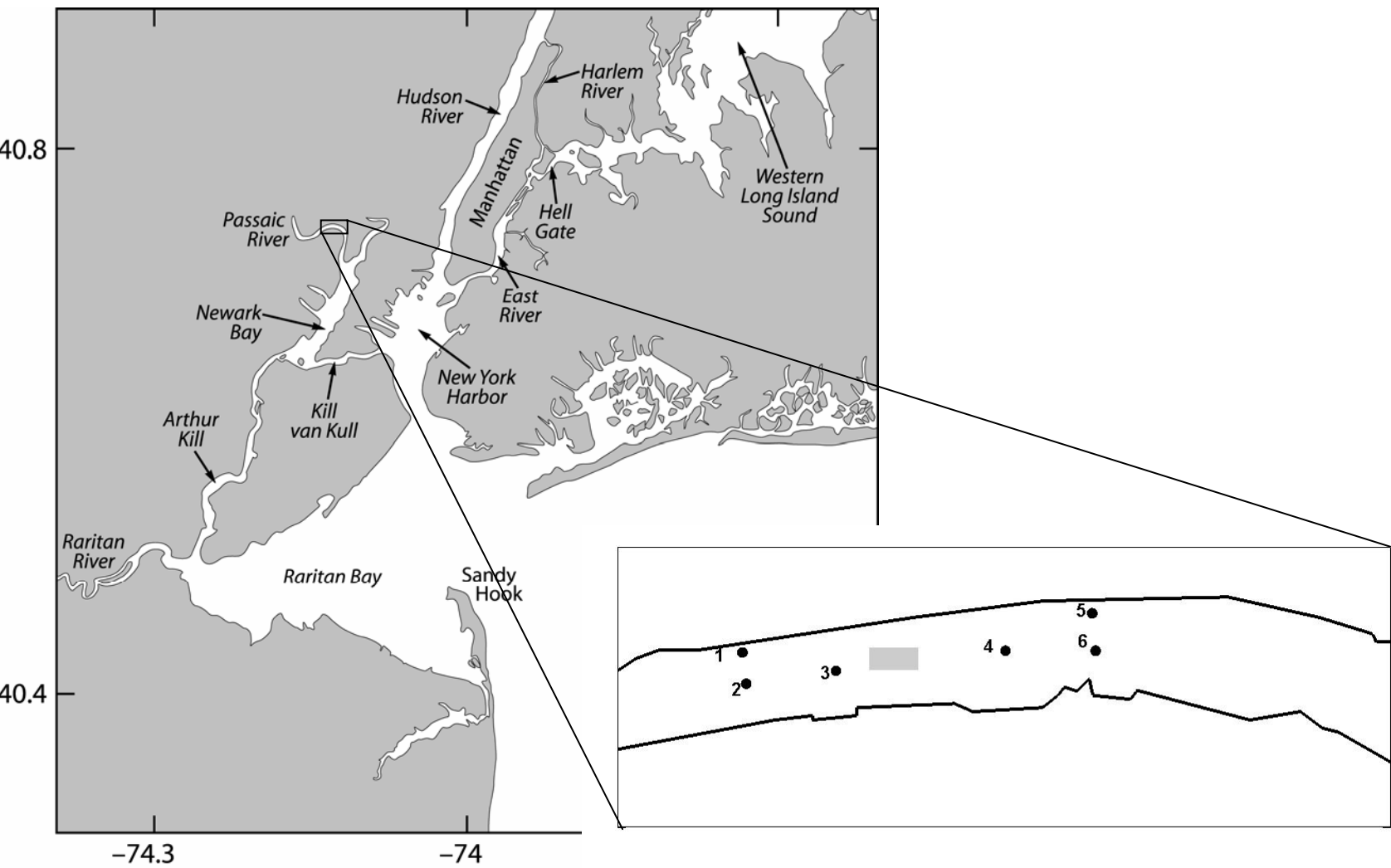


Figure 1 Study site. Insert shows location of dredge (grey box) and 6 mooring sites

ADCP TSS Calibration

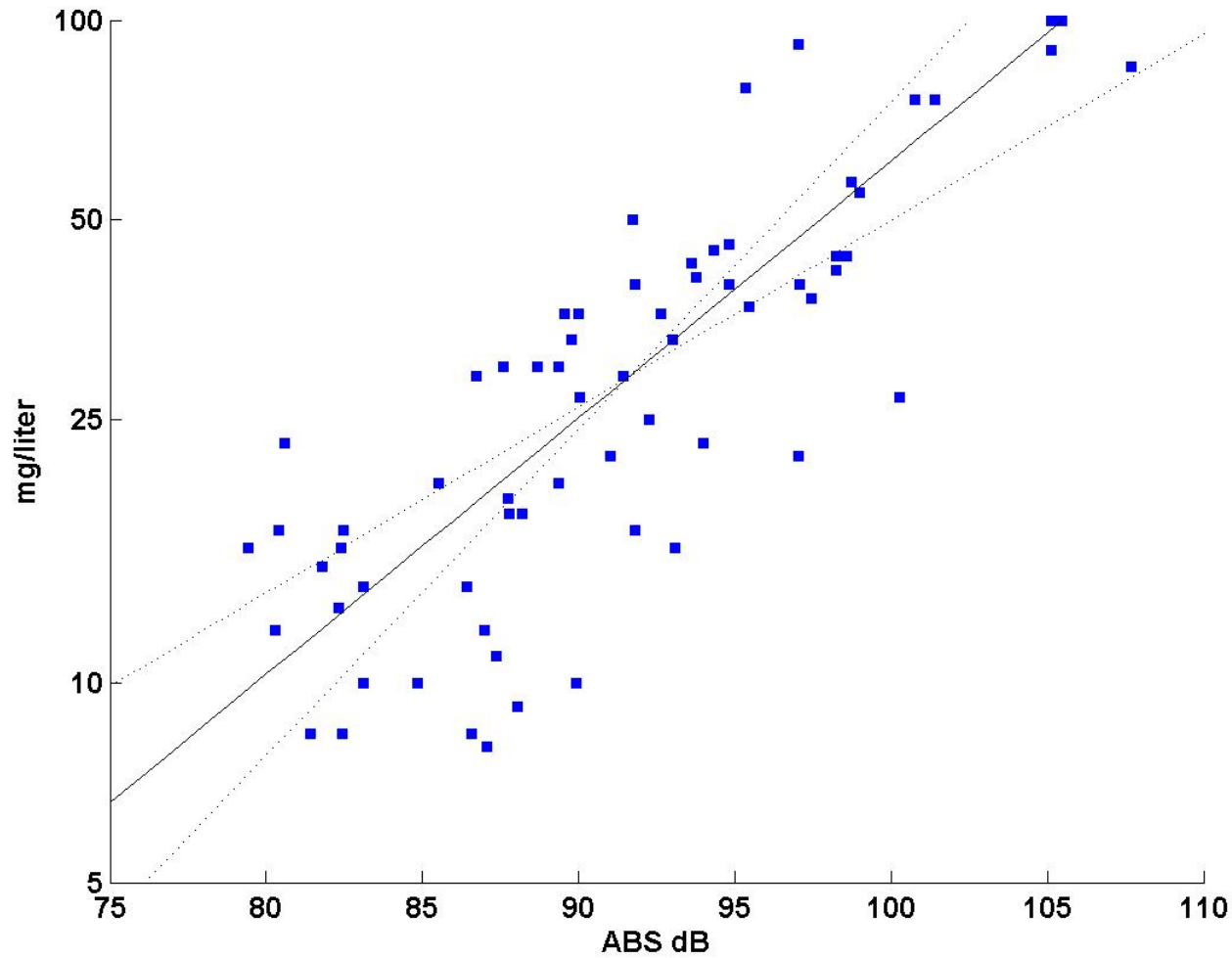


Figure 2. Scatter plot used to calibrate ADCP for TSS estimates. X axis is the acoustic backscatter from the shipboard ADCP, Y axis is total suspended sediment obtained from samples. The solid line shows the best fit for a linear regression while the dashed lines show the regression envelope for 95 % confidence limits (Emery and Thompson, 1997)

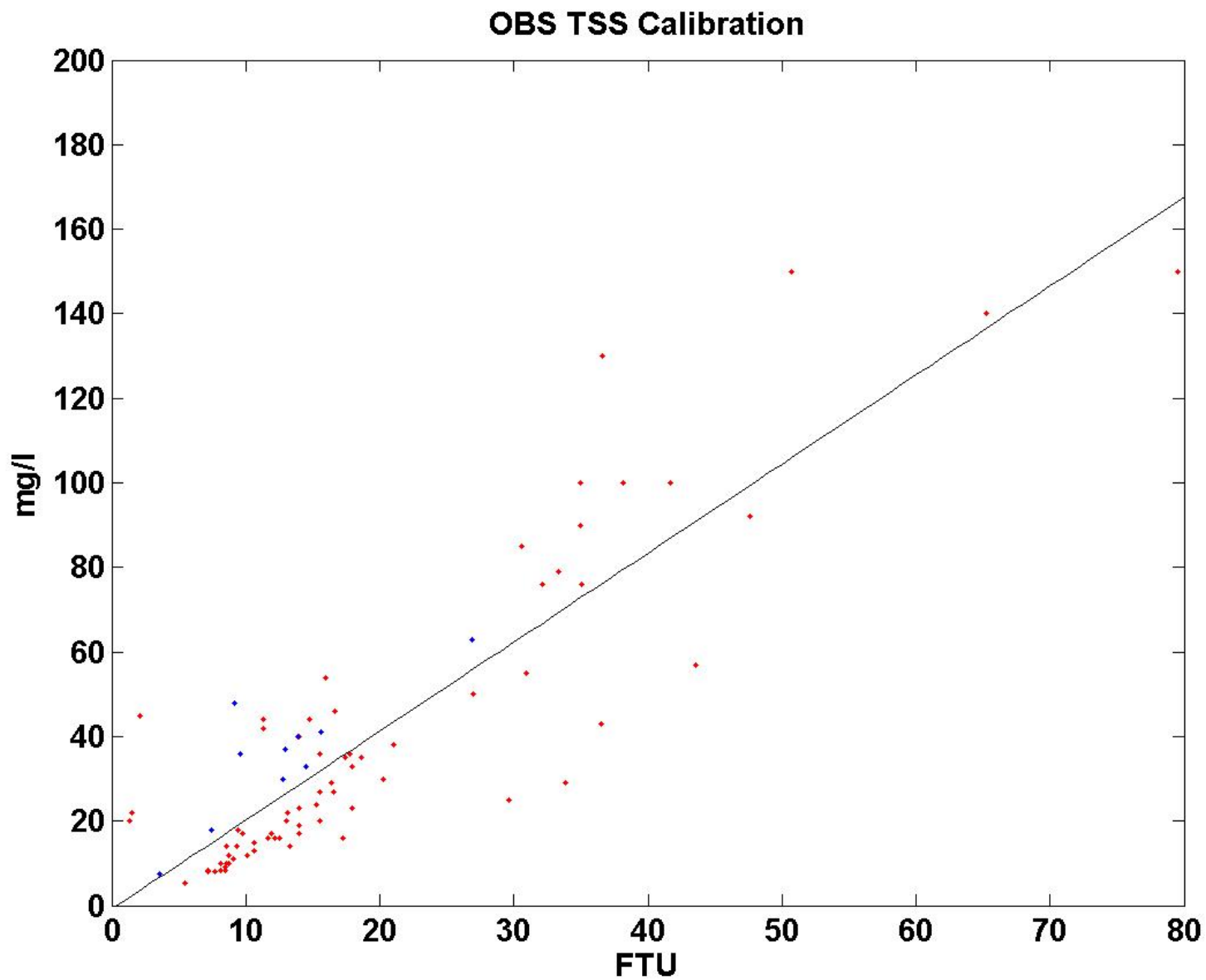


Figure 3 Scatter plot showing calibration curve for OBS. Red dots are for OBS that was used on Caleta While blue dots are for OBS used primarily on Juila Miller

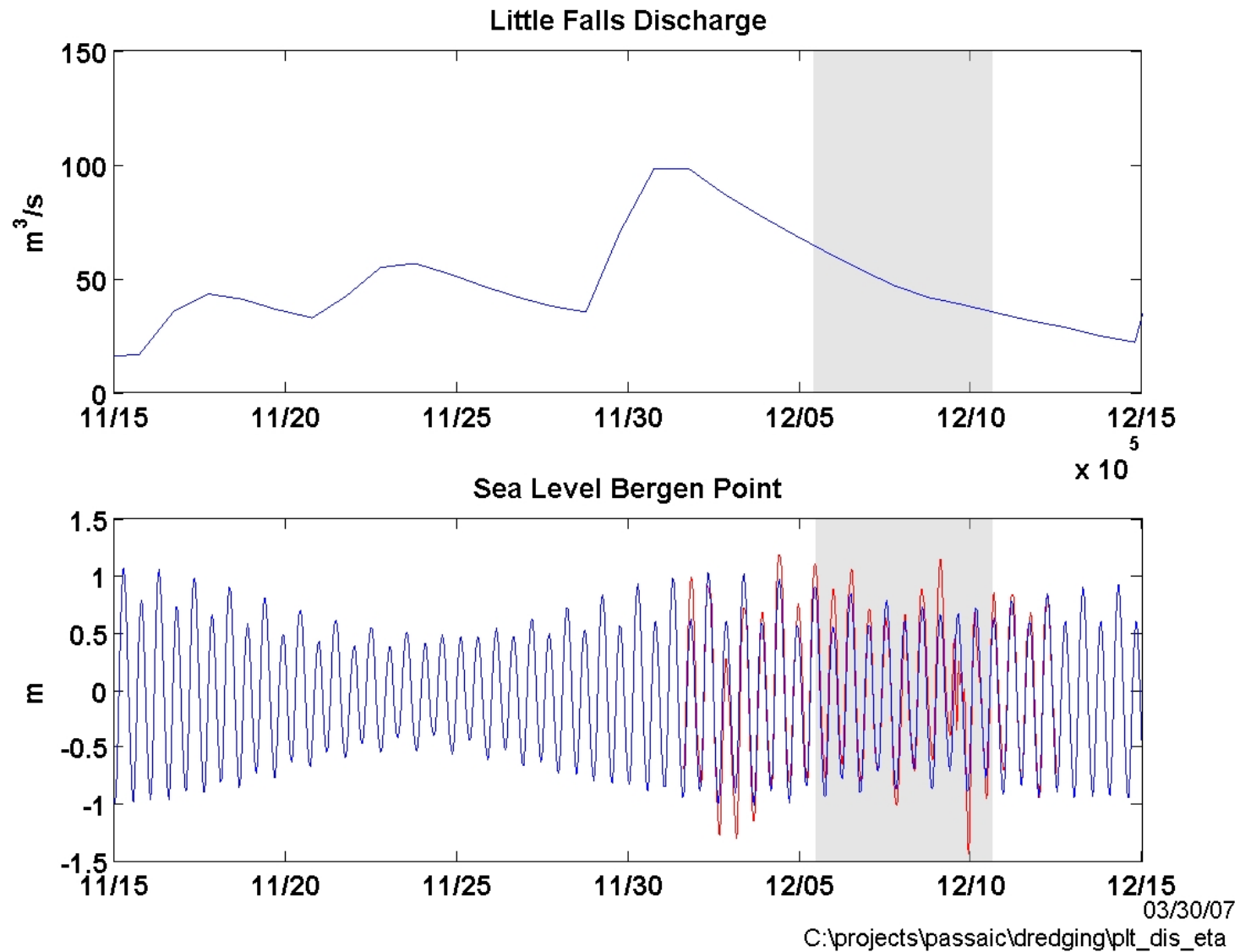


Figure 4. Upper panel shows river discharge from Little Falls. Lower panel shows sea level from NOAA station at Bergen Point (blue) and pressure sensor at mooring 6 (red). Grey box is time of dredging operation.

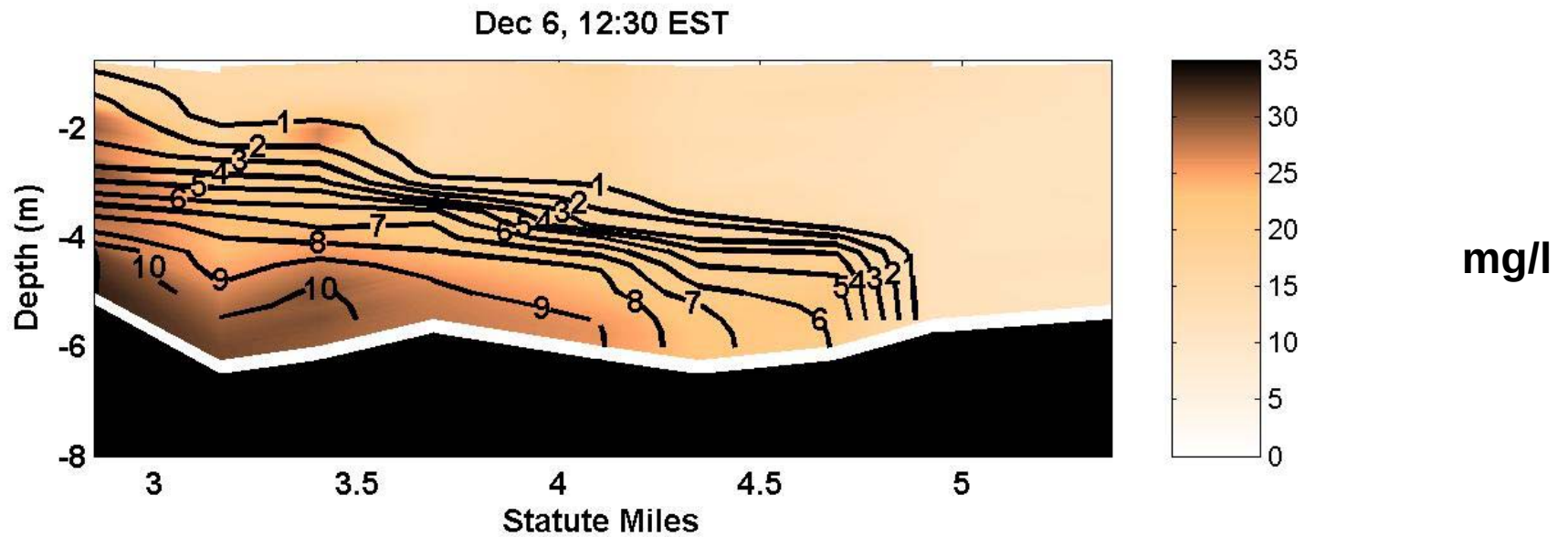
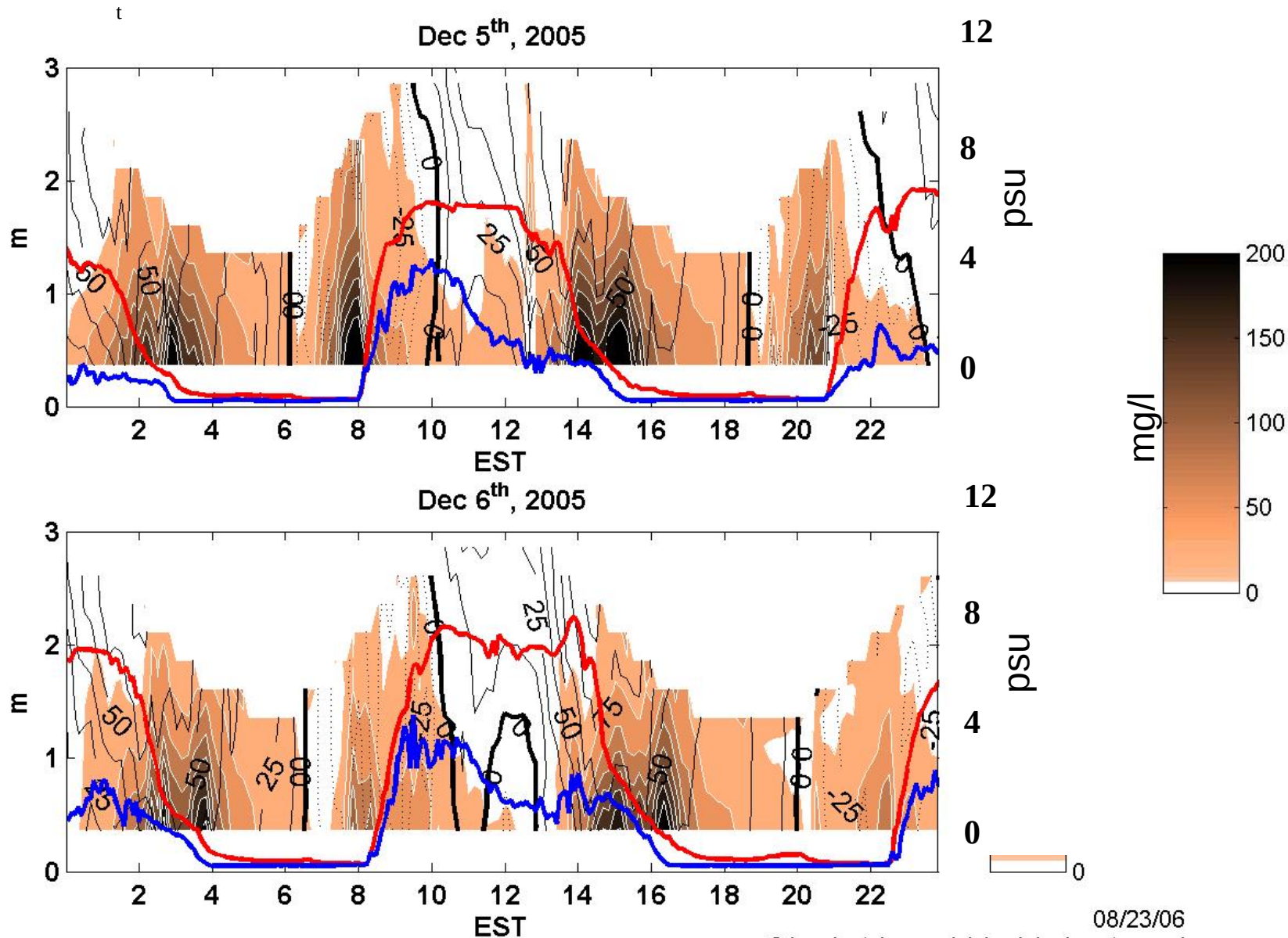


Figure 5. Salinity and TSS field on Dec 6th at the end of flood. Dredging operation is around mile 2.8. The Bridge Street Bridge in Newark is at mile 5.



08/23/06

C:\projects\passaic\dredging\ua_tss_sal

Figure 6a. Moored data from site 2 on Dec 5th and 6th. Along channel velocity is shown in black contours with the zero isopleth drawn as a thick line. Flooding velocities are dotted black contours while ebbing currents are solid black. Red and blue line show bottom and surface salinity respectively (axis to right). Brown color indicates TSS levels, which are contoured in white and levels are denoted by colorbar to right.

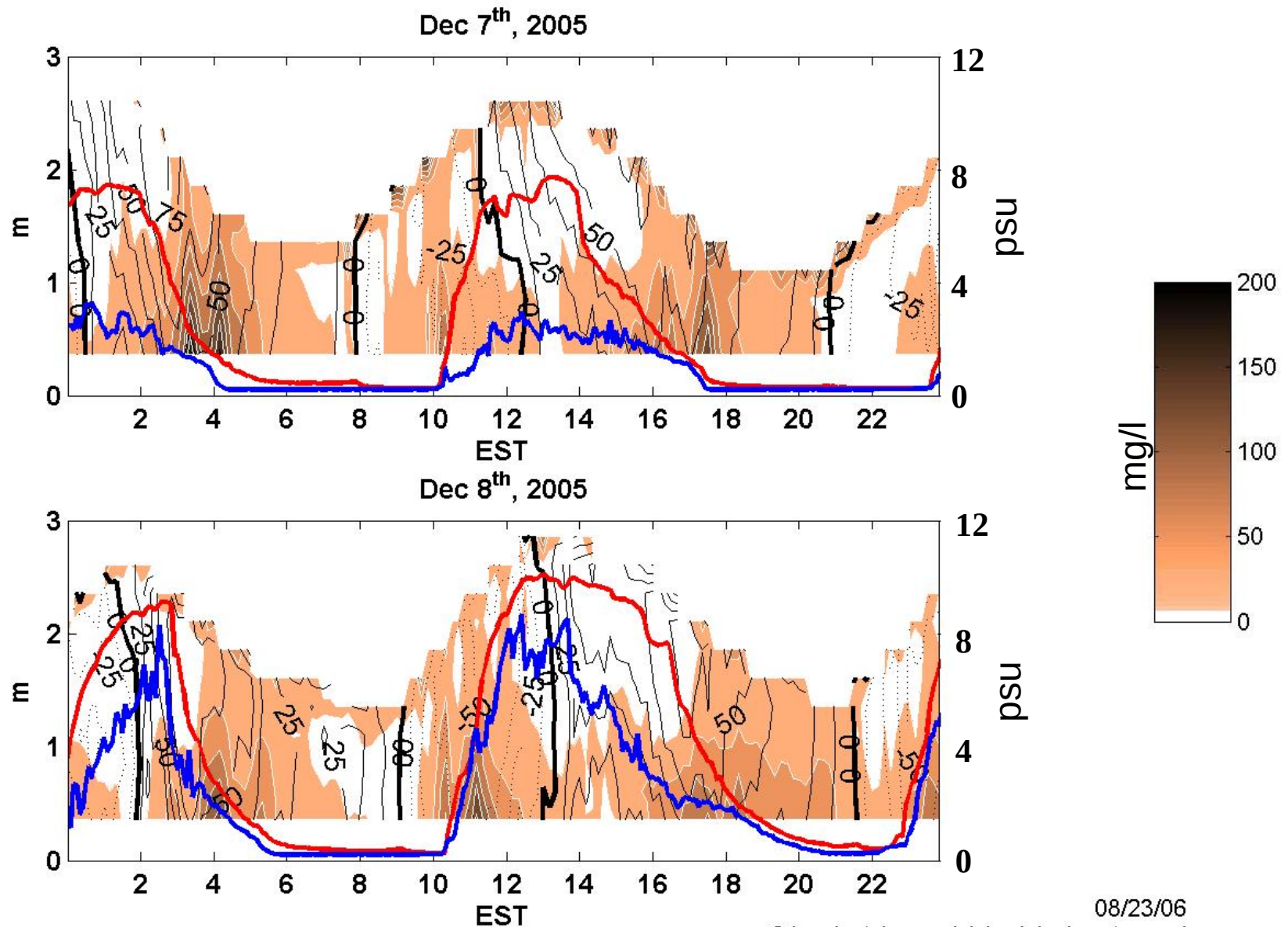


Figure 6b. Moored data from site 2 on Dec 7th and 8th. Along channel velocity is shown in black contours with the zero isopleth drawn as a thick line. Flooding velocities are dotted black contours while ebbing currents are solid black. Red and blue line show bottom and surface salinity respectively (axis to right). Brown color indicates TSS levels, which are contoured in white which are contoured in white and levels are denoted by colorbar to right.

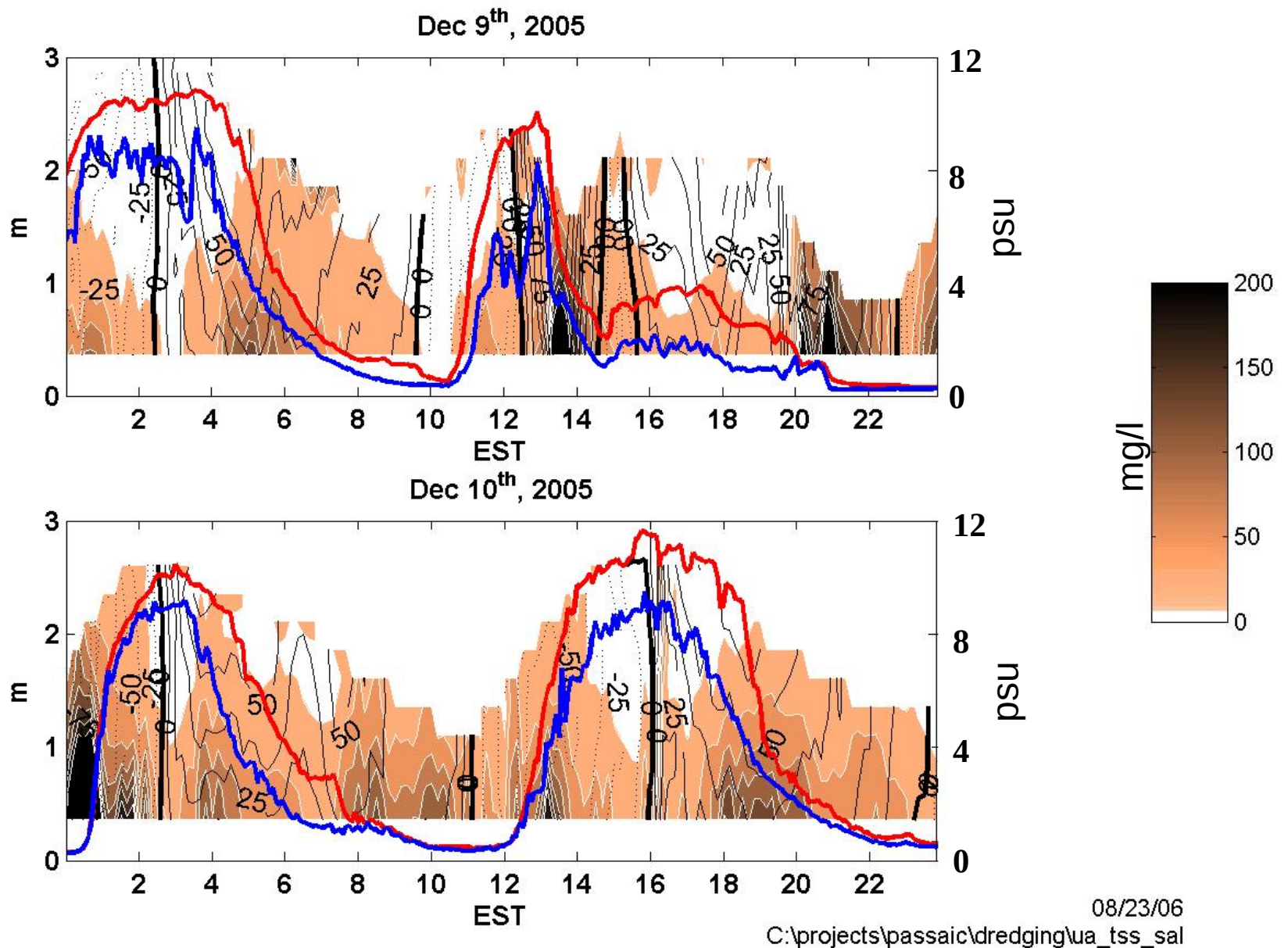


Figure 6c. Moored data from site 2 on Dec 9th and 10th. Along channel velocity is shown in black contours with the zero isopleth drawn as a thick line. Flooding velocities are dotted black contours while ebbing currents are solid black. Red and blue line show bottom and surface salinity respectively (axis to right). Brown color indicates TSS levels, which are contoured in white and levels are denoted by colorbar to right.

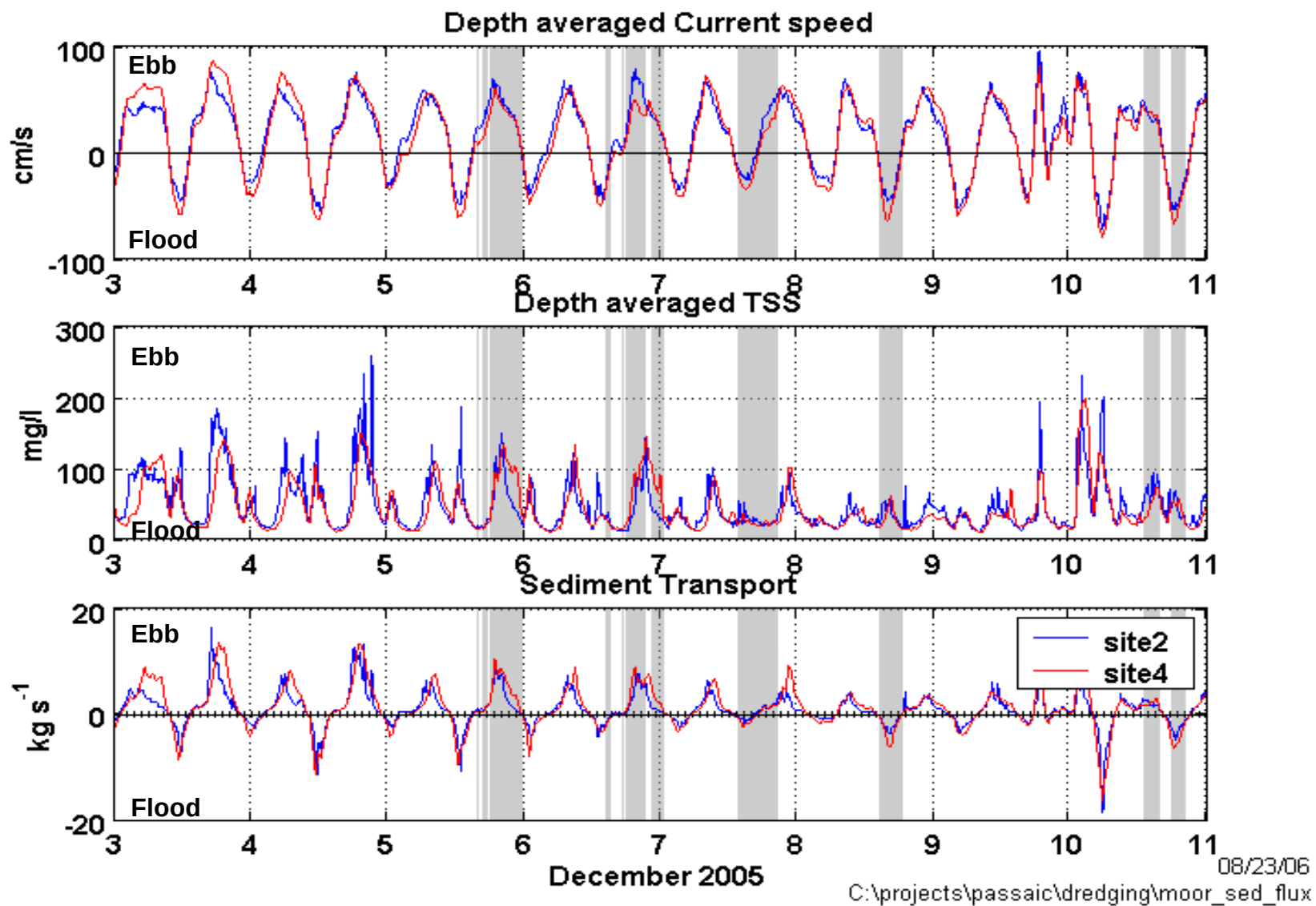


Figure 7 Top panel. Depth averaged current from site 2 (blue) and site 4 (red). Middle panel depth averaged TSS at site 2 and site 4. Lower panel. Estimate of the transport of suspended sediment from site 2 and site 4.

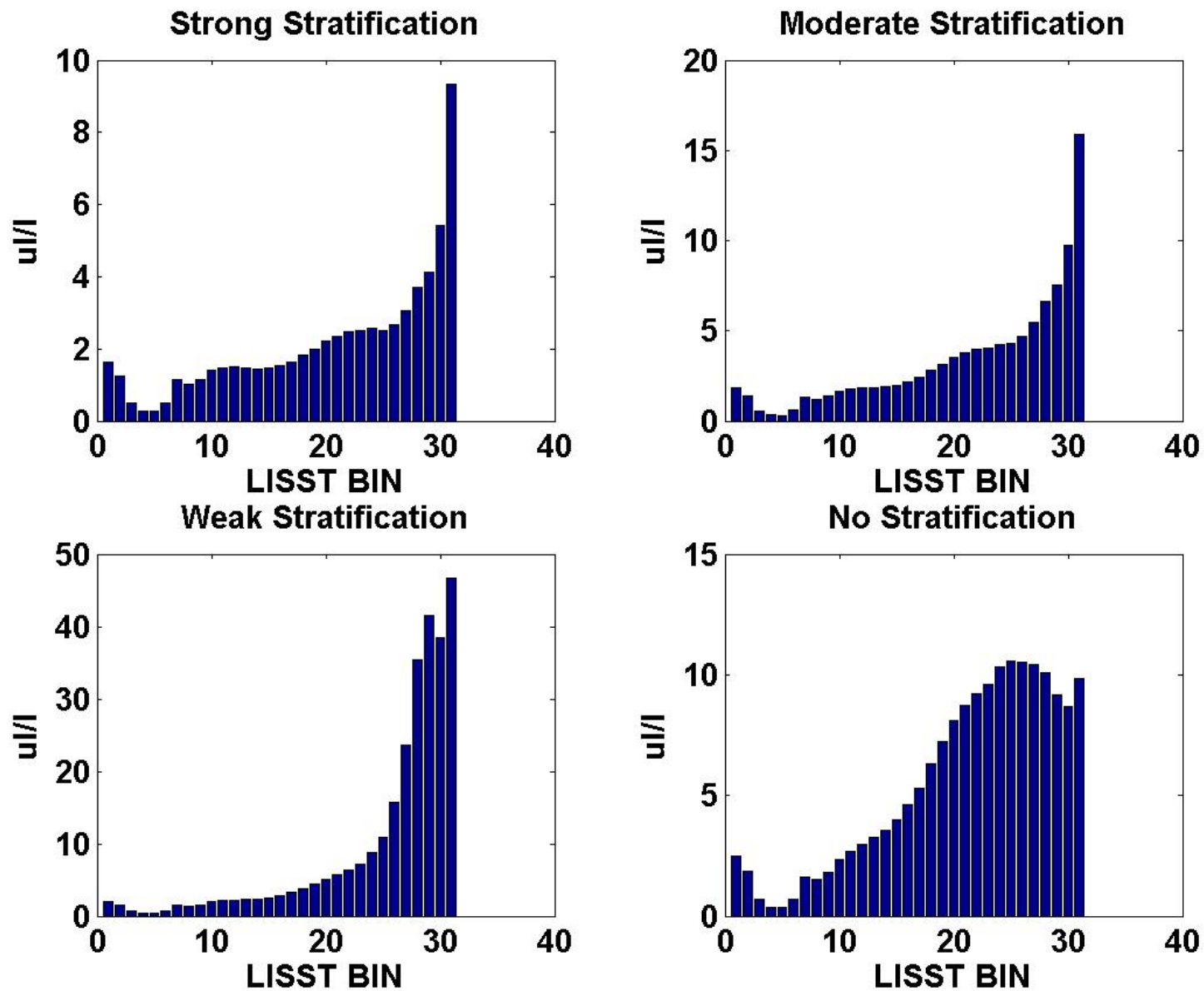


Figure 8. Particle size distribution from LISST at site 4 as a function of stratification. Strong stratification is defined for times when surface and bottom salinity differences (ΔS) are greater than 5. Moderate stratification defined as $3 < \Delta S < 5$, weak stratification as $1 < \Delta S < 3$ and weak stratification for $\Delta S < 1$.

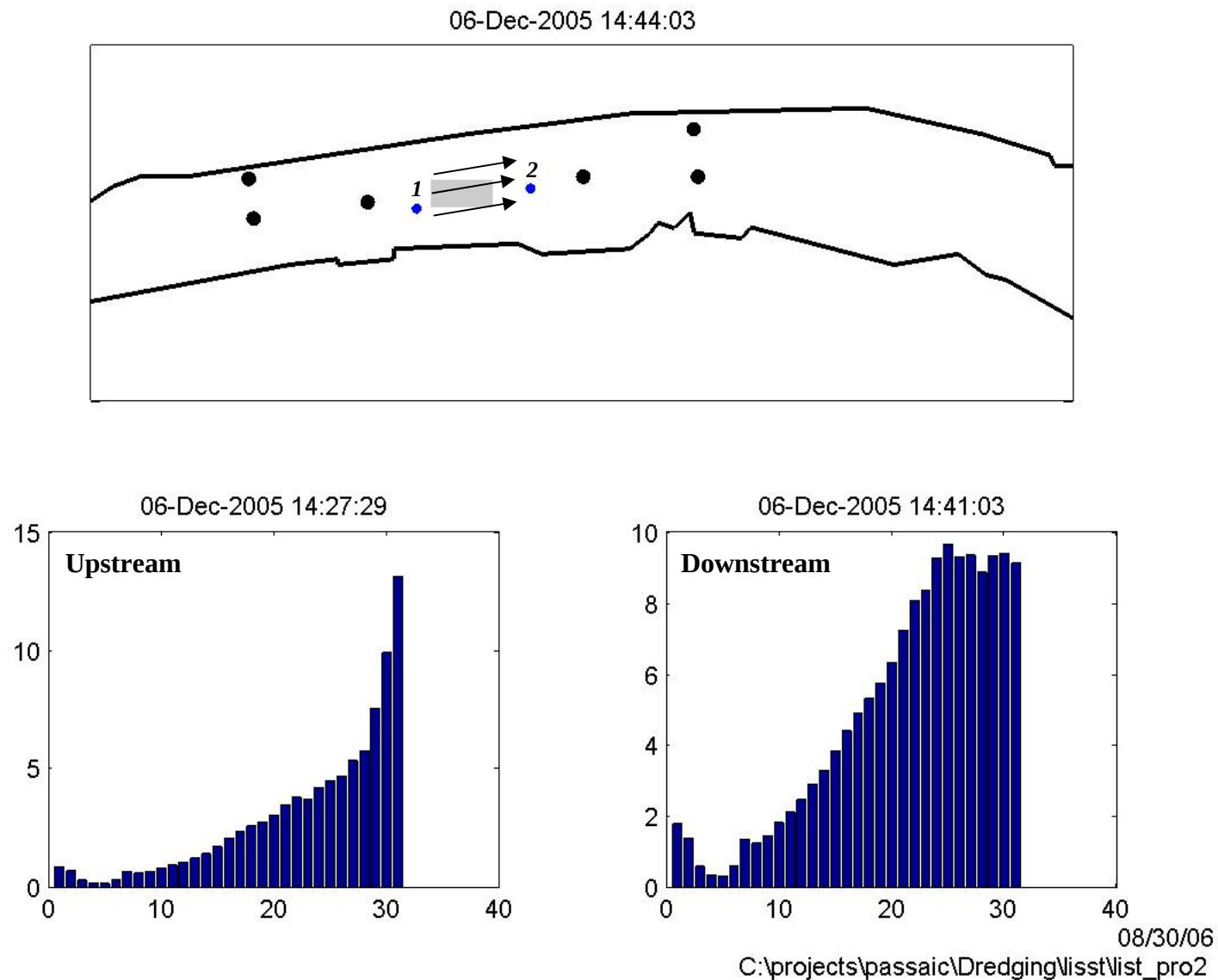


Figure 9. Depth averaged Particle size distribution from LISST data from Julia Miller from casts taken upstream (1) and down stream of dredge during time of significant release of dredged materials.

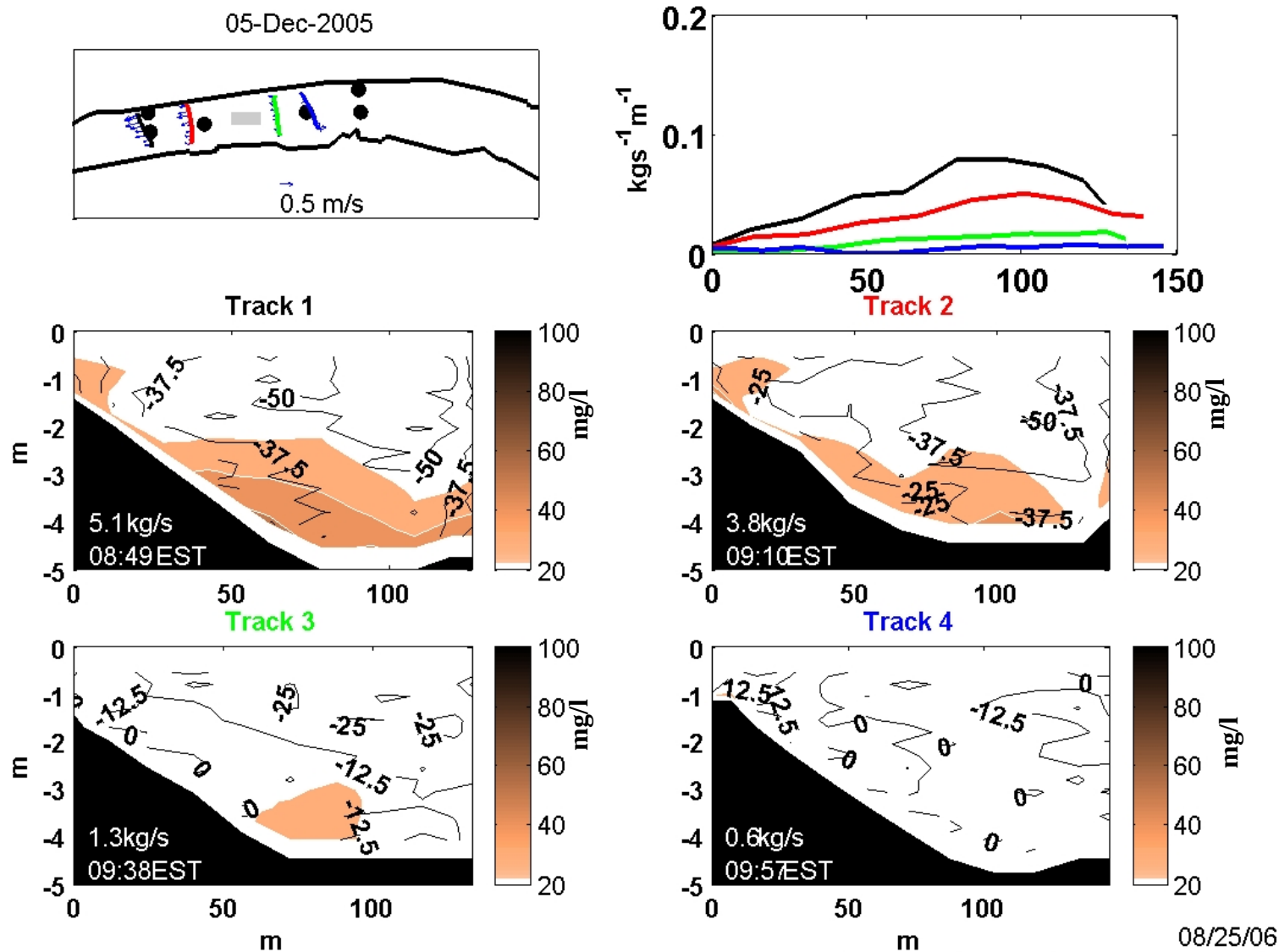


Figure 10-1. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

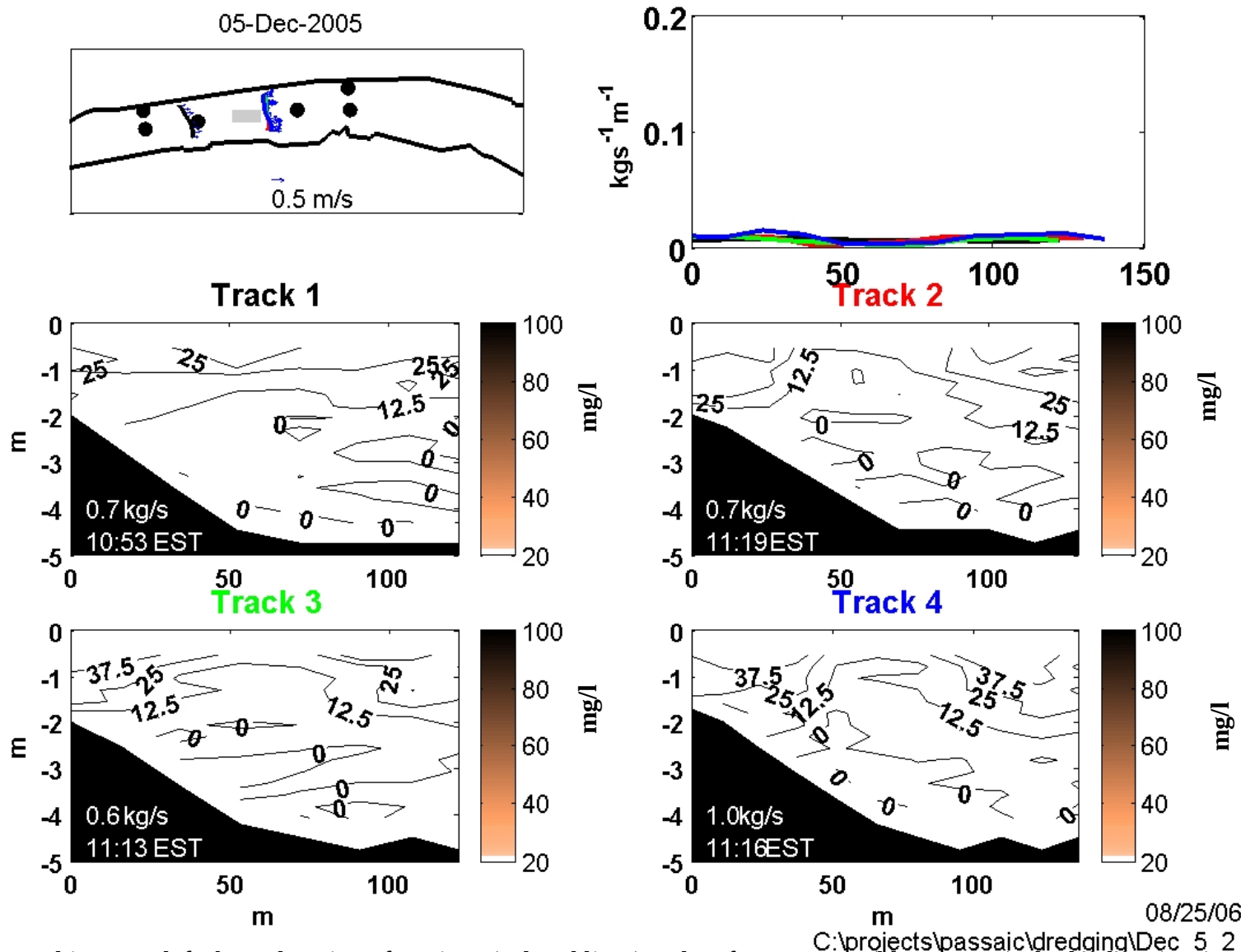


Figure 10-2. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

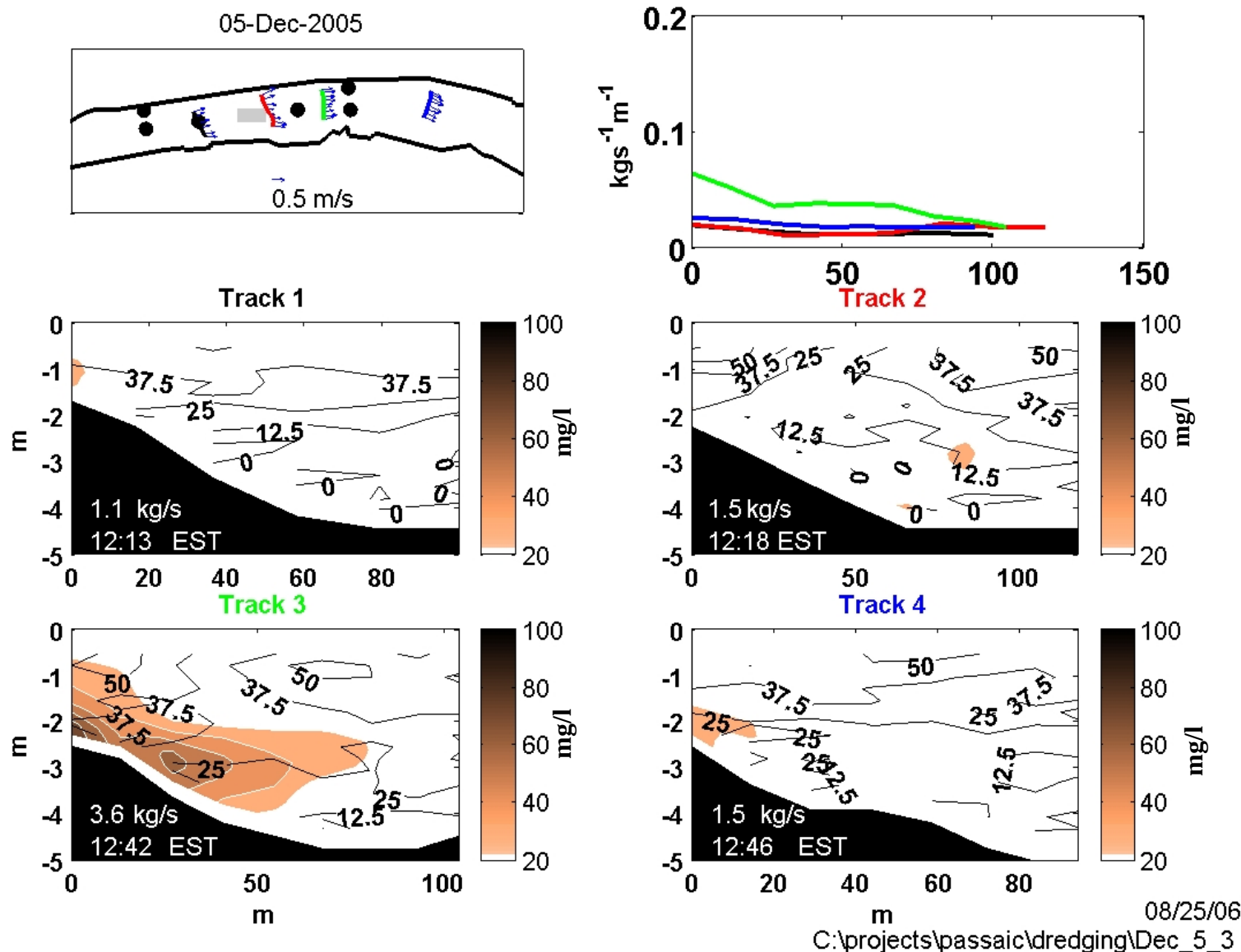


Figure 10-3. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

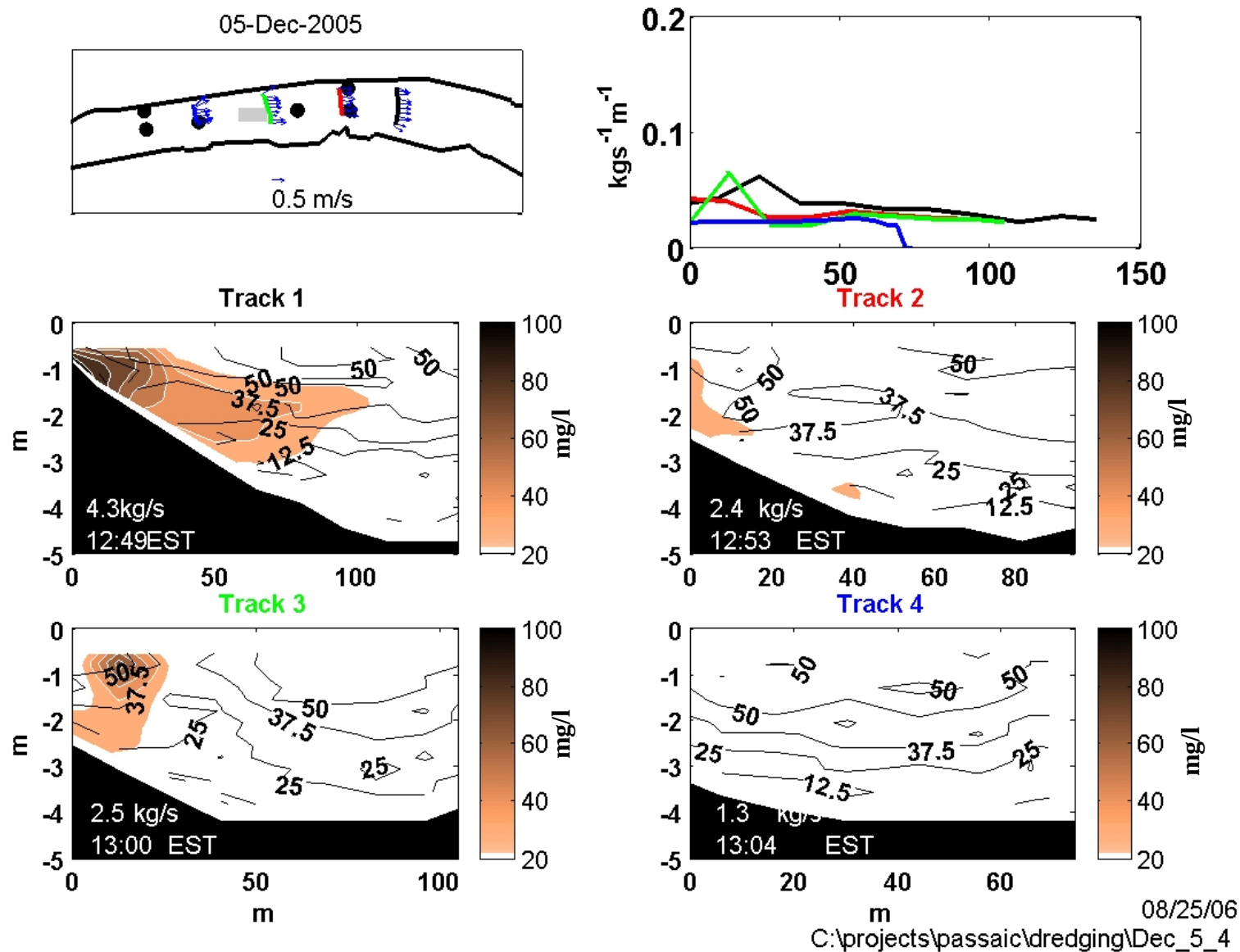


Figure 10-4. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

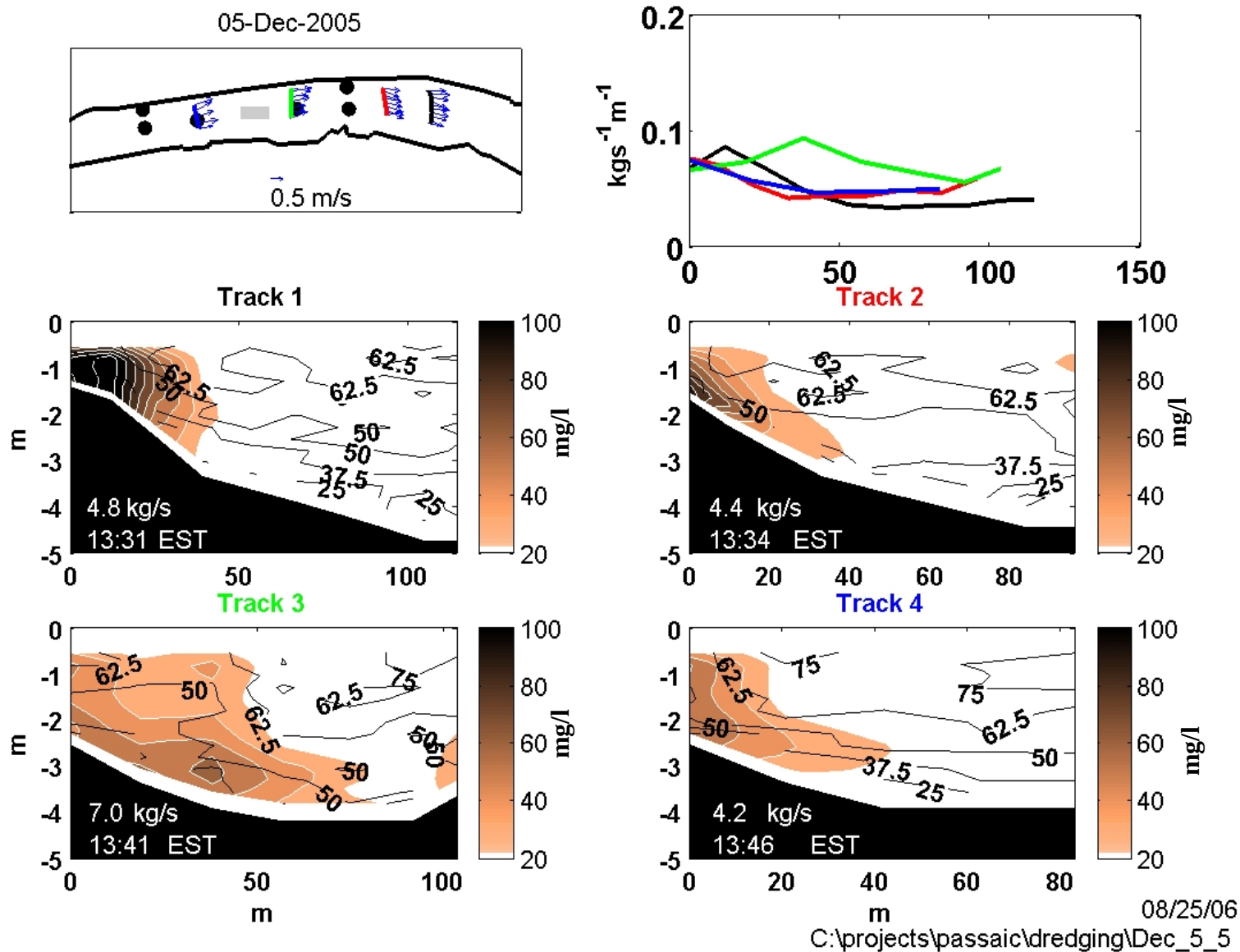


Figure 10-5. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

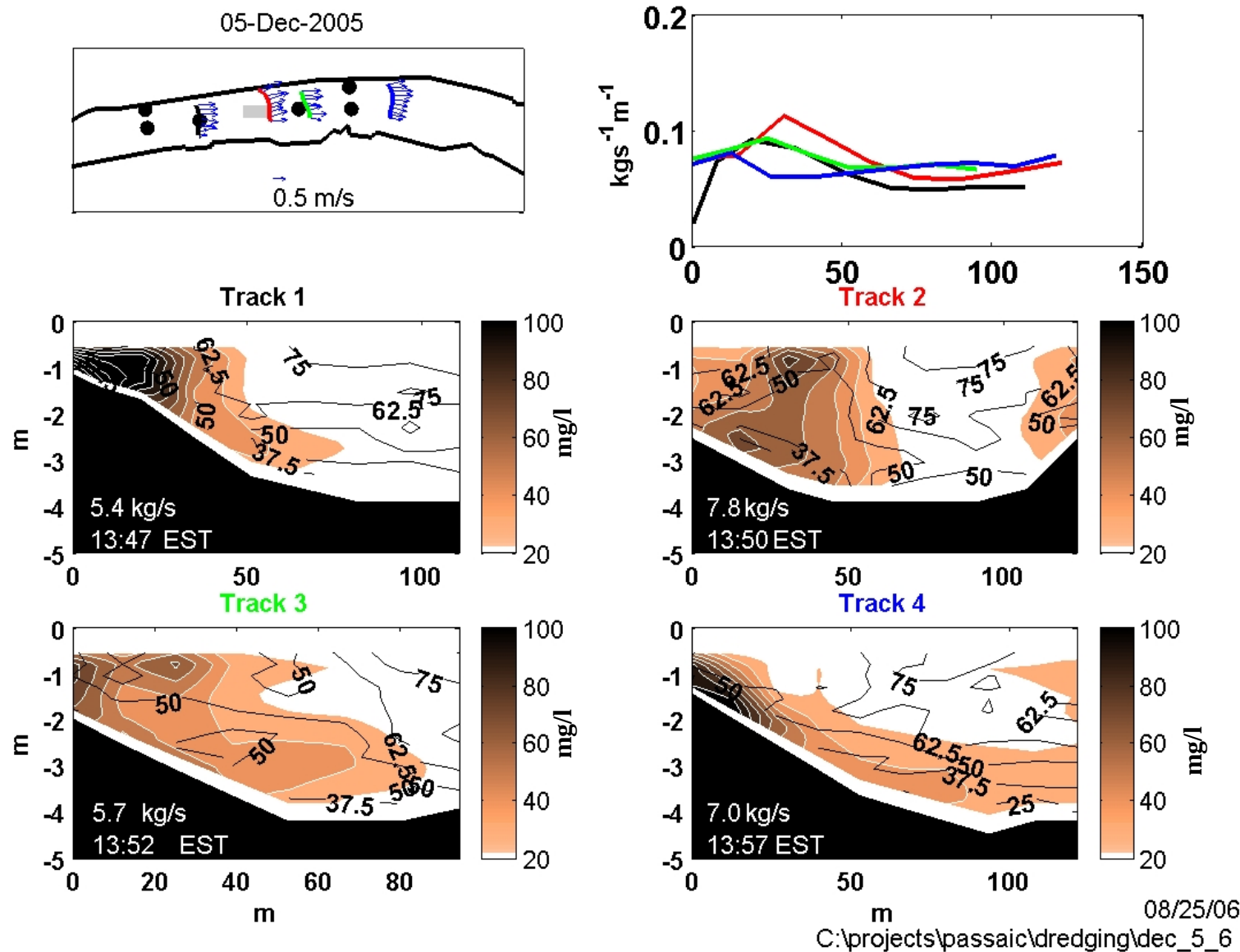


Figure 10-6. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

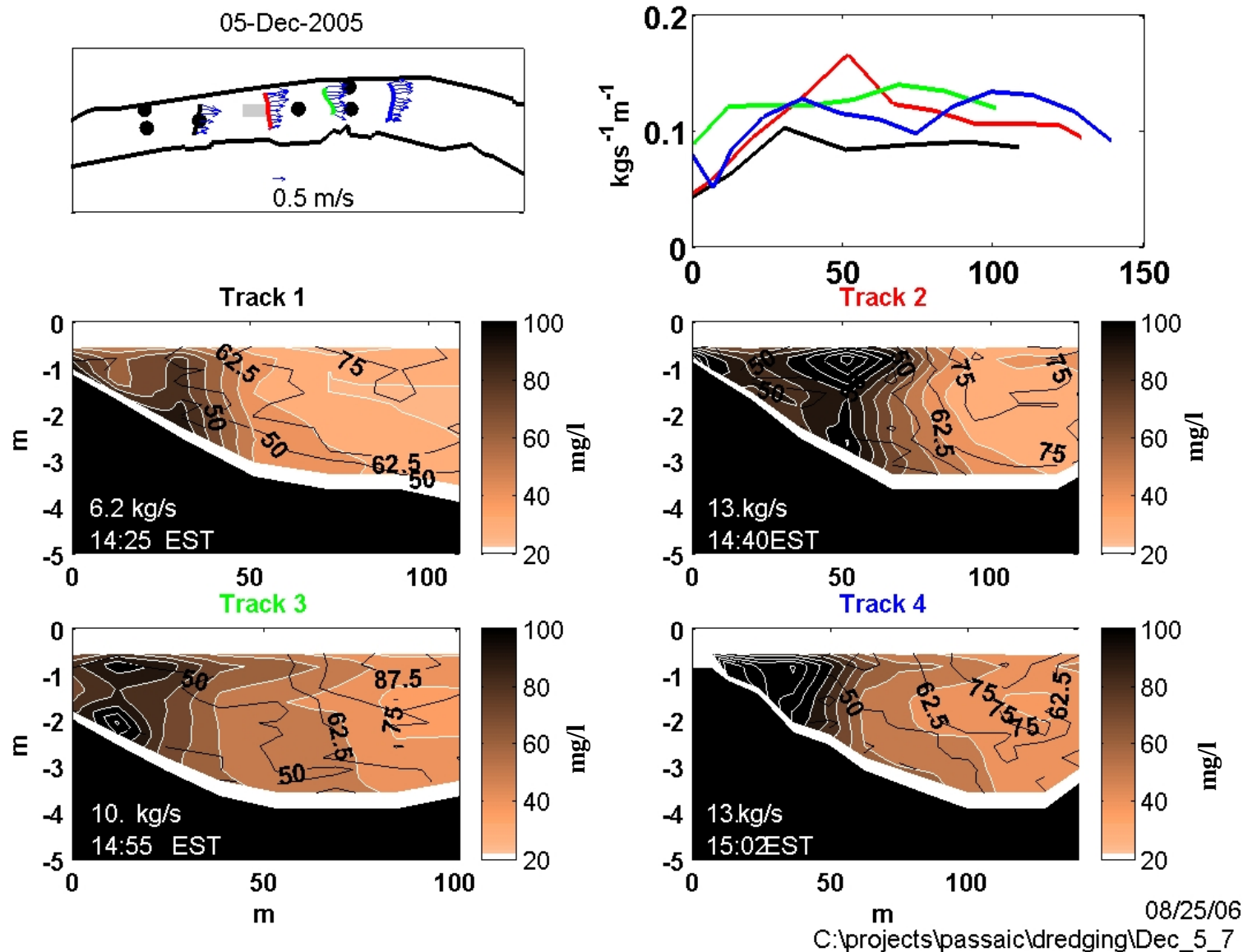


Figure 10-7. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

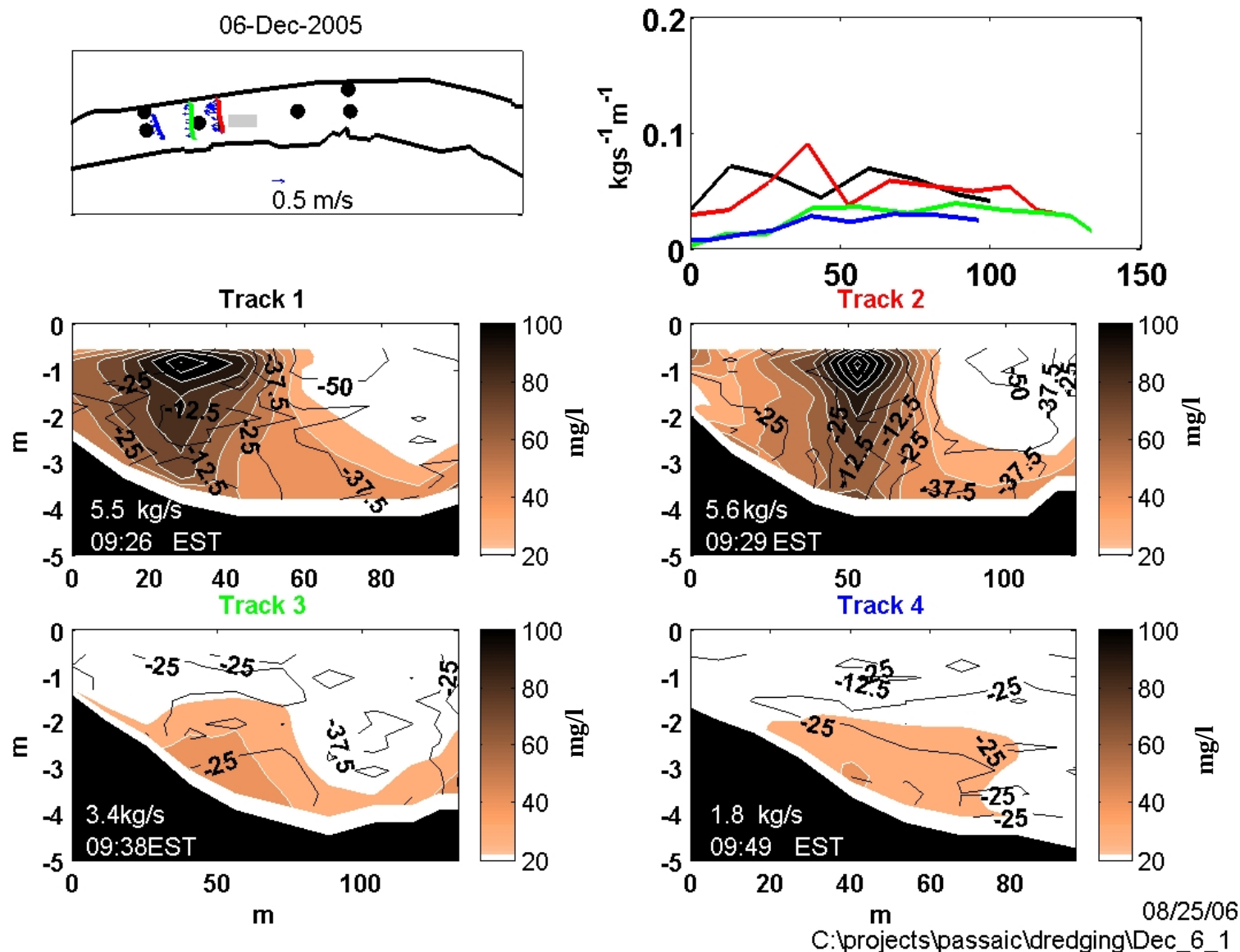


Figure 10-8. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels. Note that track 1 and track 2 are on top of one another in map

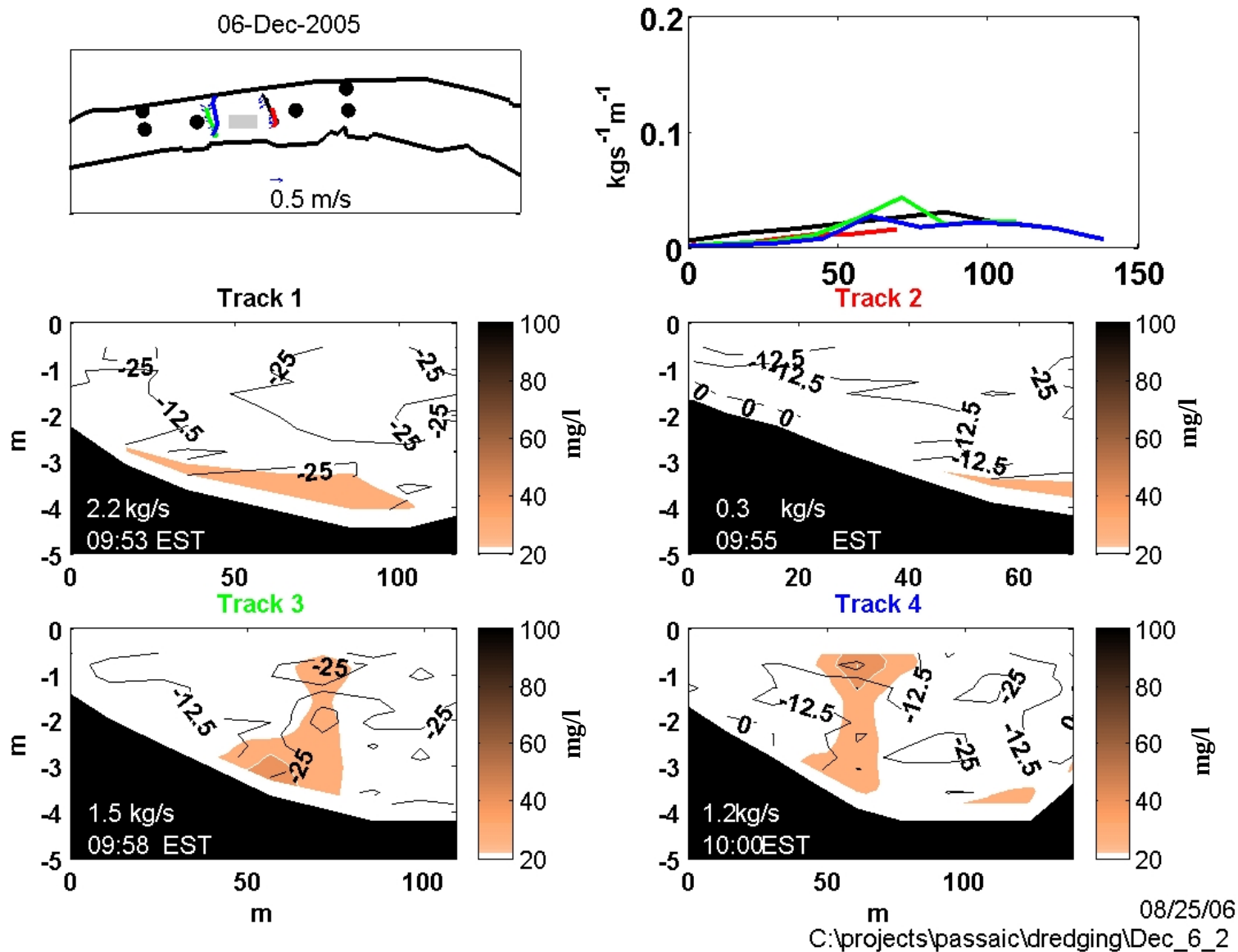


Figure 10-9. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

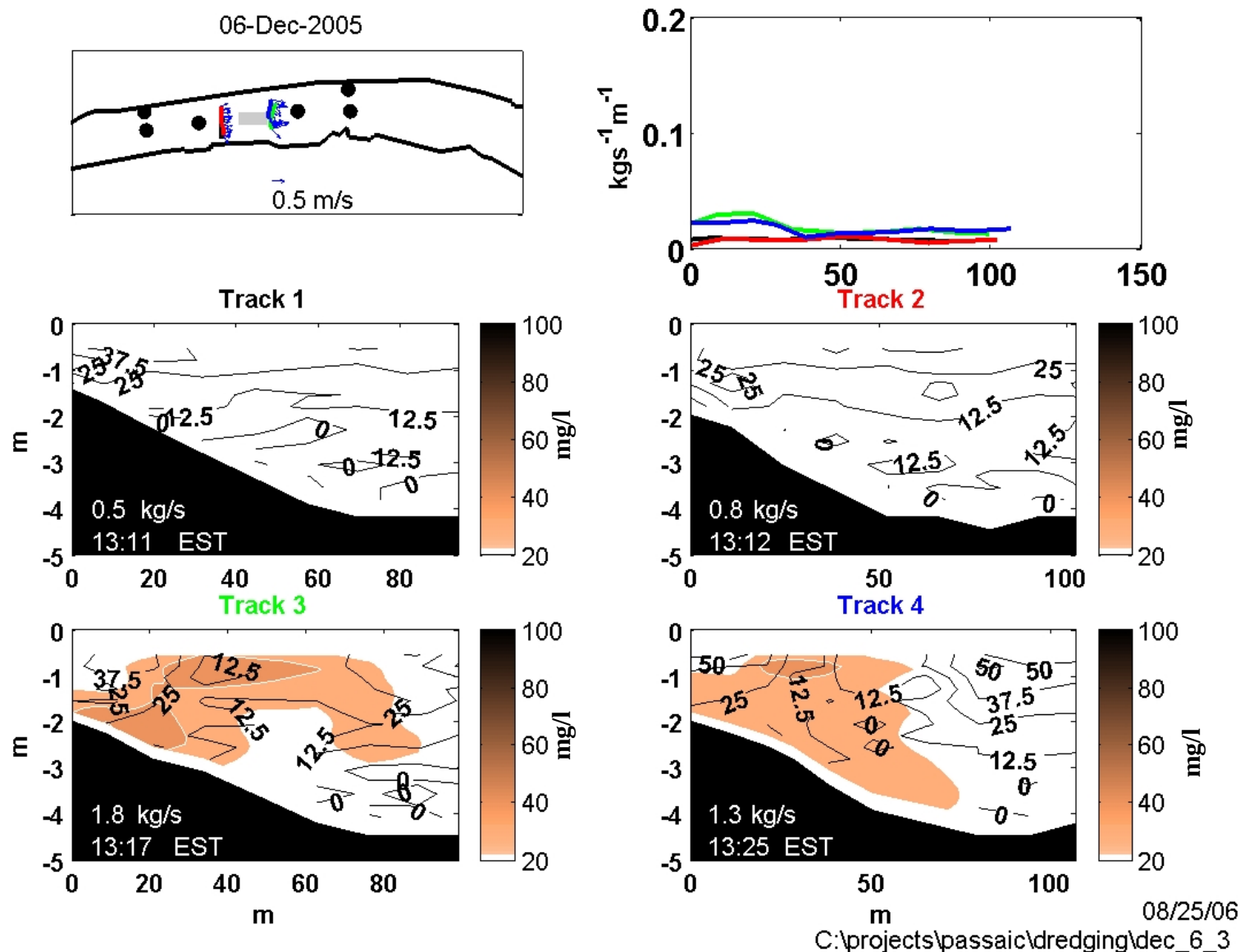


Figure 10-10. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

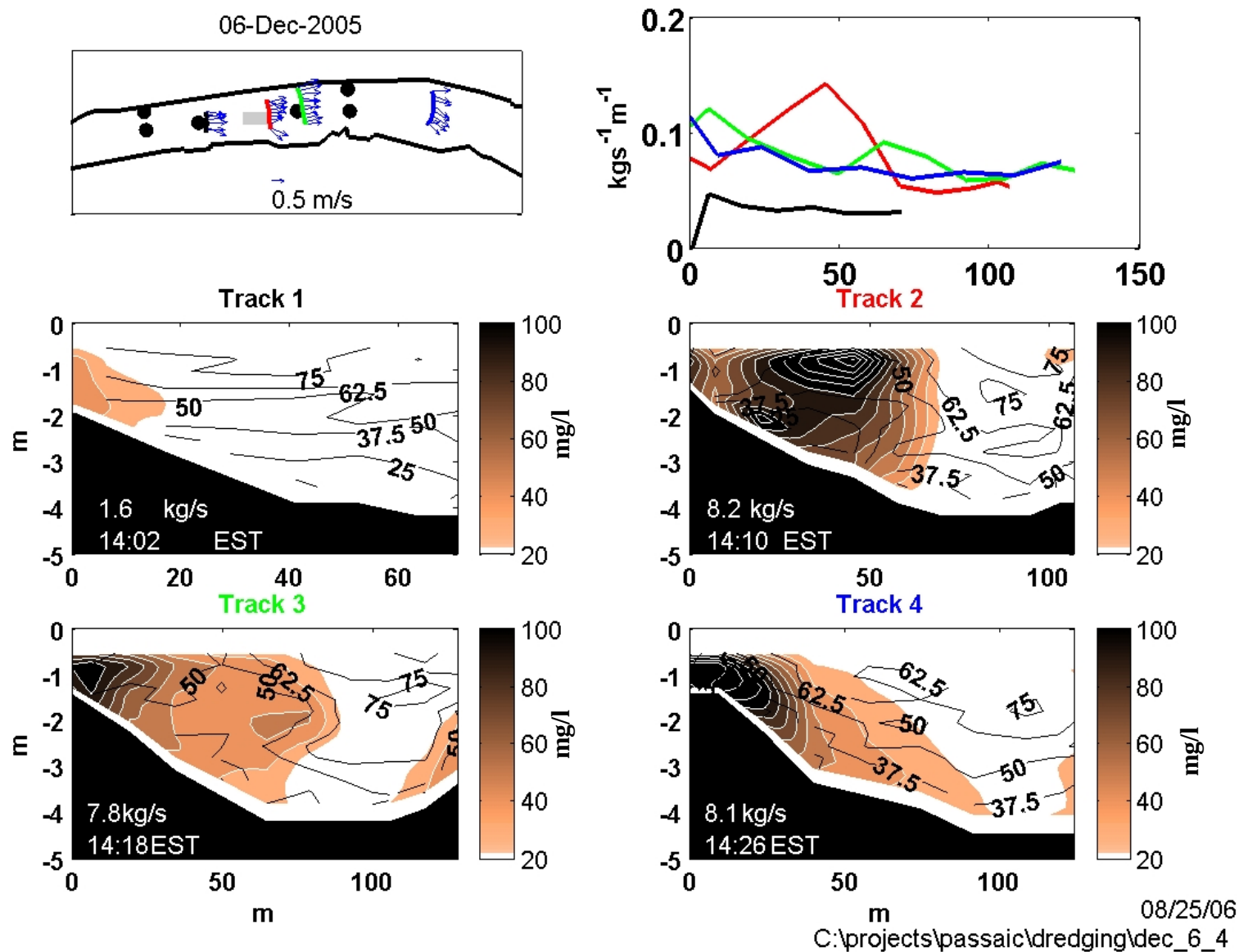


Figure 10-11. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

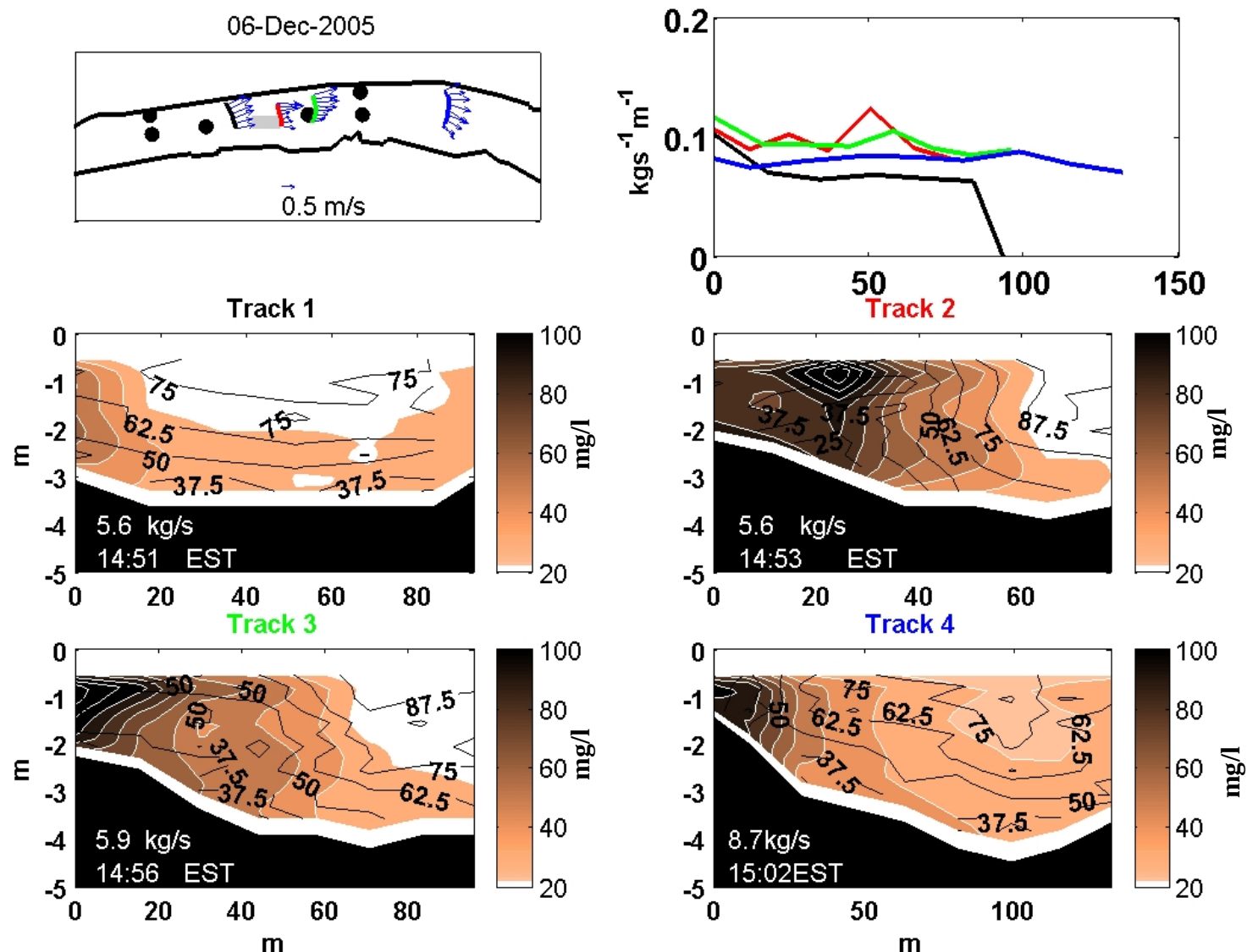


Figure 10-12. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

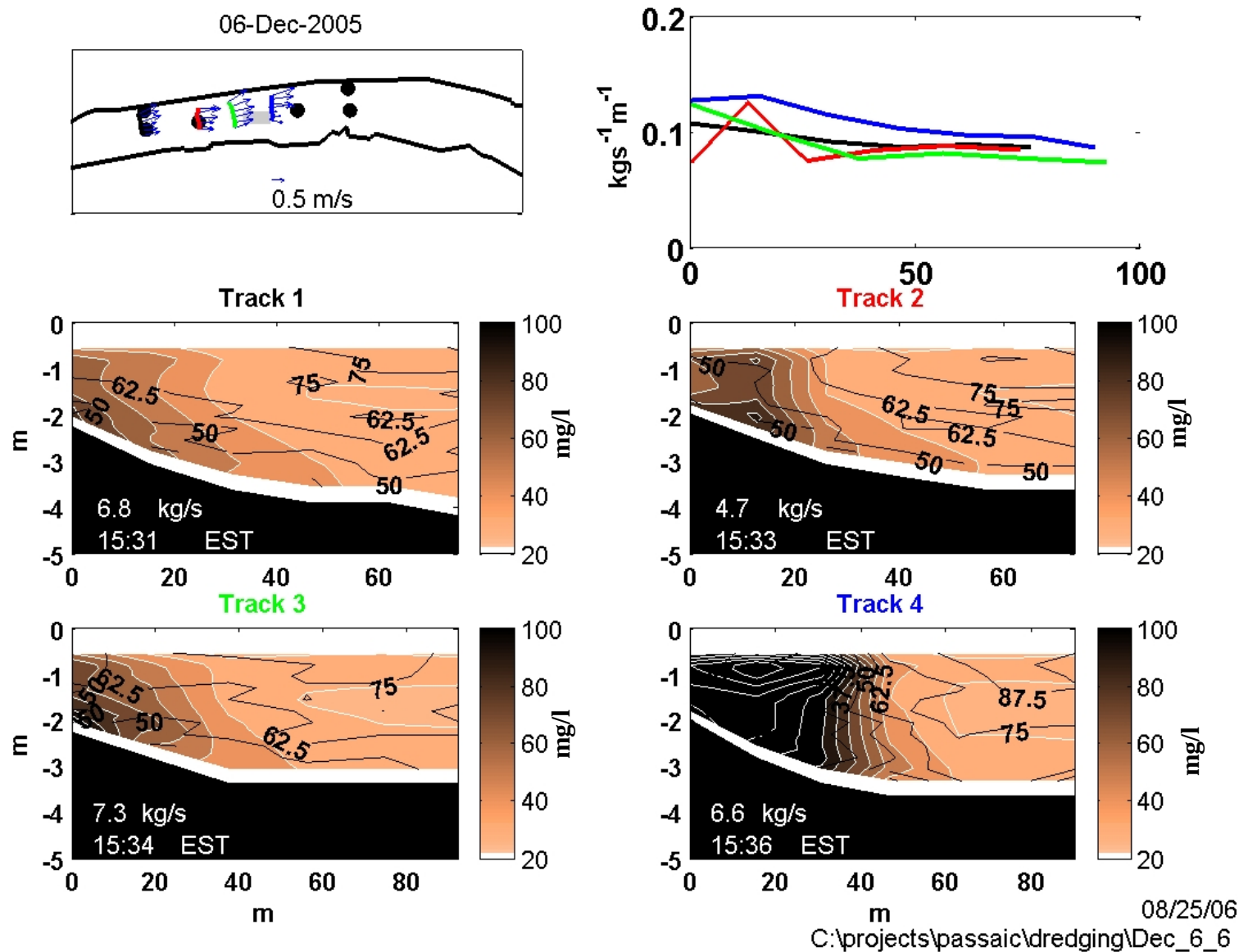


Figure 10-13. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

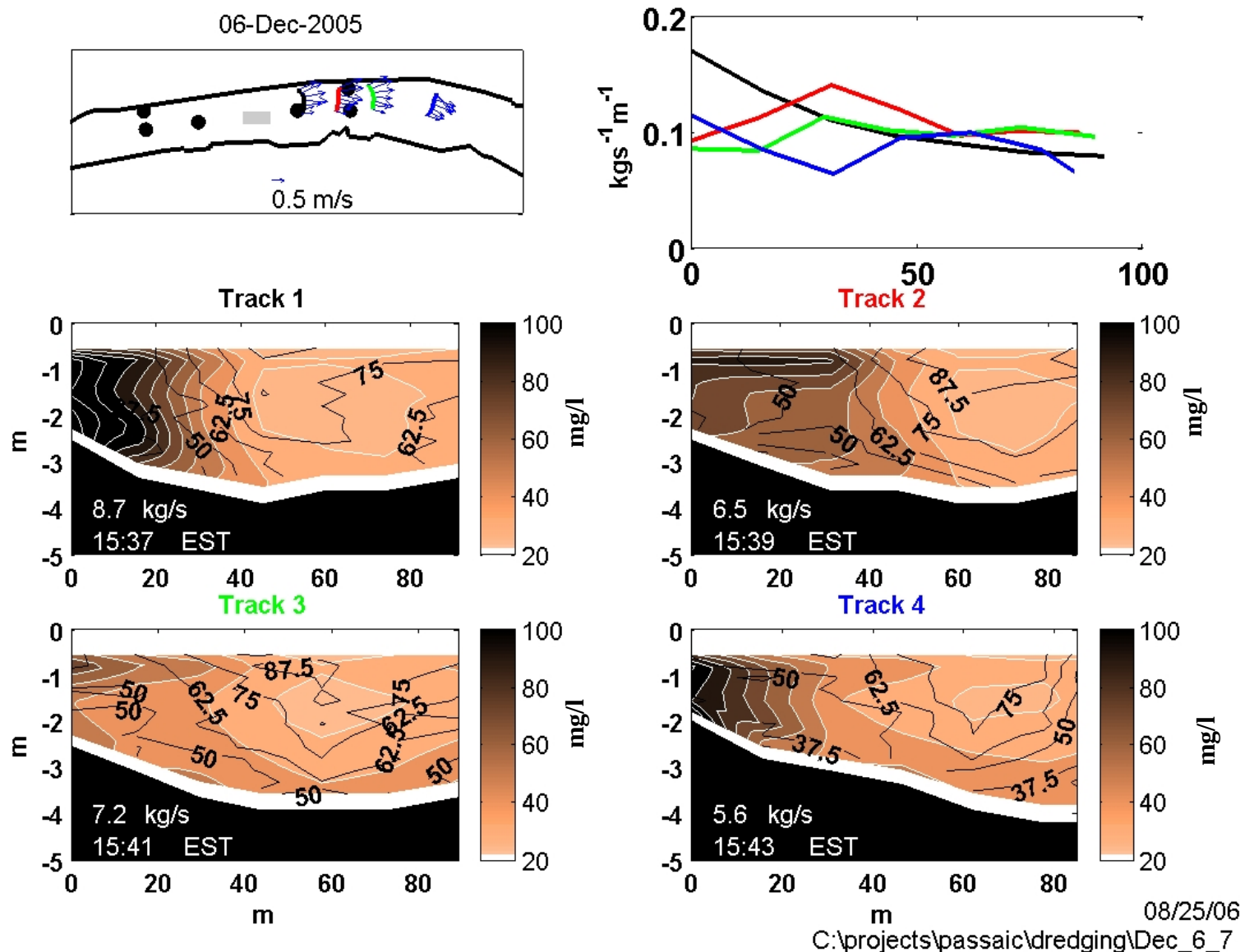


Figure 10-14. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

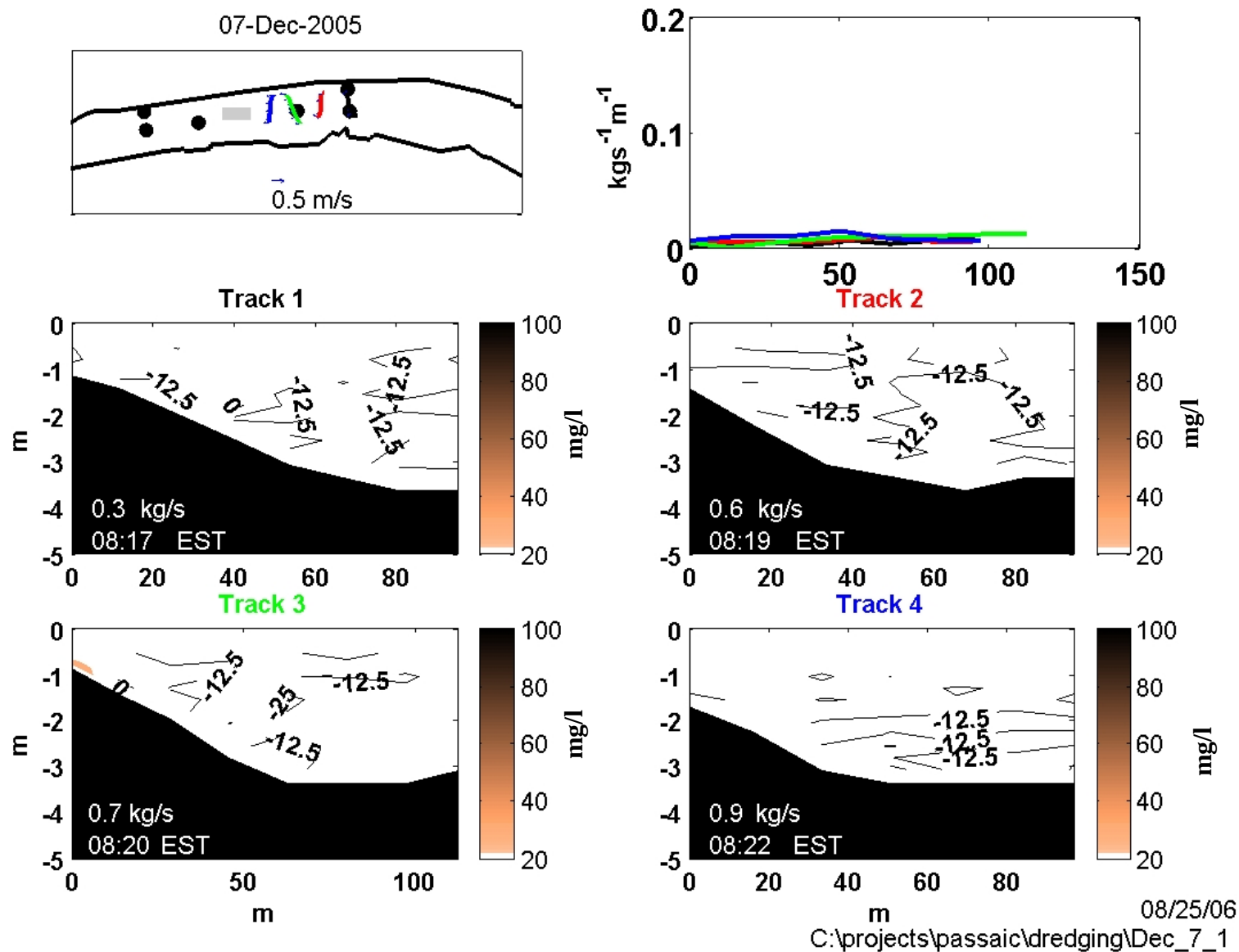


Figure 10-15. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

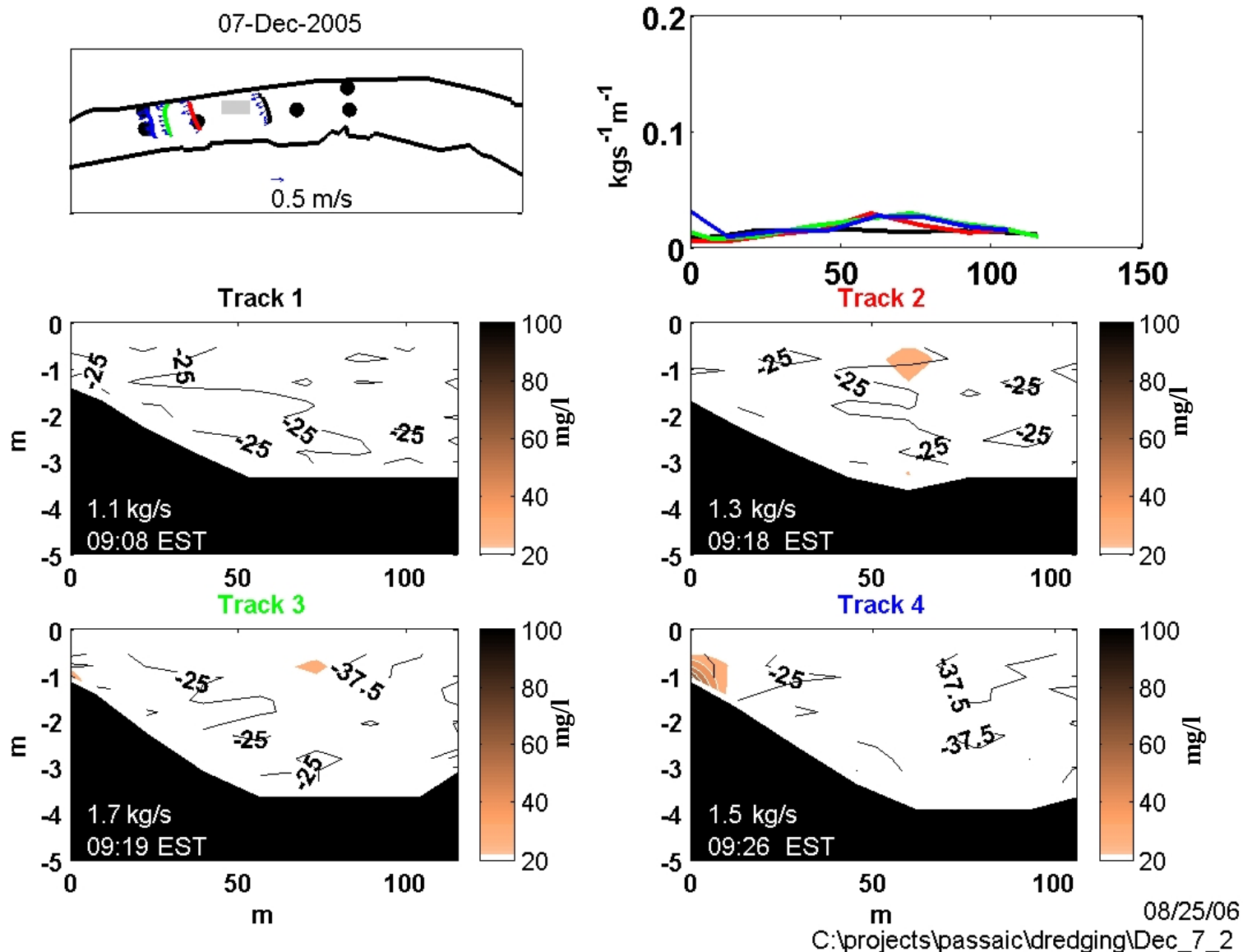


Figure 10-16. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

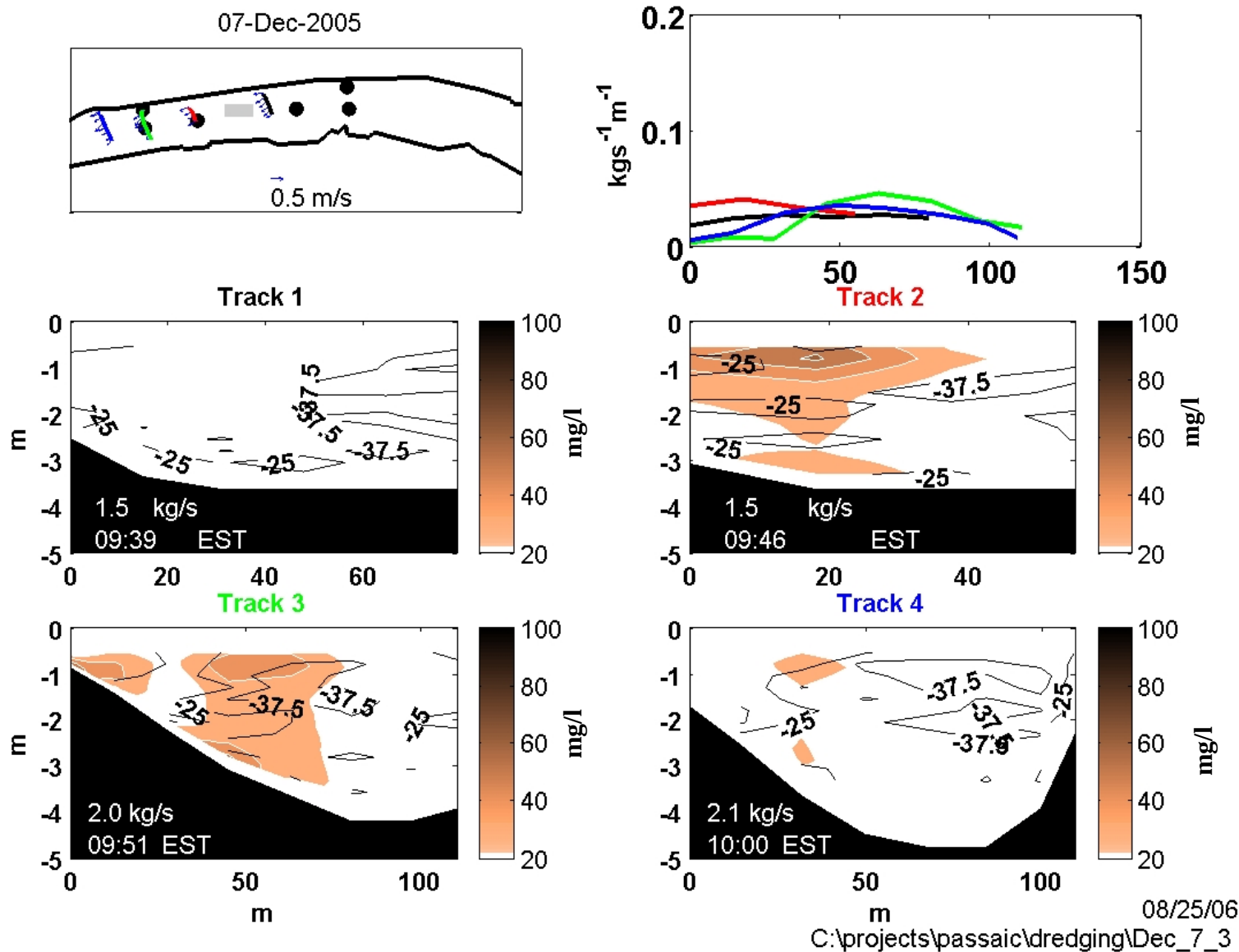


Figure 10-17. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

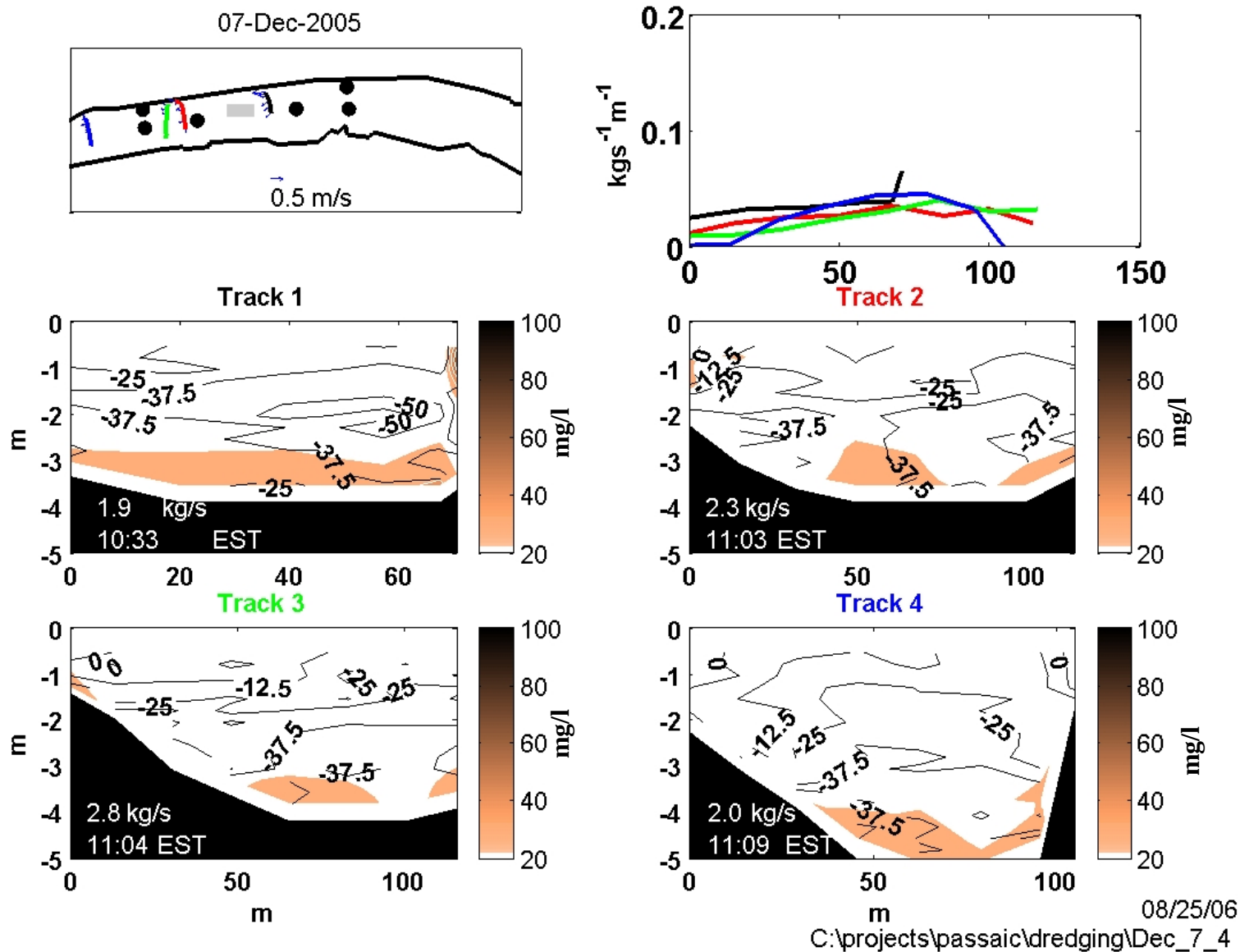


Figure 10-18. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

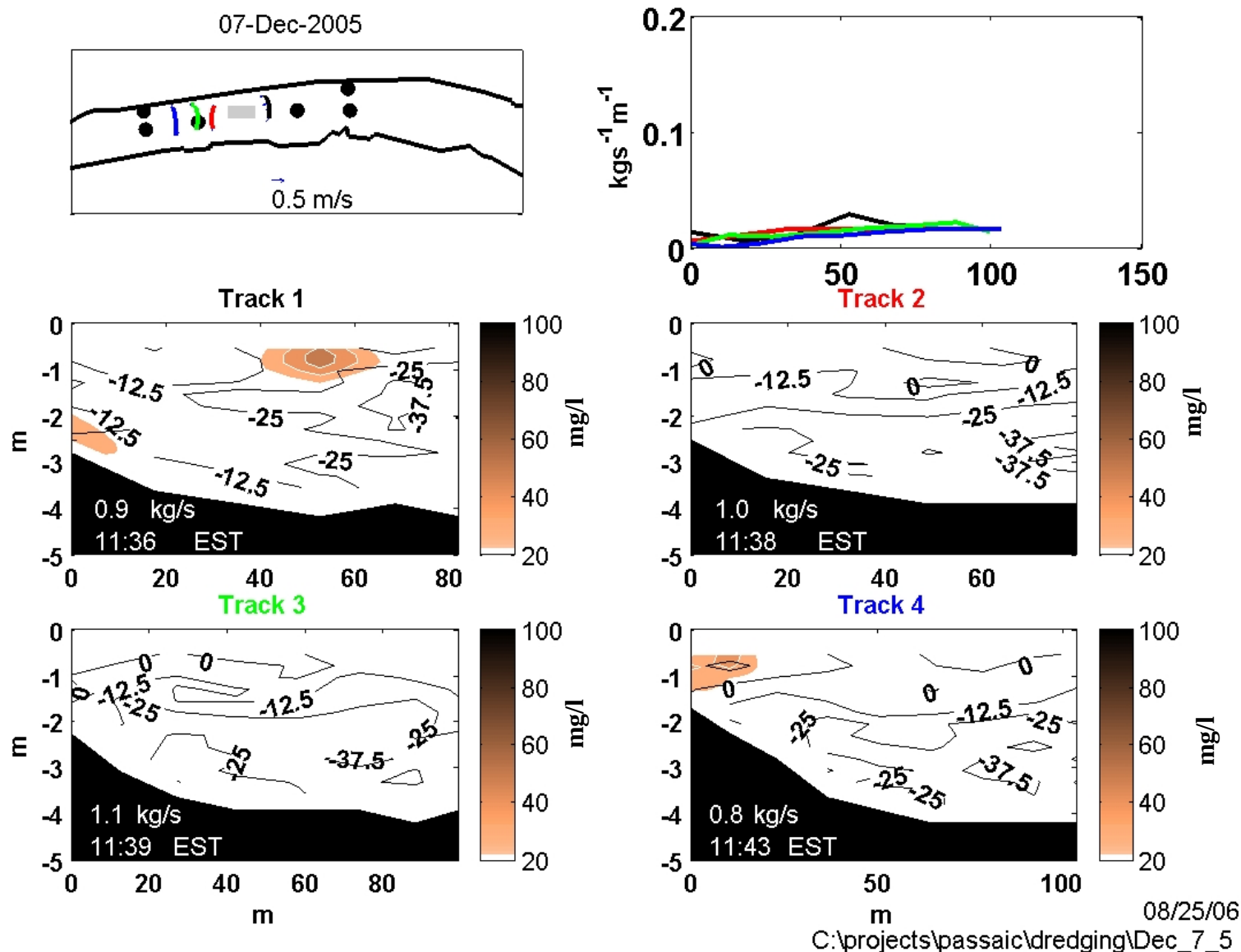


Figure 10-19. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

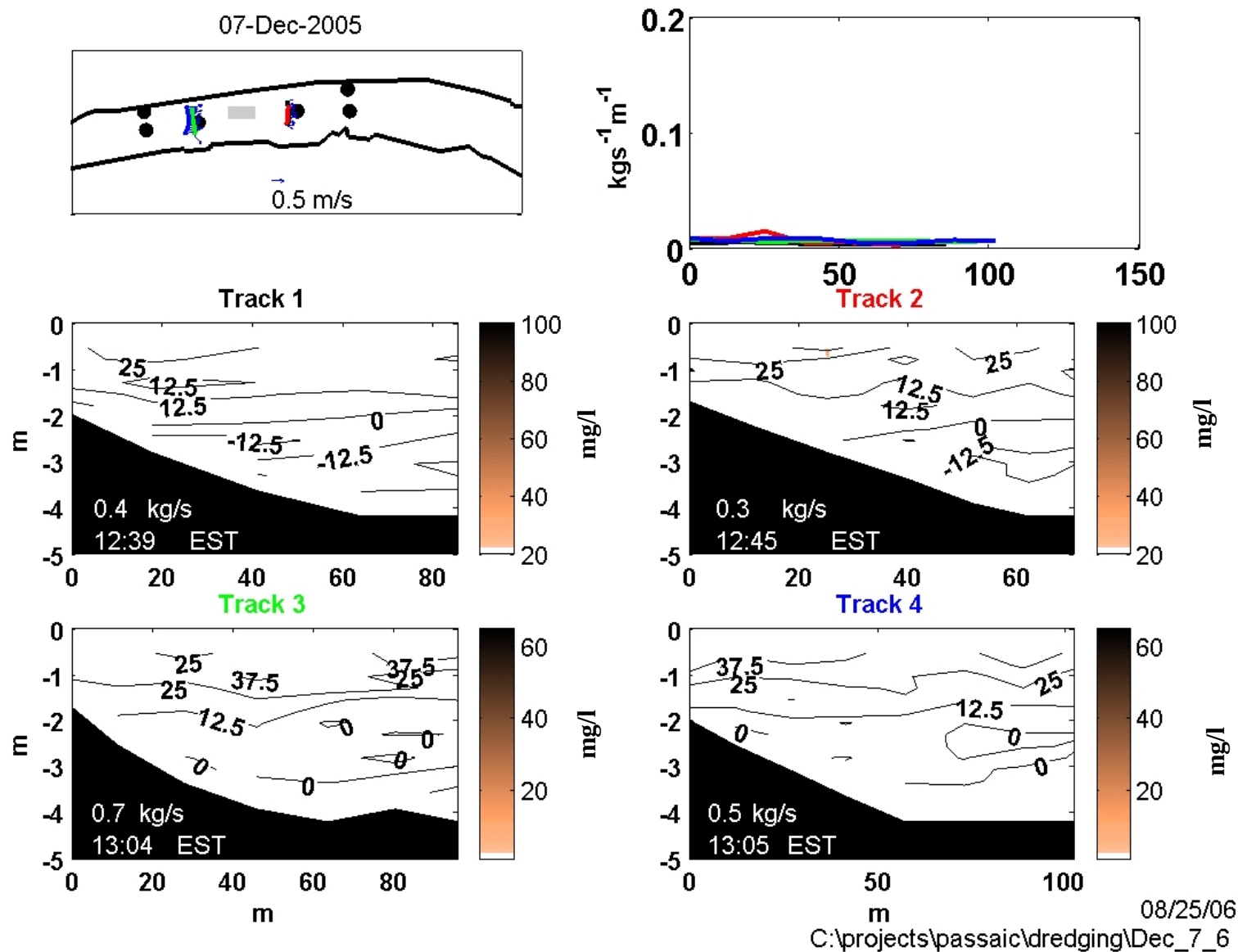


Figure 10-20. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

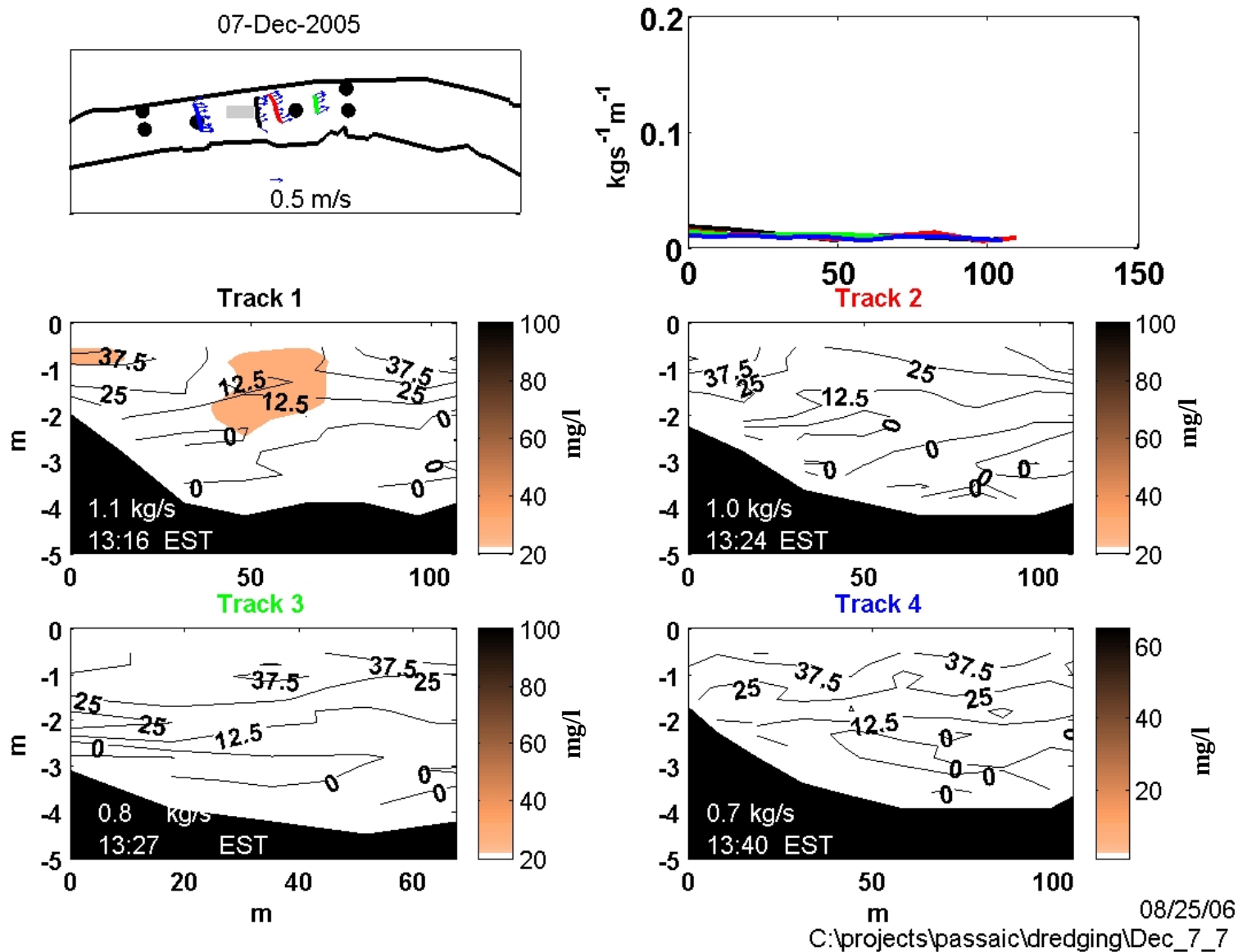


Figure 10-21. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

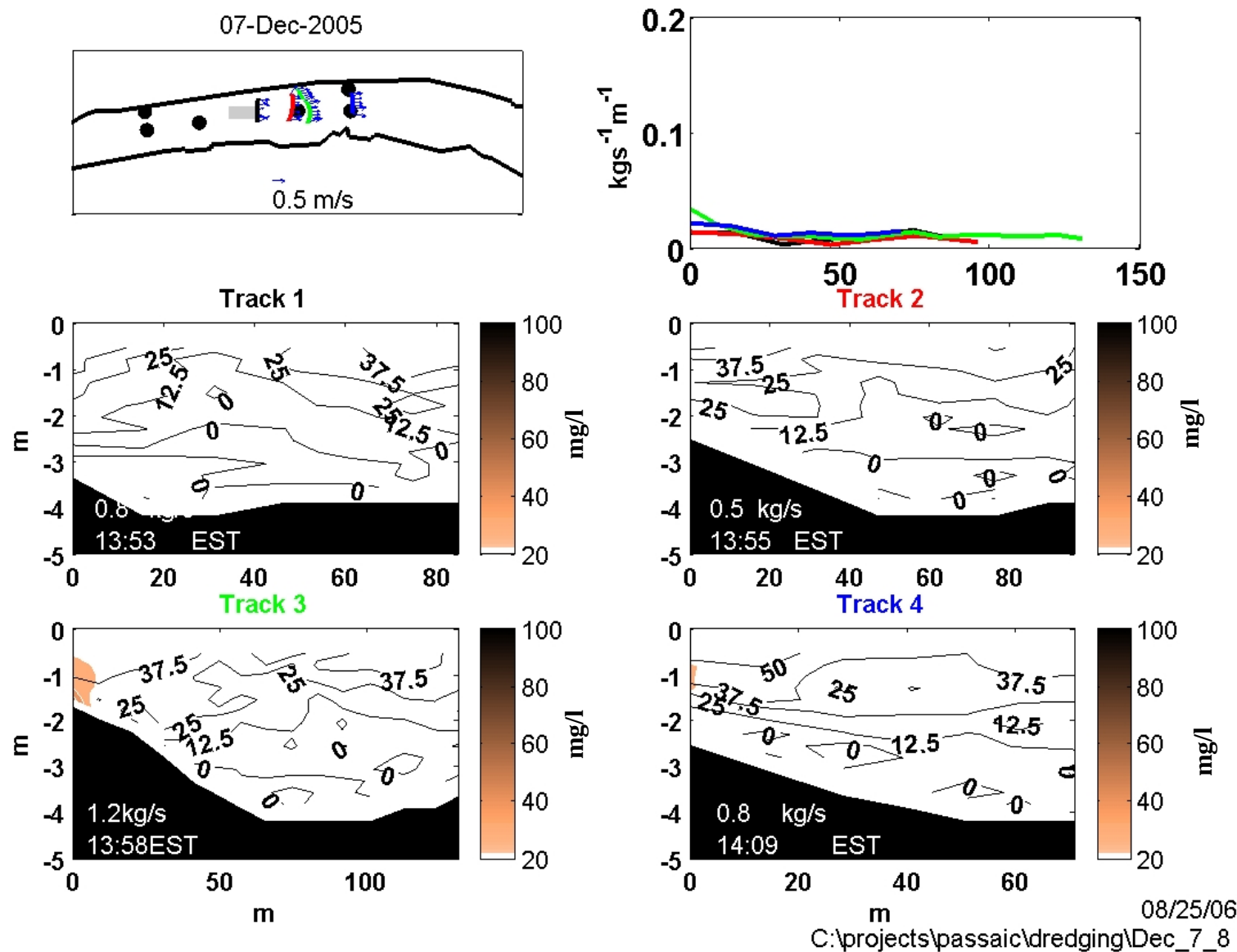


Figure 10-22. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

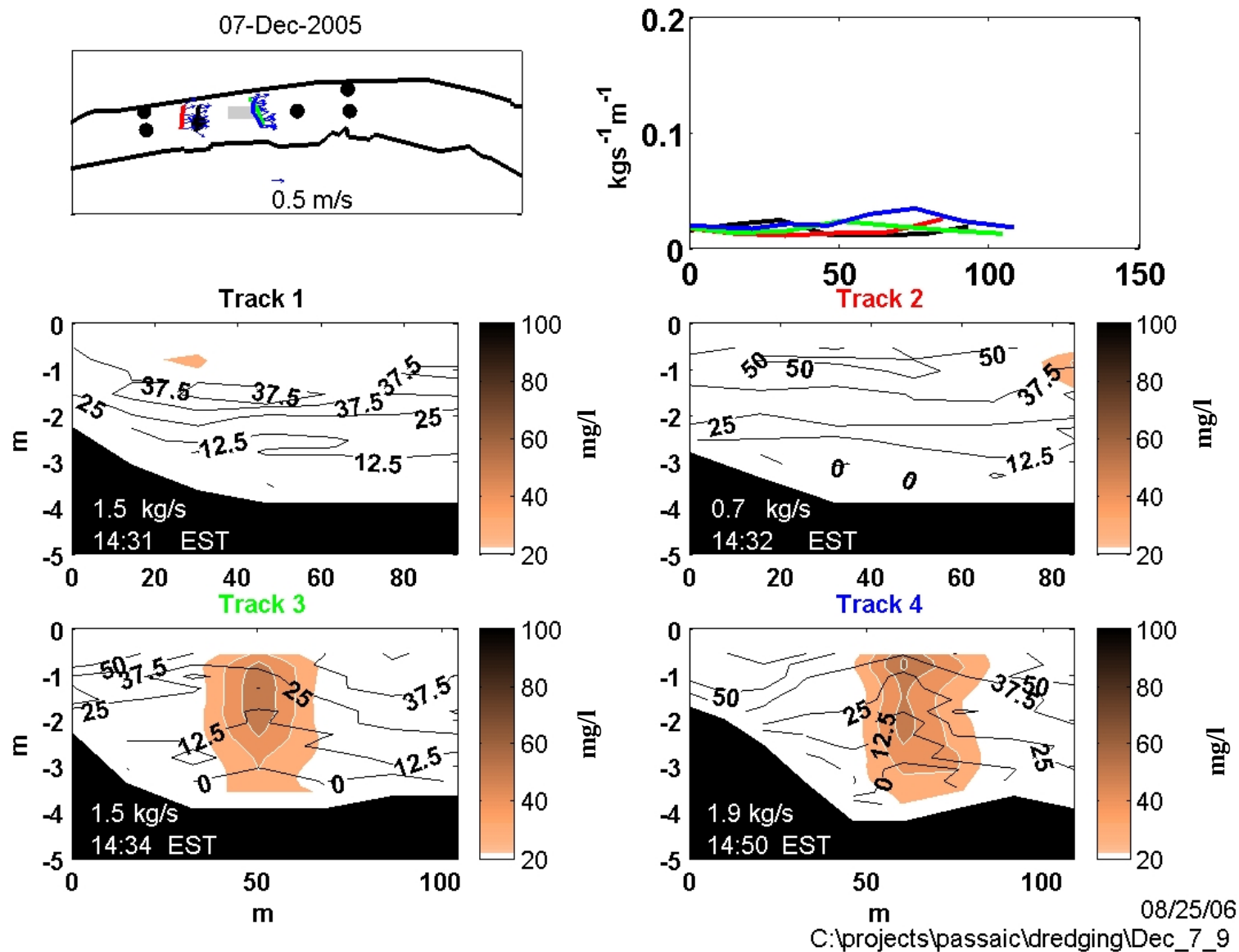


Figure 10-23. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

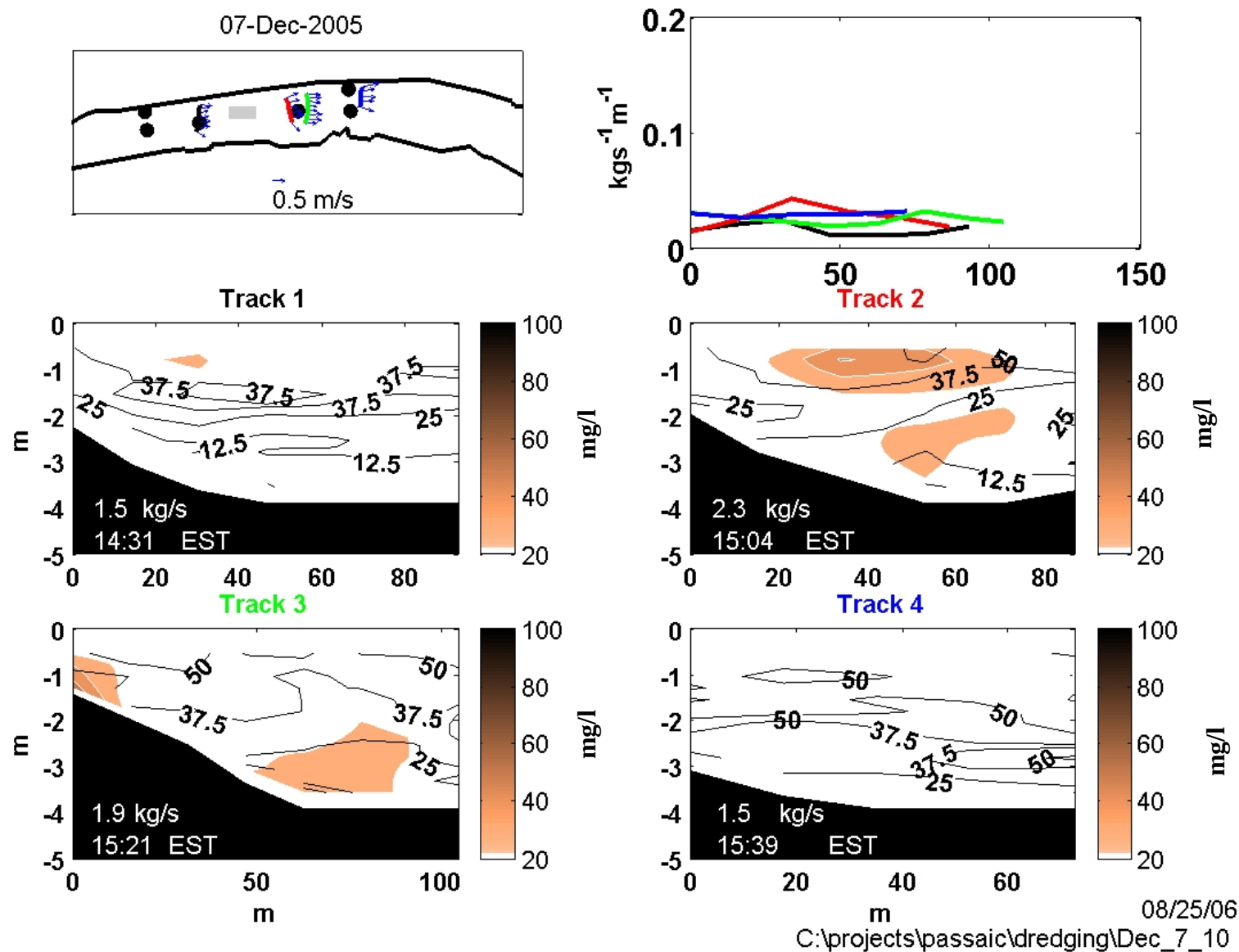


Figure 10-24. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

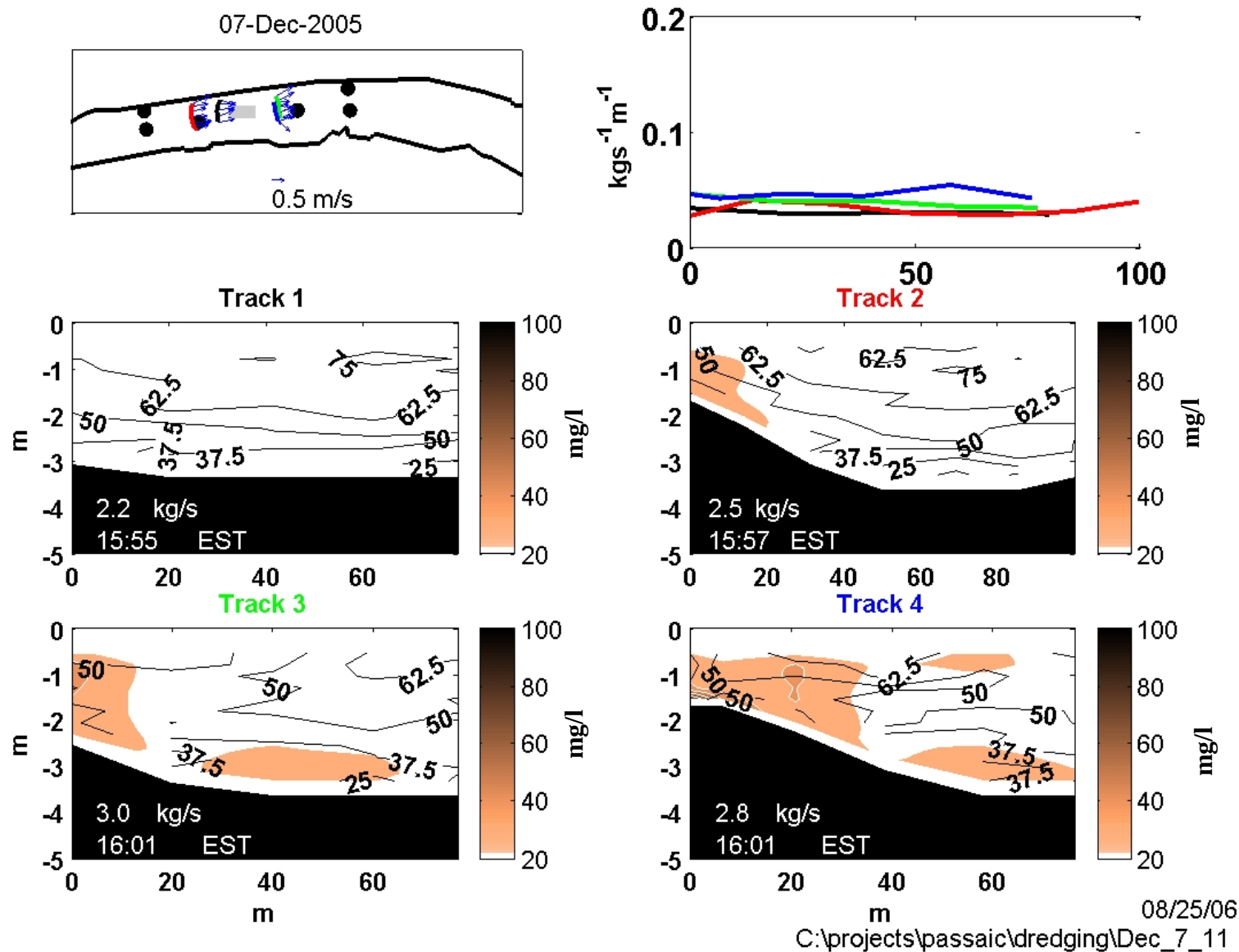


Figure 10-25. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

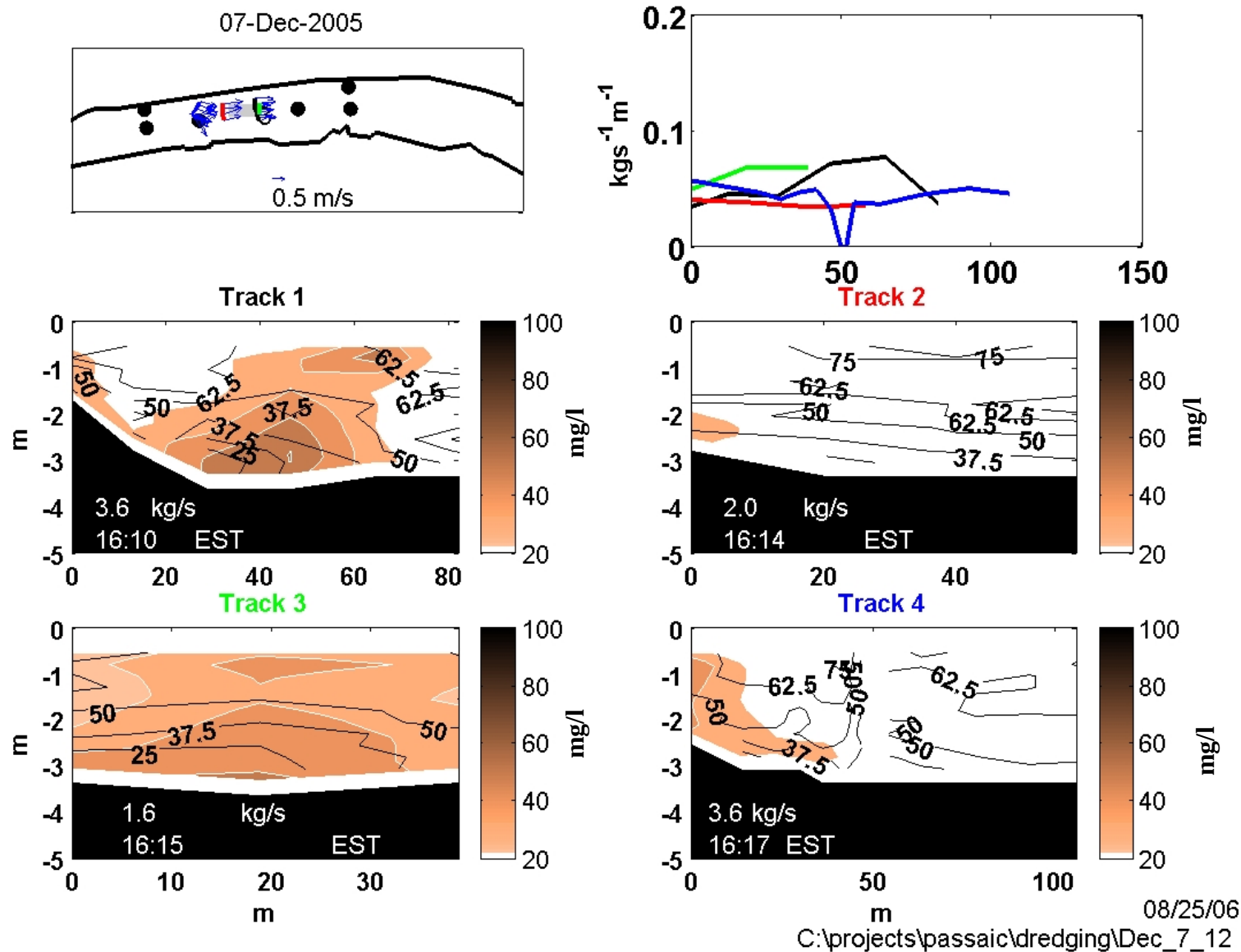


Figure 10-26. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

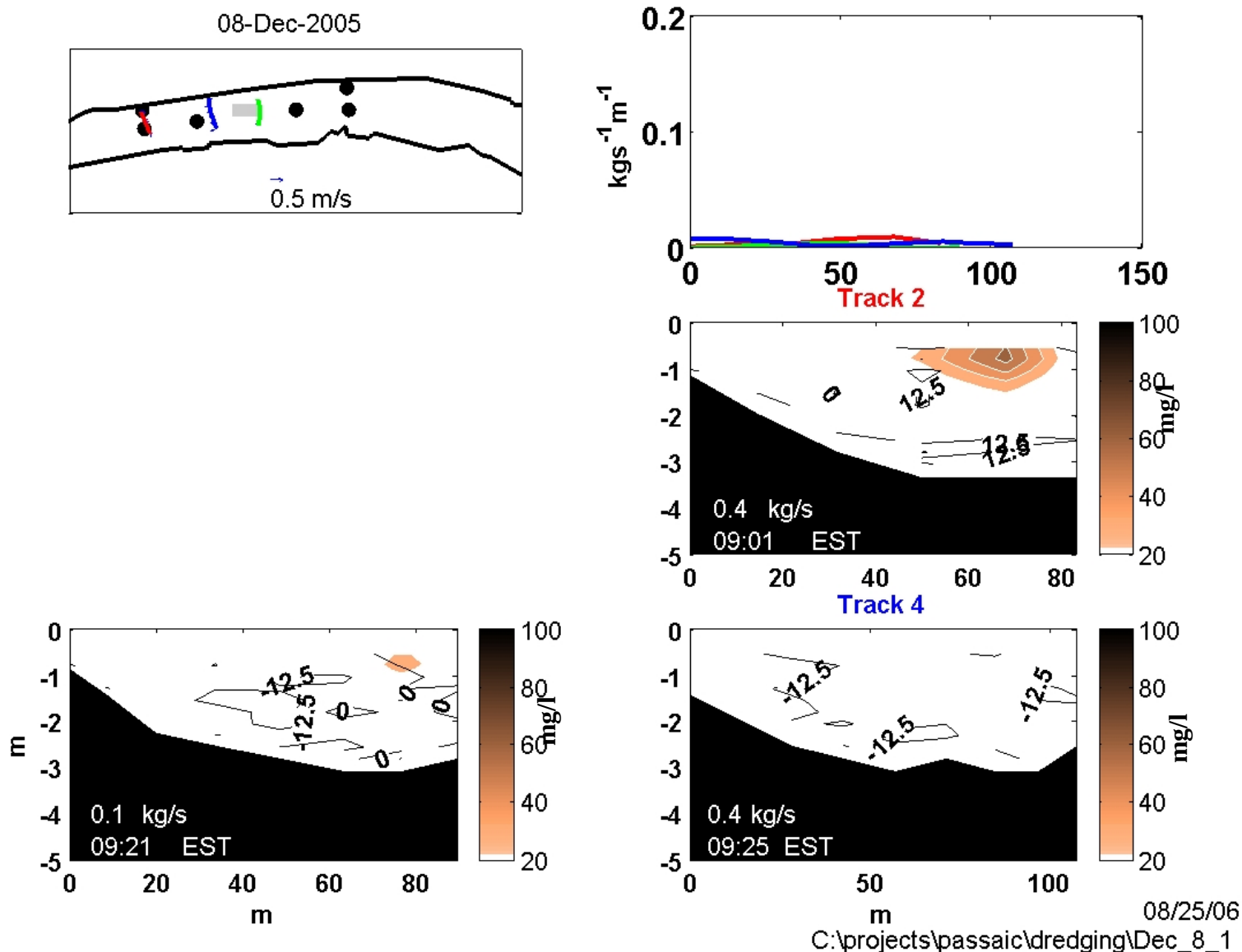


Figure 10-27. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

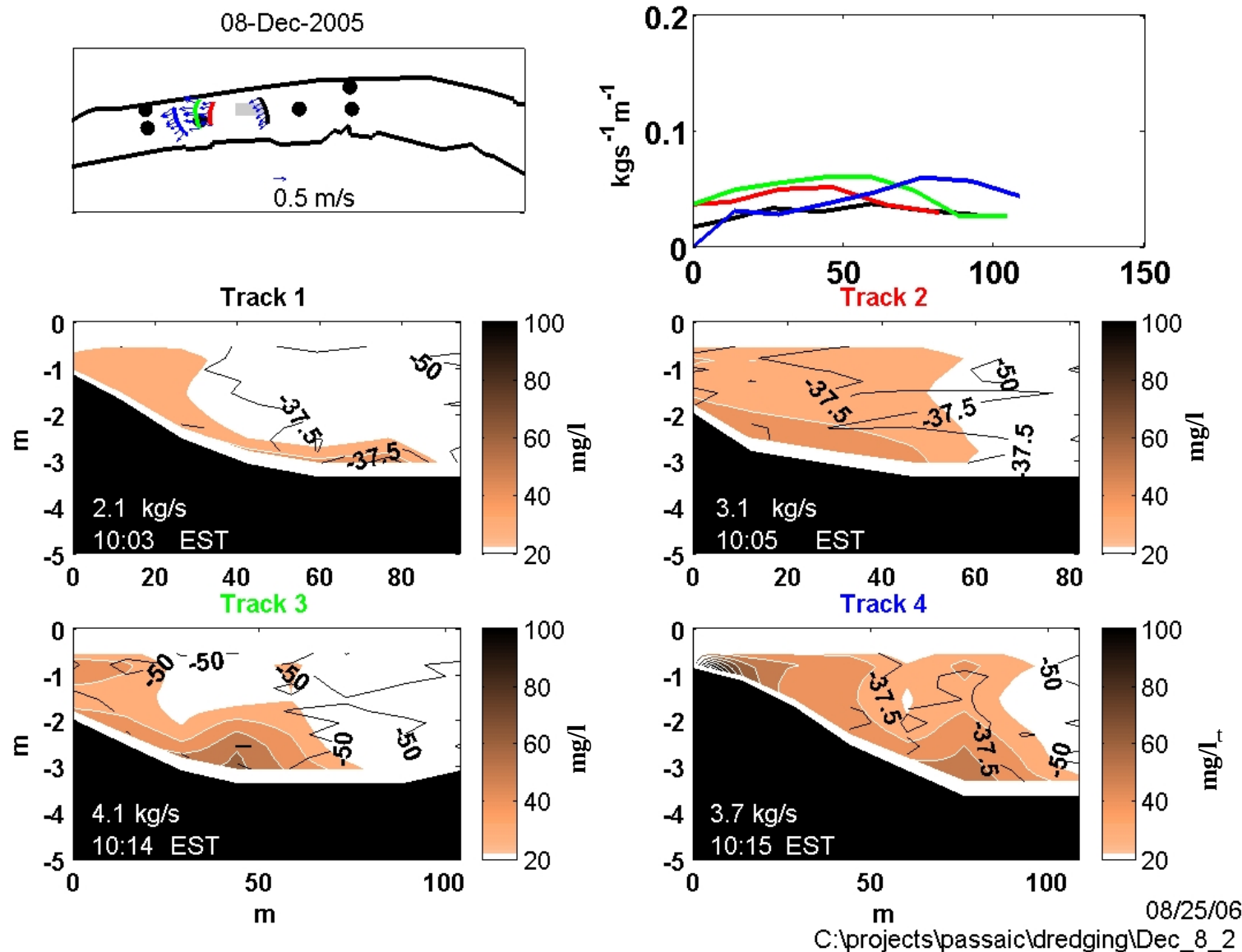


Figure 10-28. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

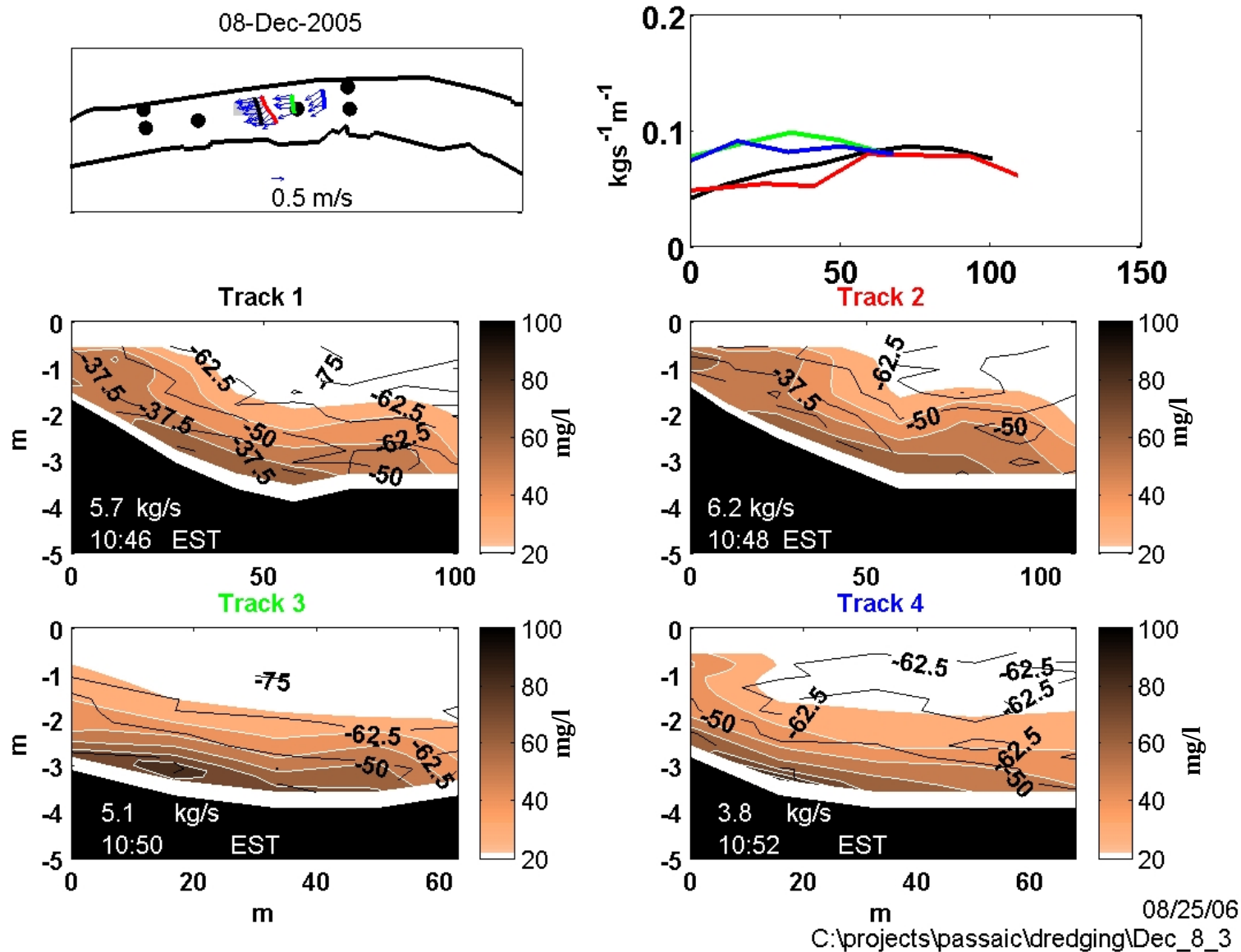


Figure 10-29. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

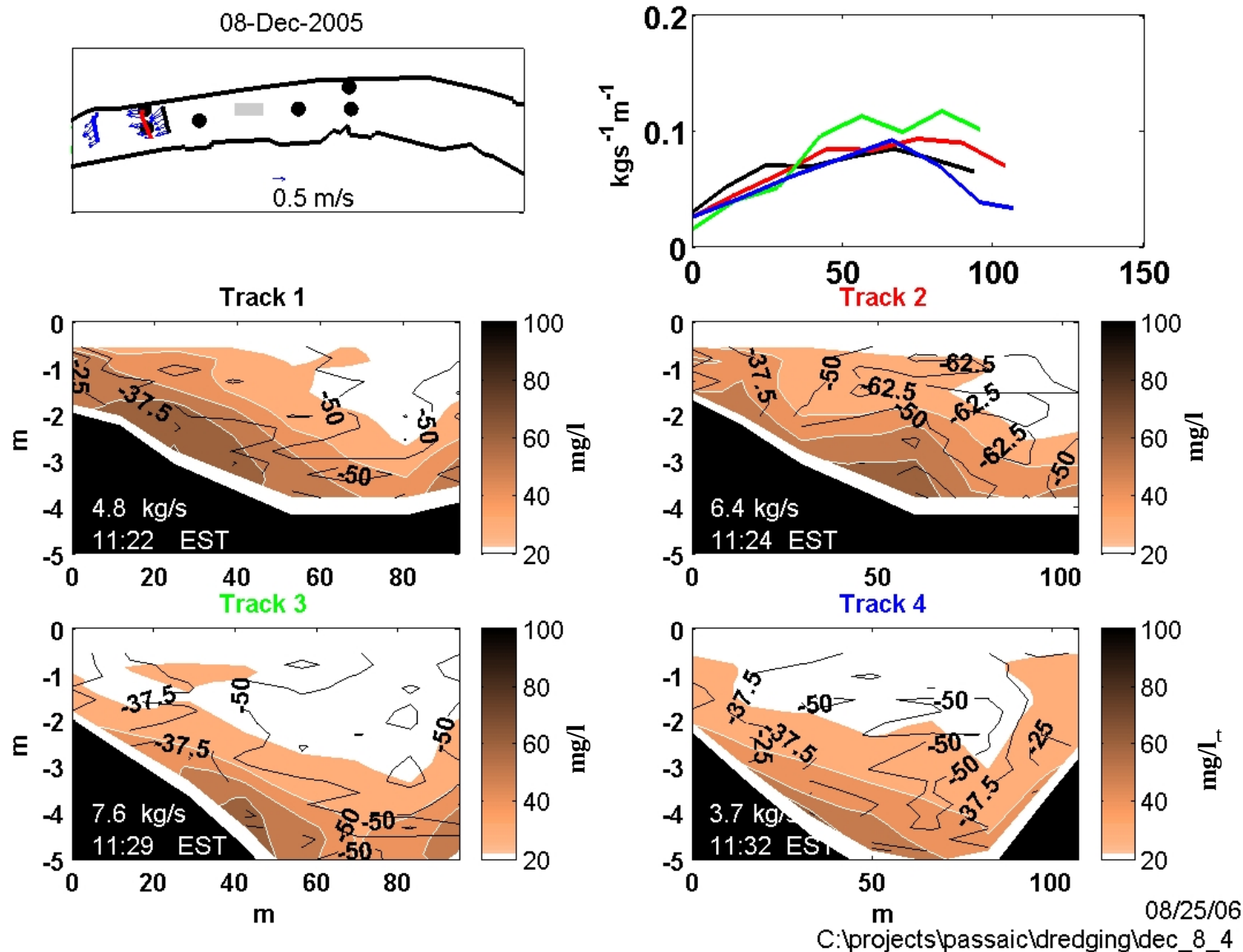


Figure 10-30. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

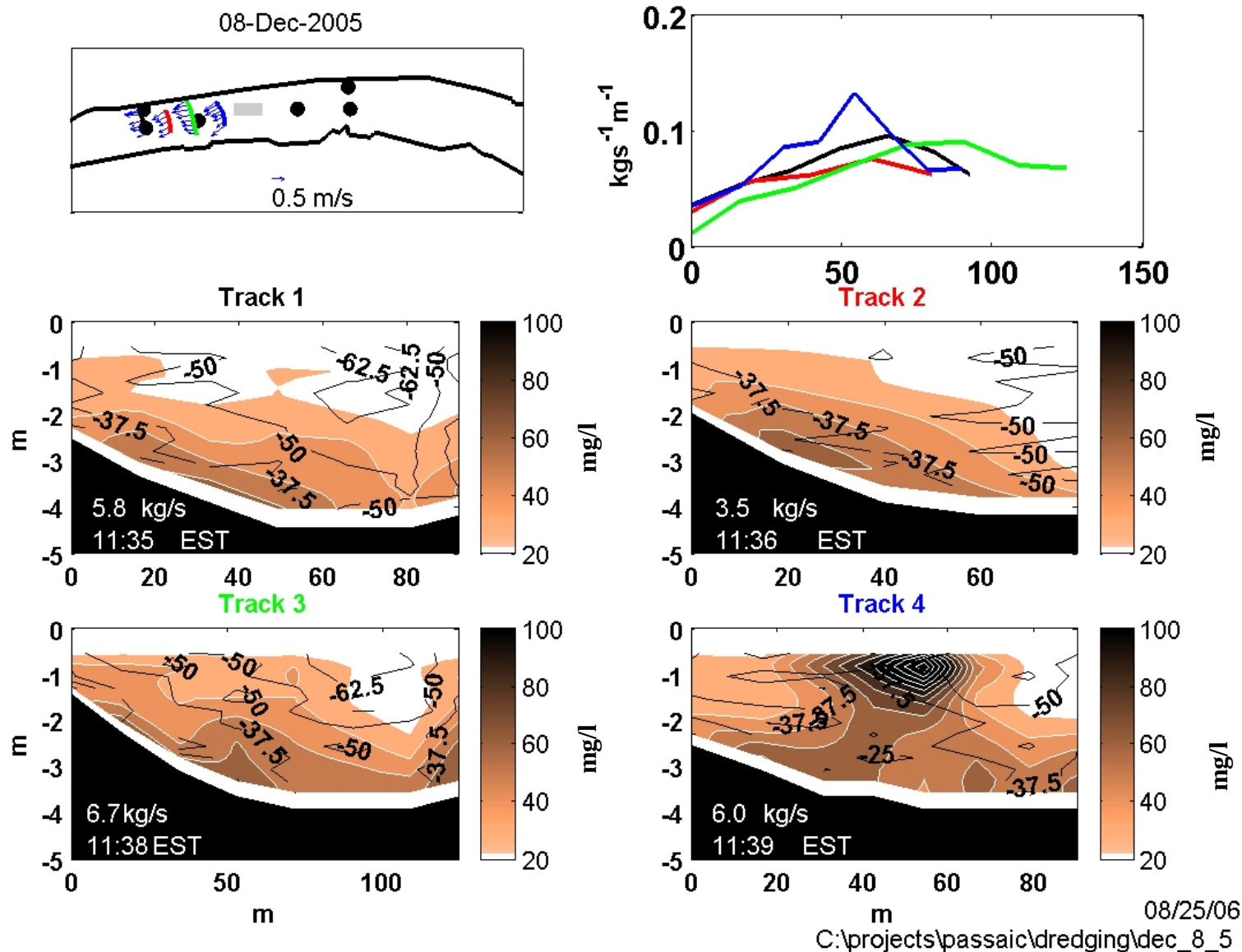


Figure 10-31. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

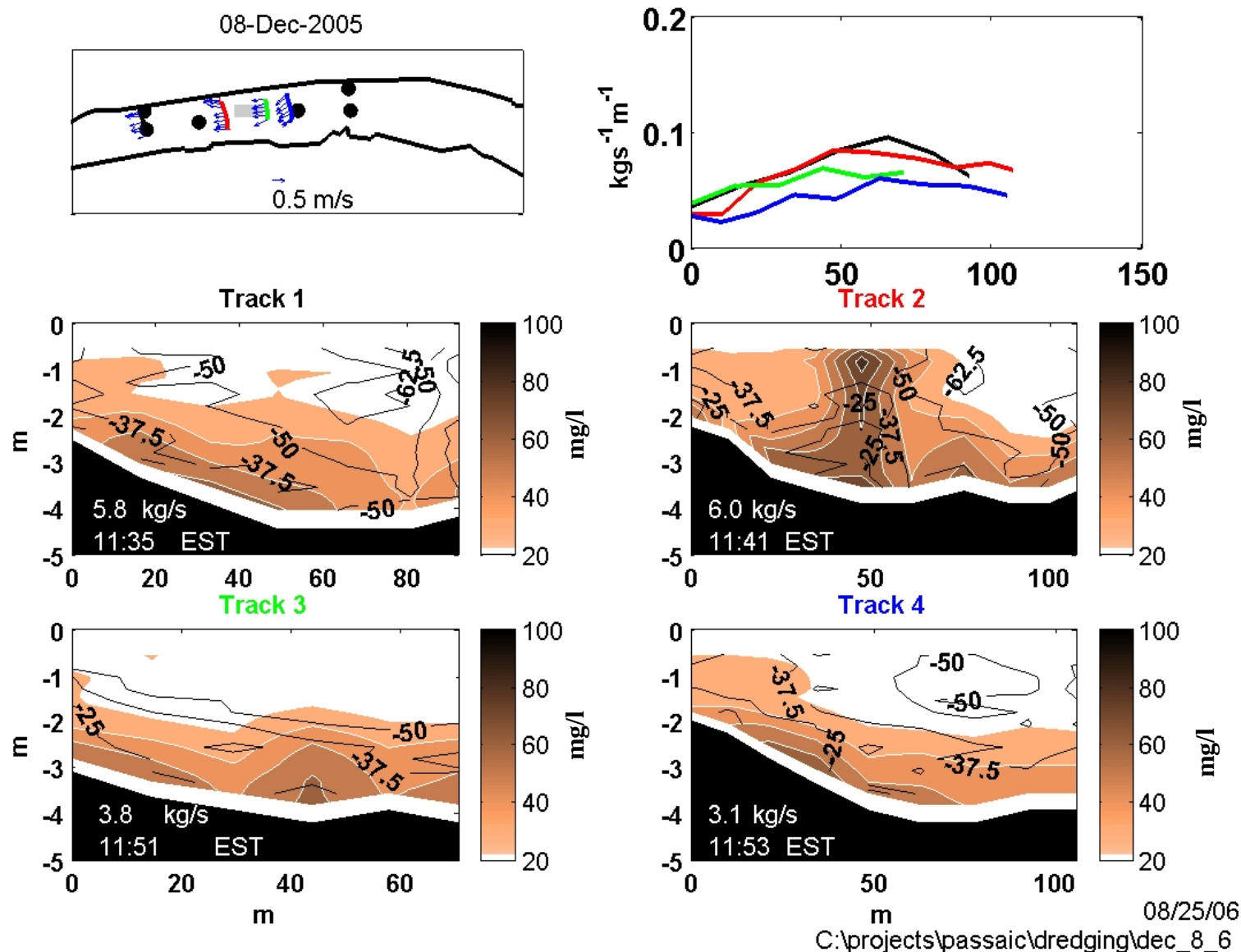


Figure 10-32. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

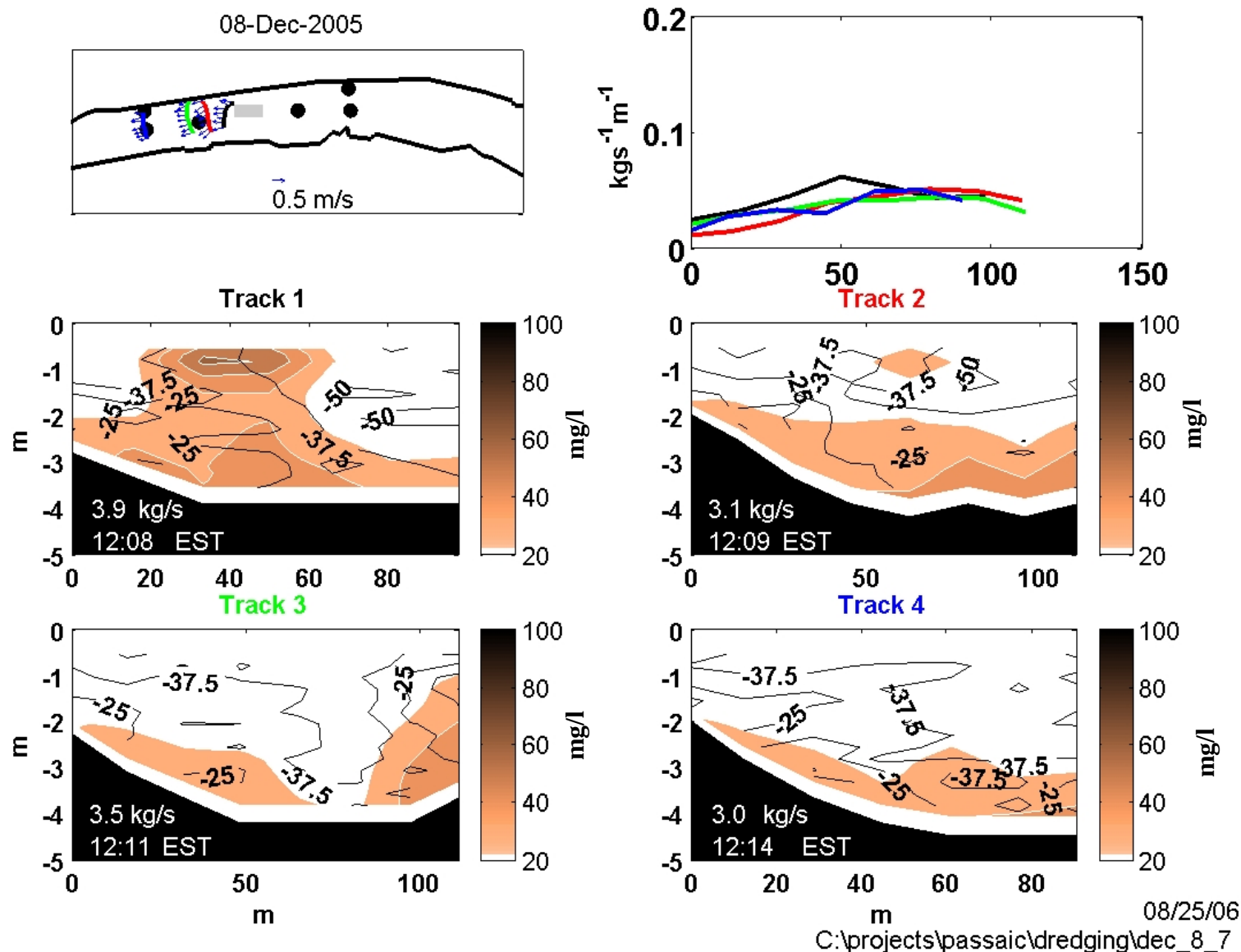


Figure 10-33. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

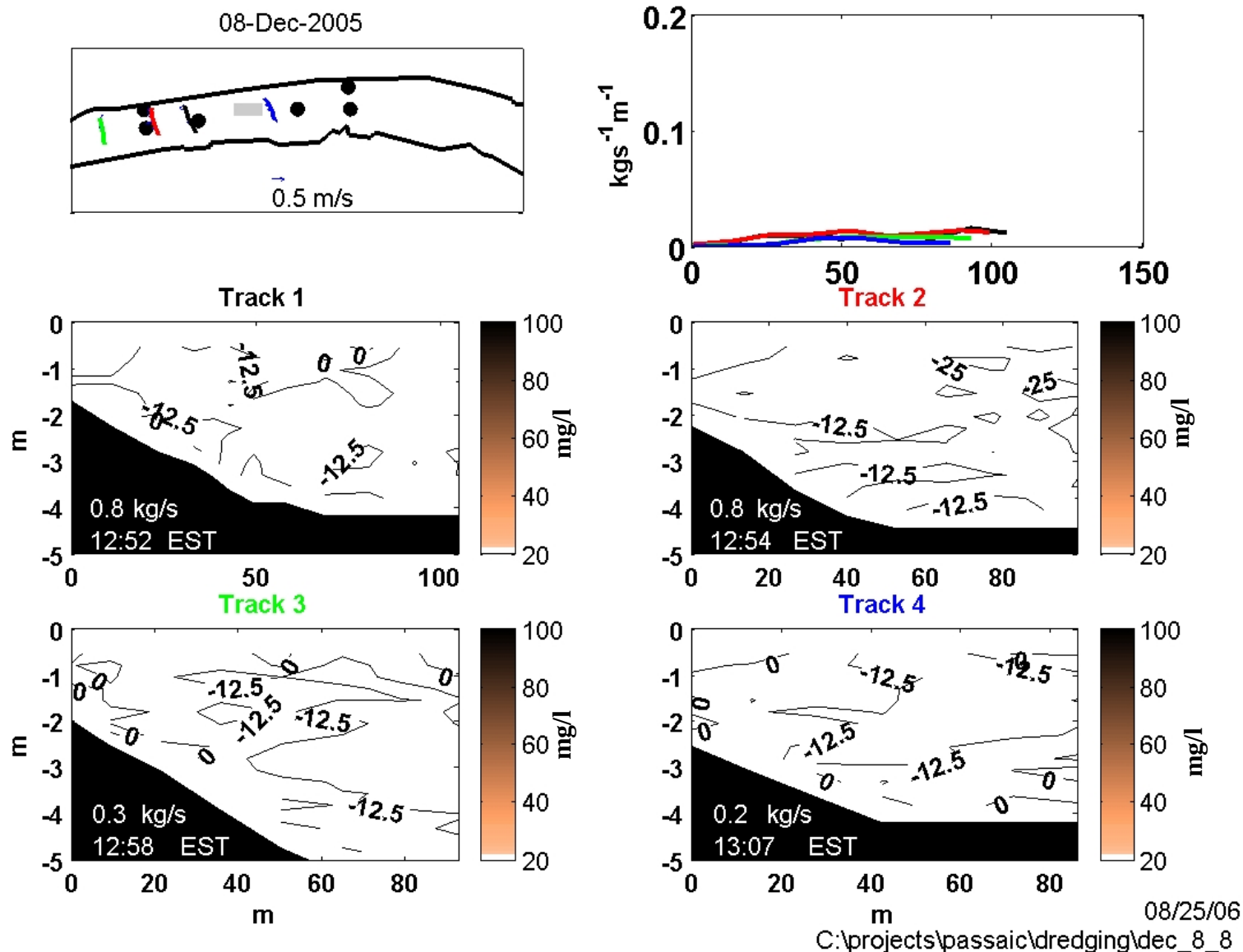


Figure 10-34. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

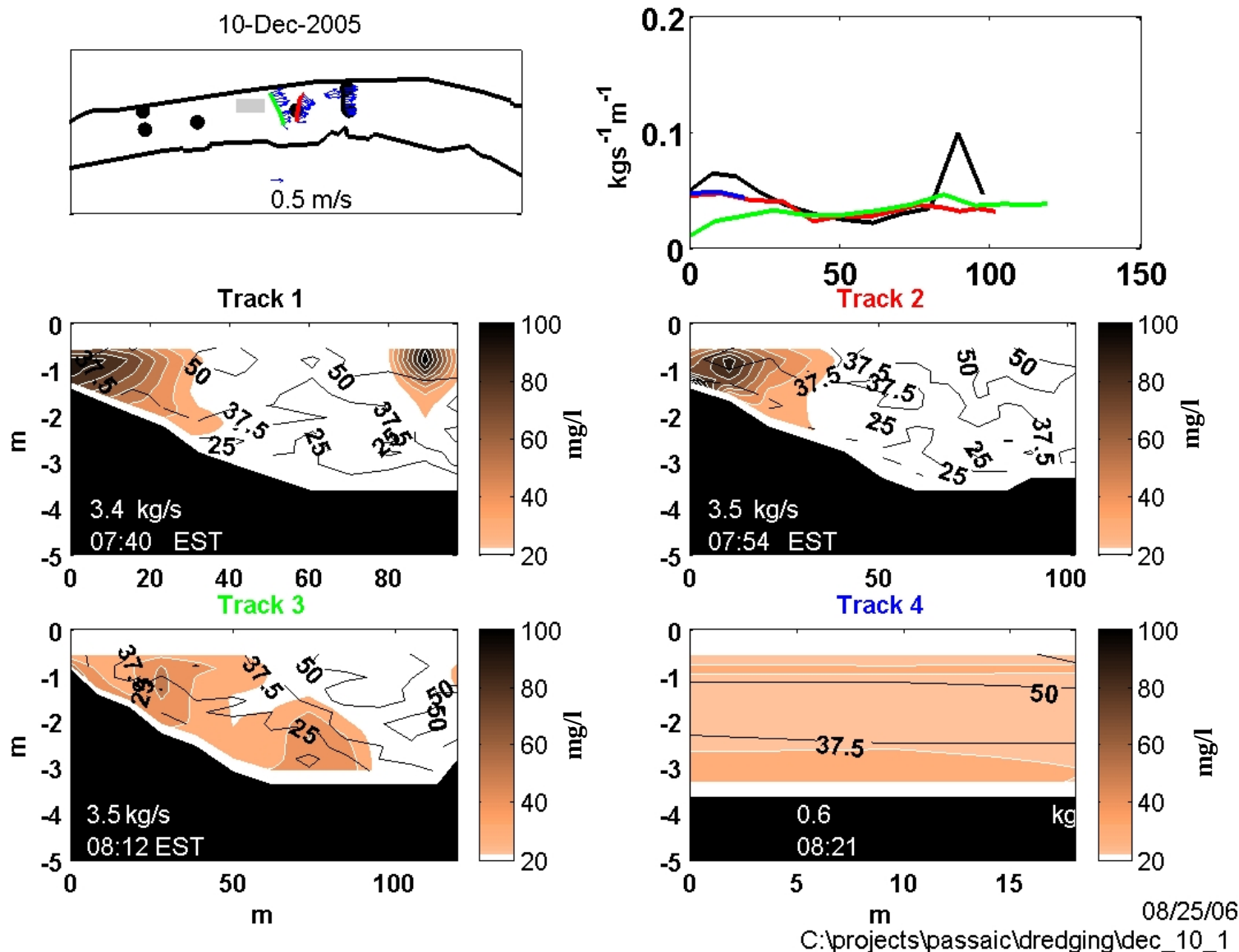


Figure 10-36. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels. Note that track 4 is short only covering 15 meters.

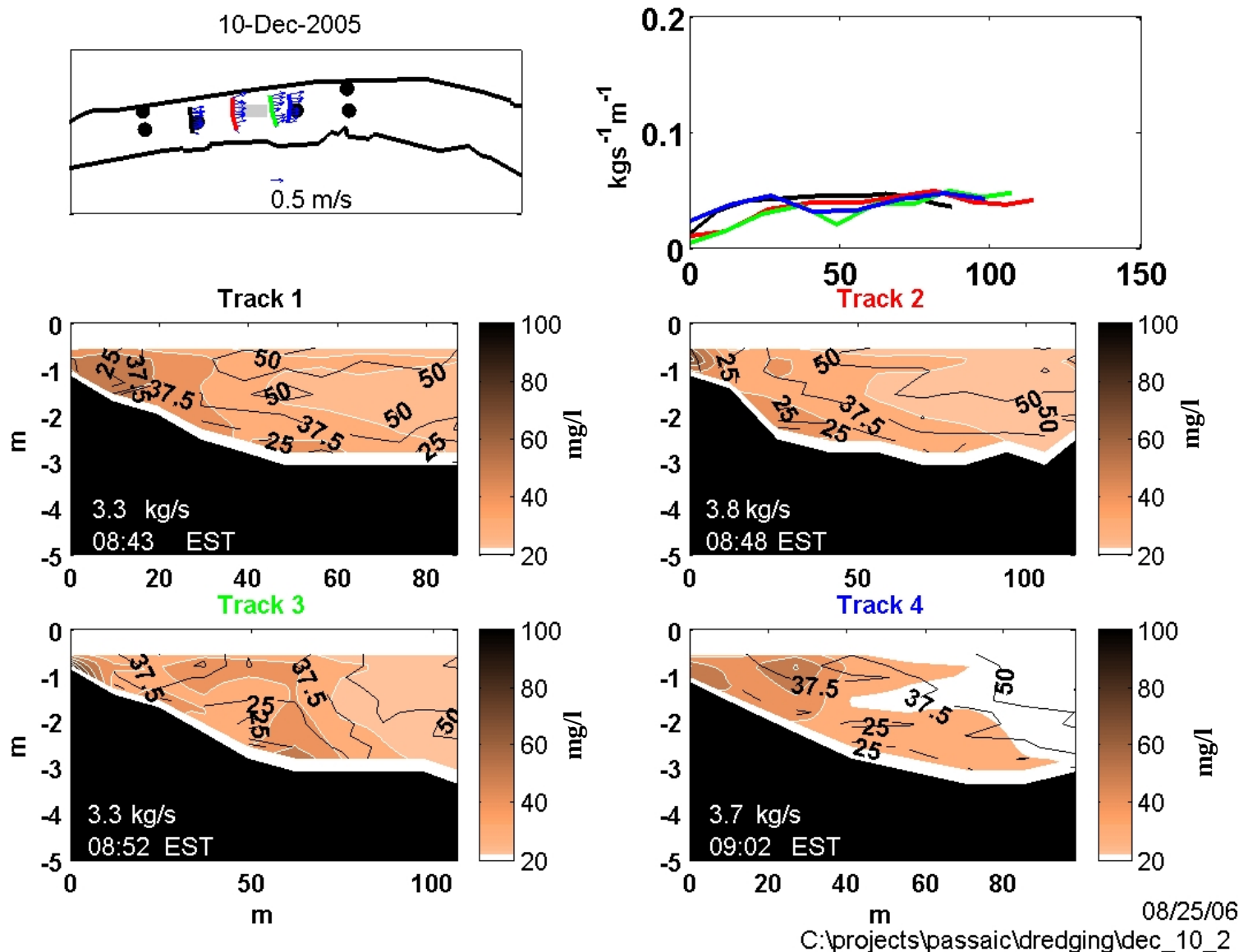


Figure 10-37. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

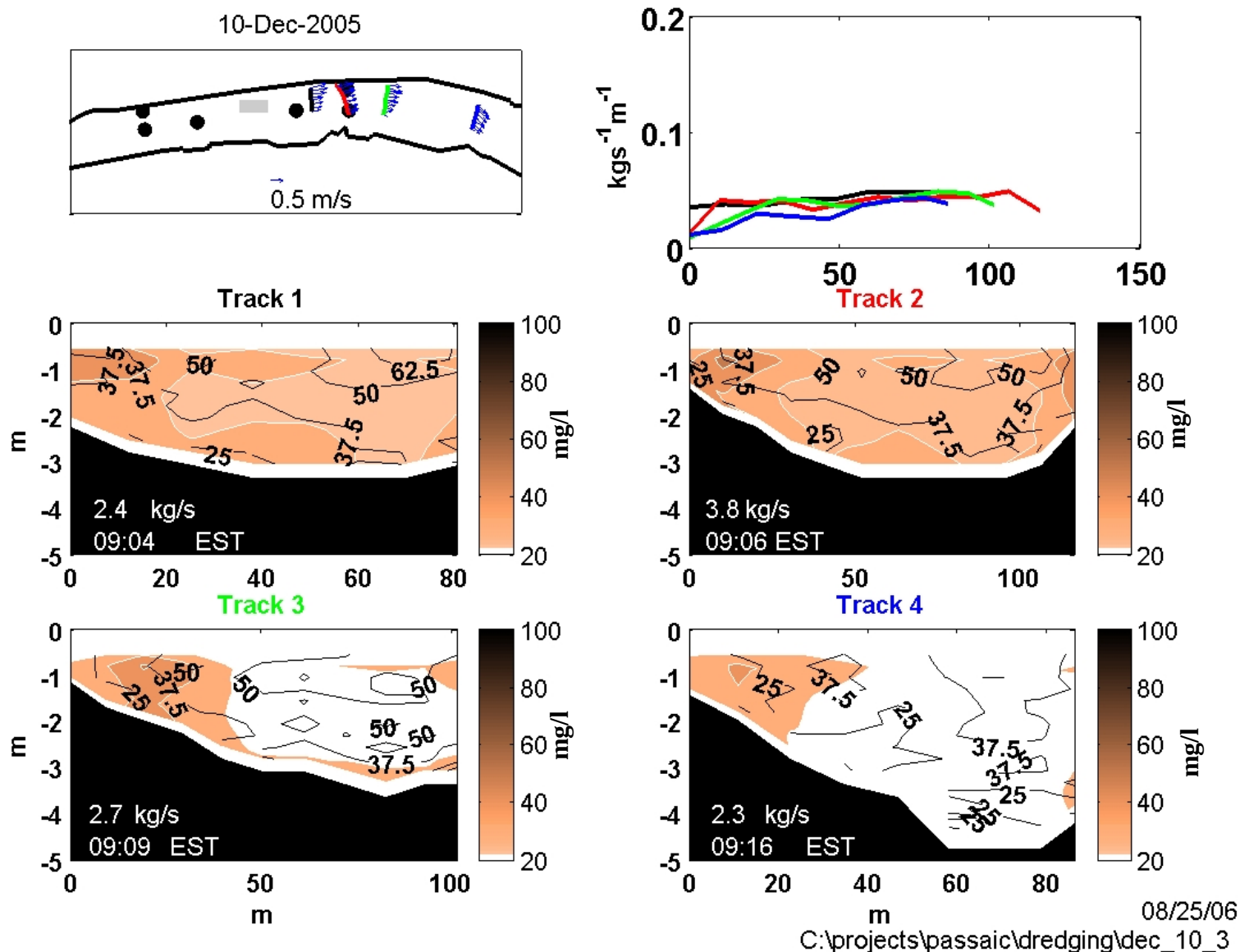


Figure 10-38. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

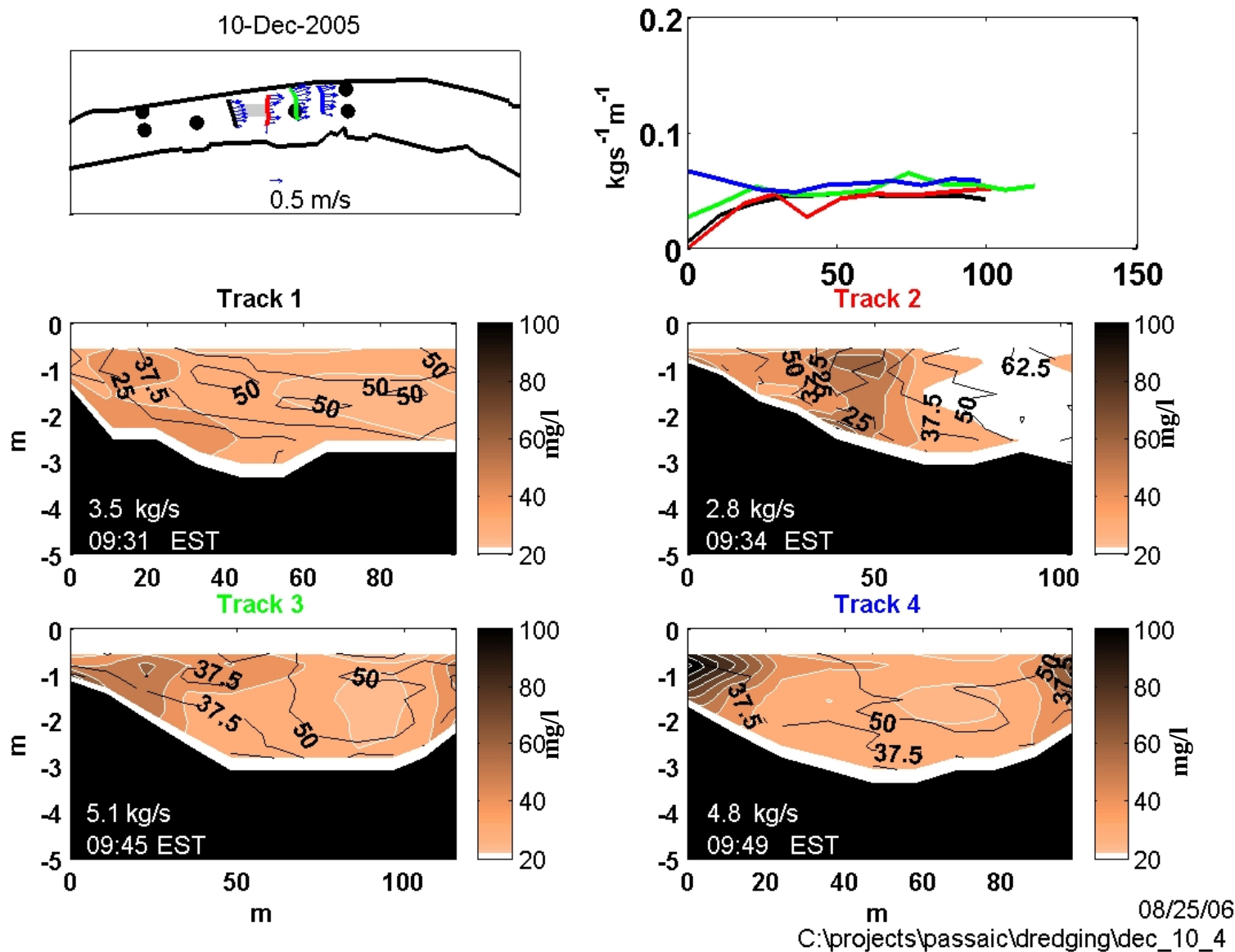


Figure 10-39. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

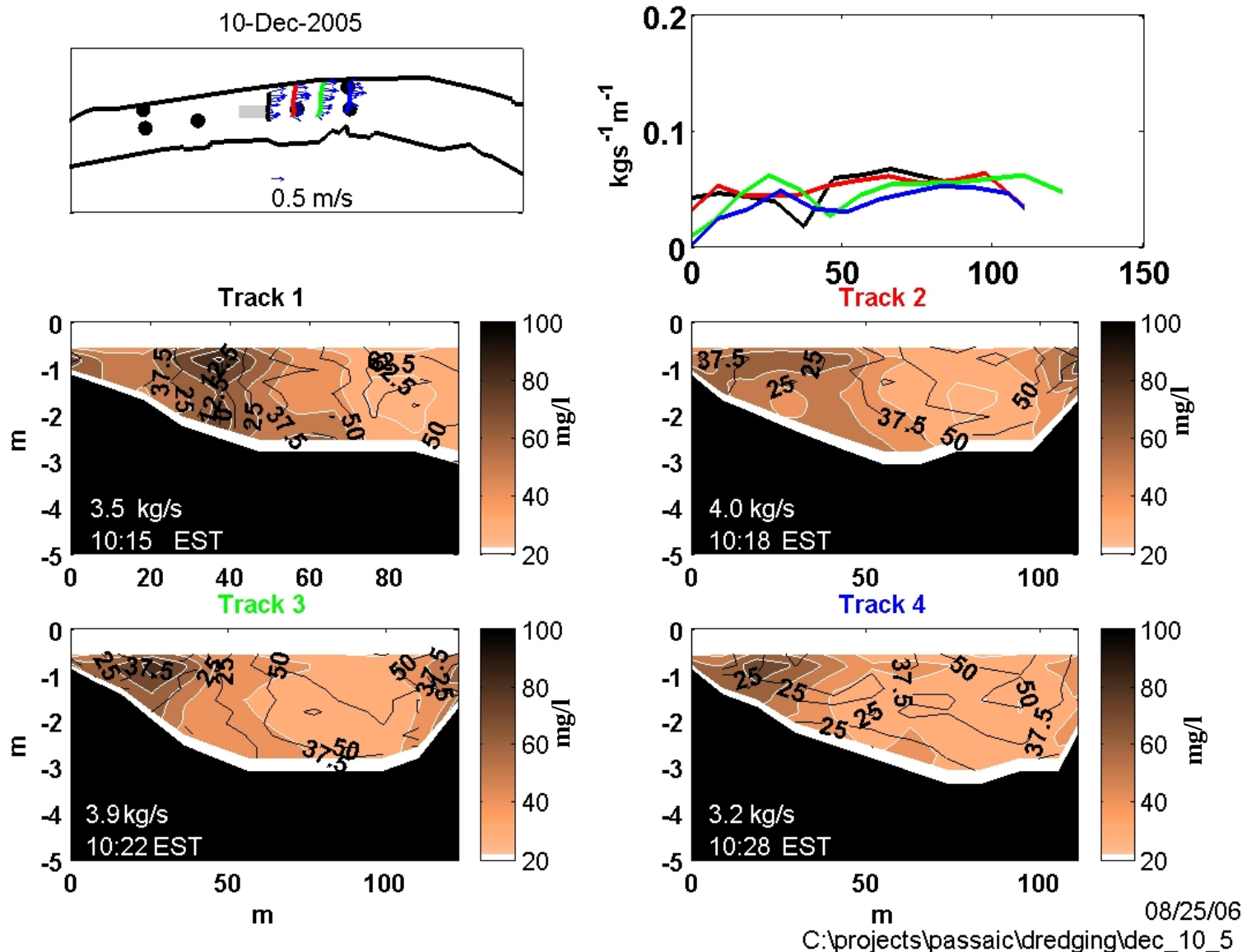


Figure 10-40. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

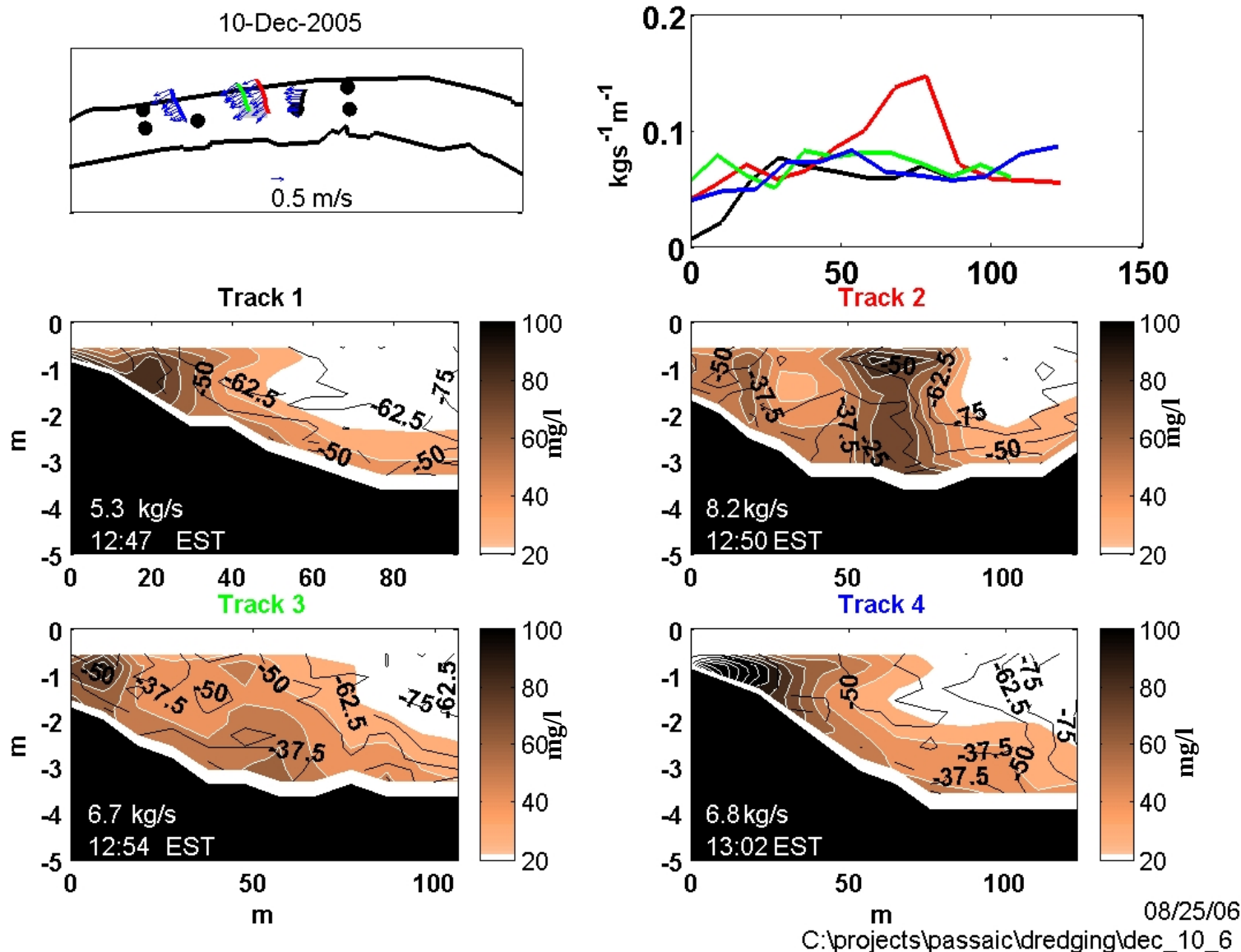


Figure 10-41. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

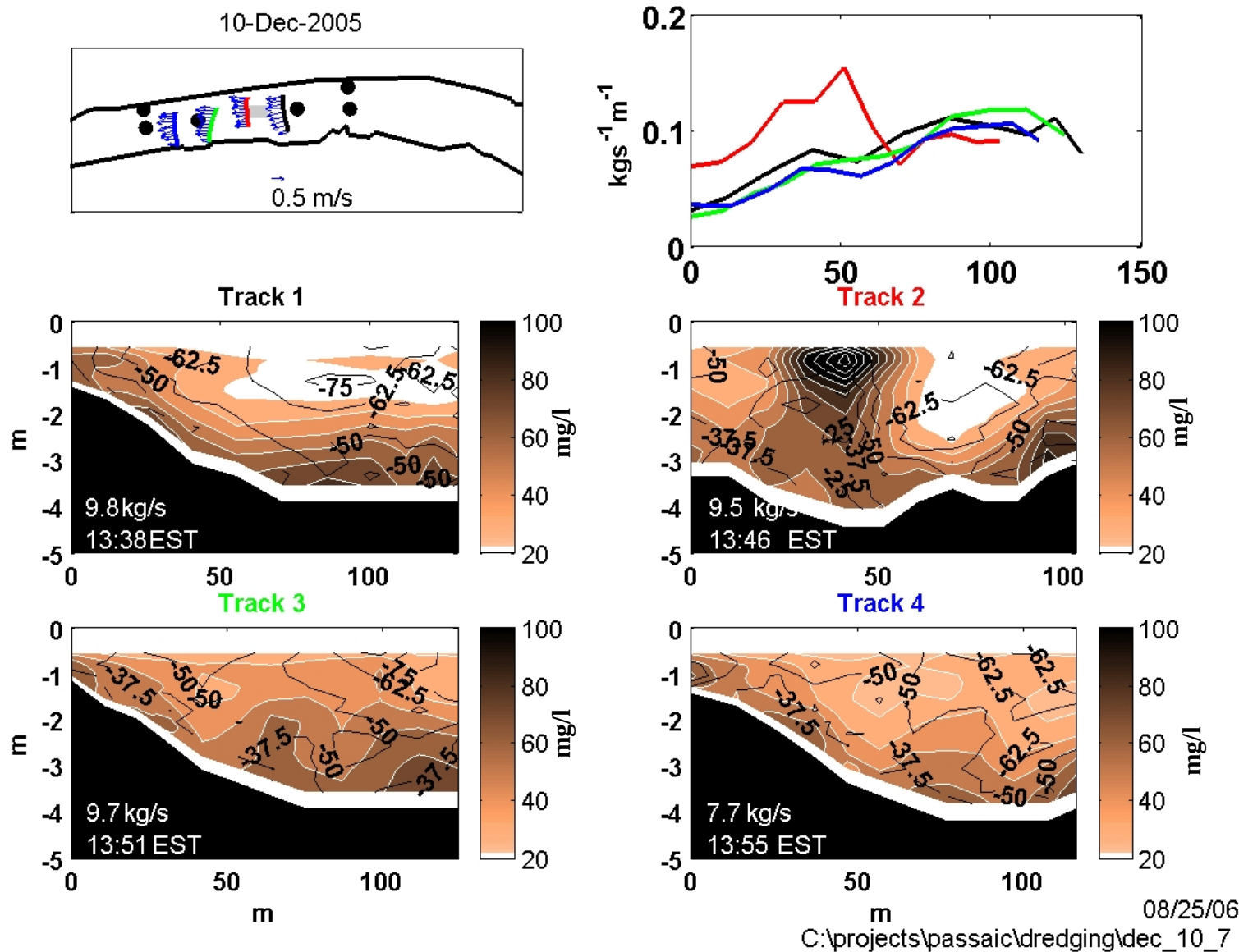


Figure 10-42. Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from the four sections. The color of each line is consistent with the colors drawn on maps. Lower four panels show velocity (contours) and TSS (brown) for each of the four transects. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

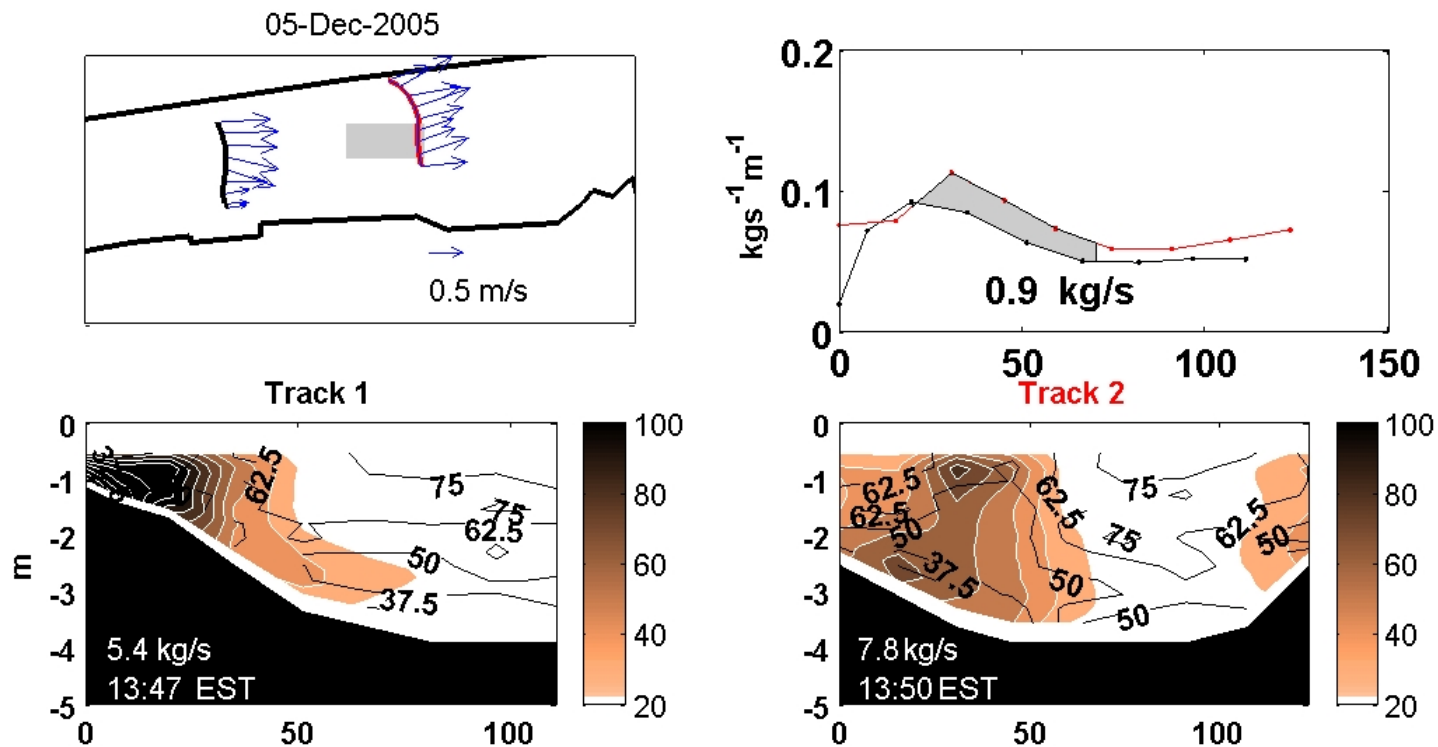


Figure 11-1 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of the difference between the red and the black line). The release rate estimated from this analysis is included in the panel. Lower two panels show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

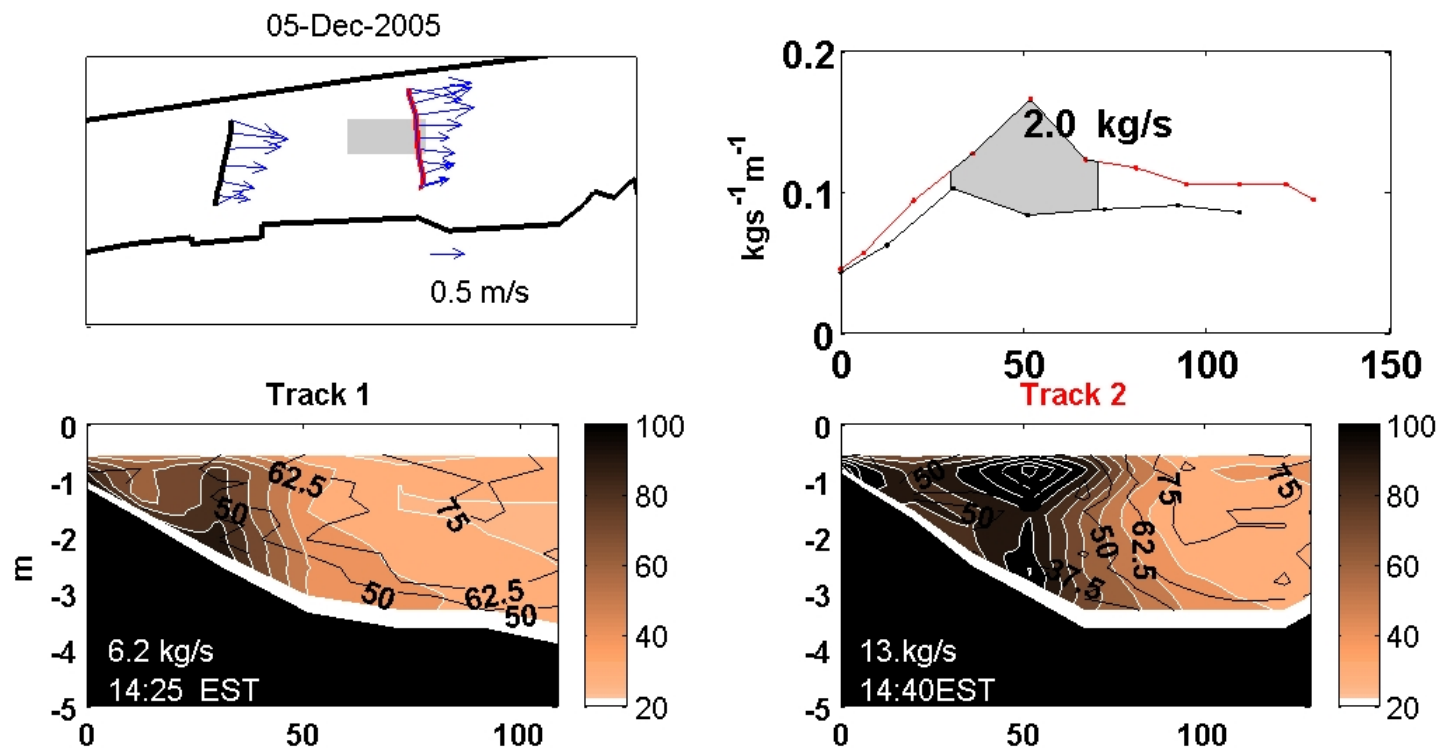


Figure 11-2 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) a mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of t difference between the red and the black line). The release rate estimated from this analysis is included in the panel Lower two pa show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the flux and time are indicated in white In lower left on each of these four panels.

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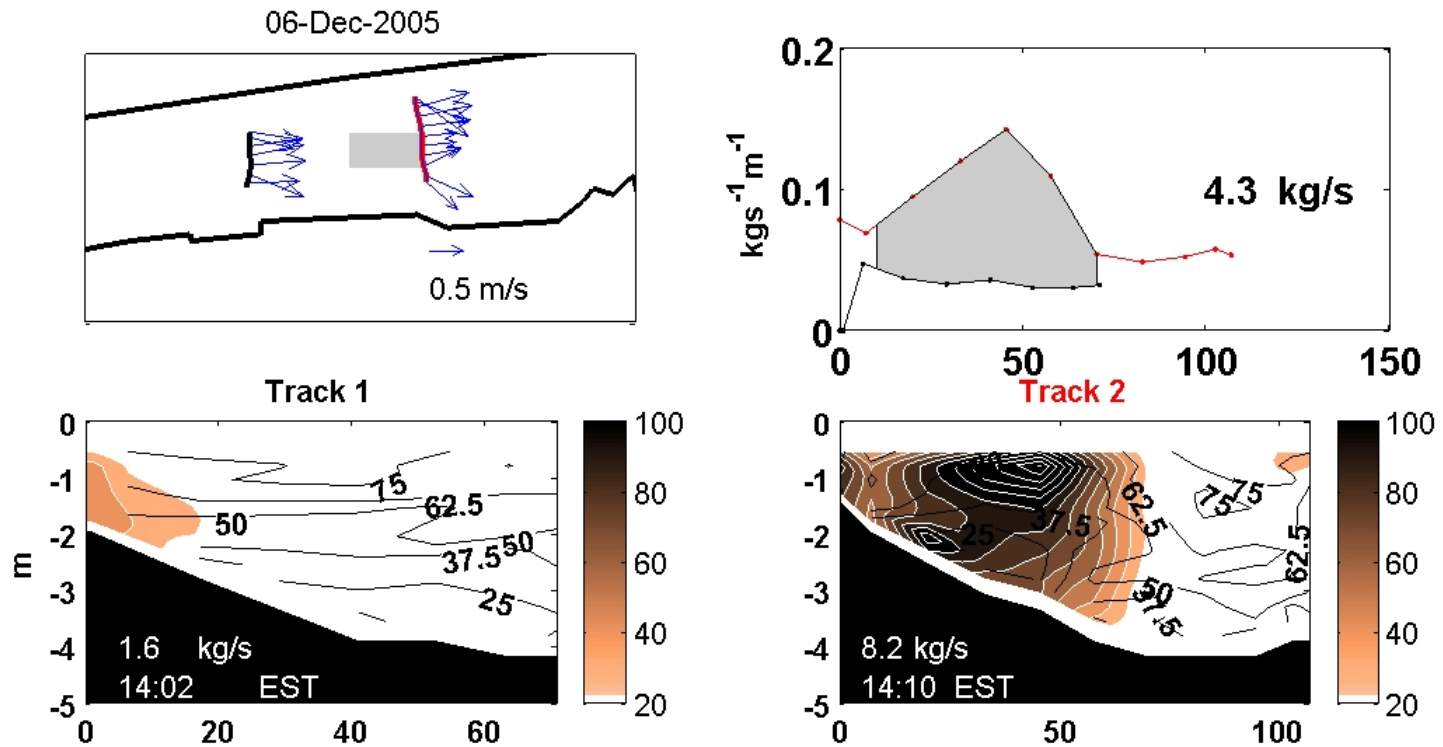


Figure 11-3 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of the difference between the red and the black line). The release rate estimated from this analysis is included in the panel. Lower two panels show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

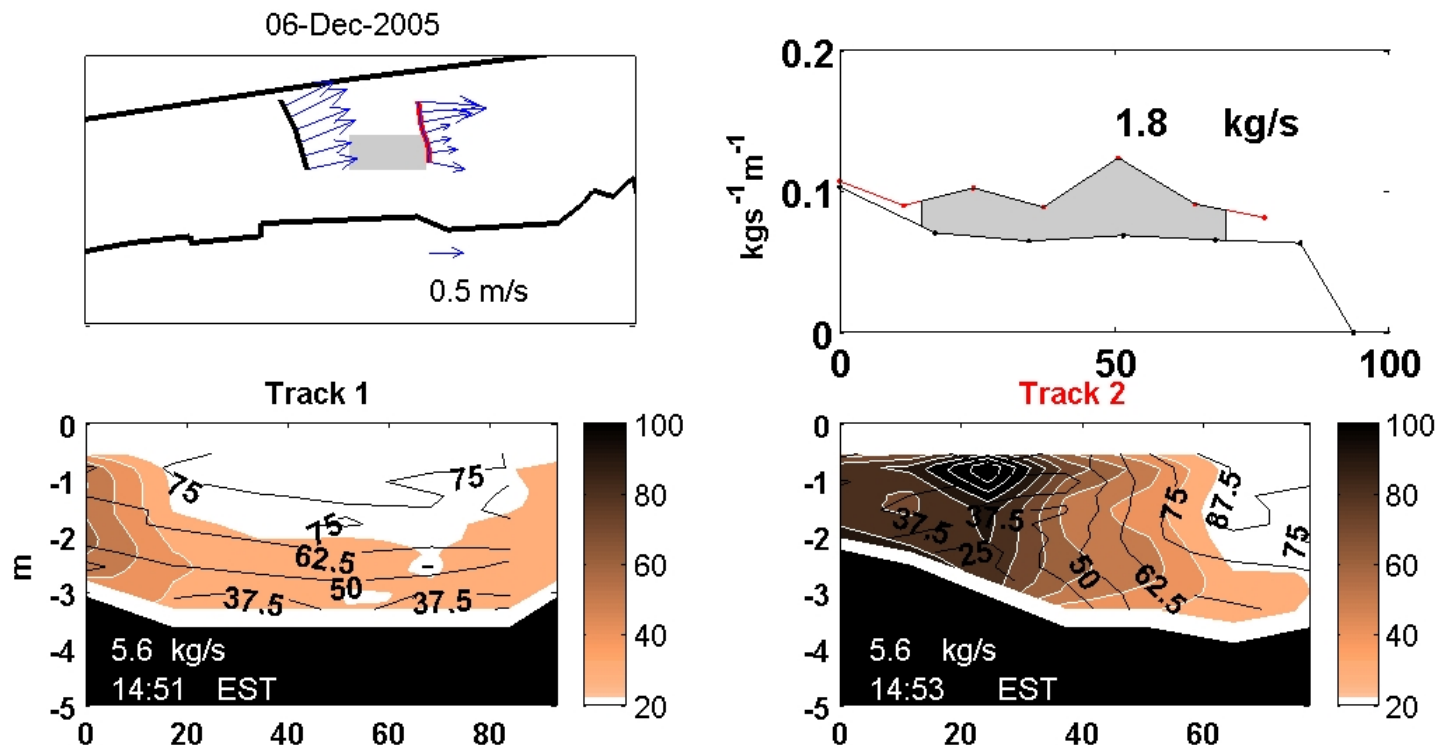


Figure 11-4 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of the difference between the red and the black line). The release rate estimated from this analysis is included in the panel. Lower two panels show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

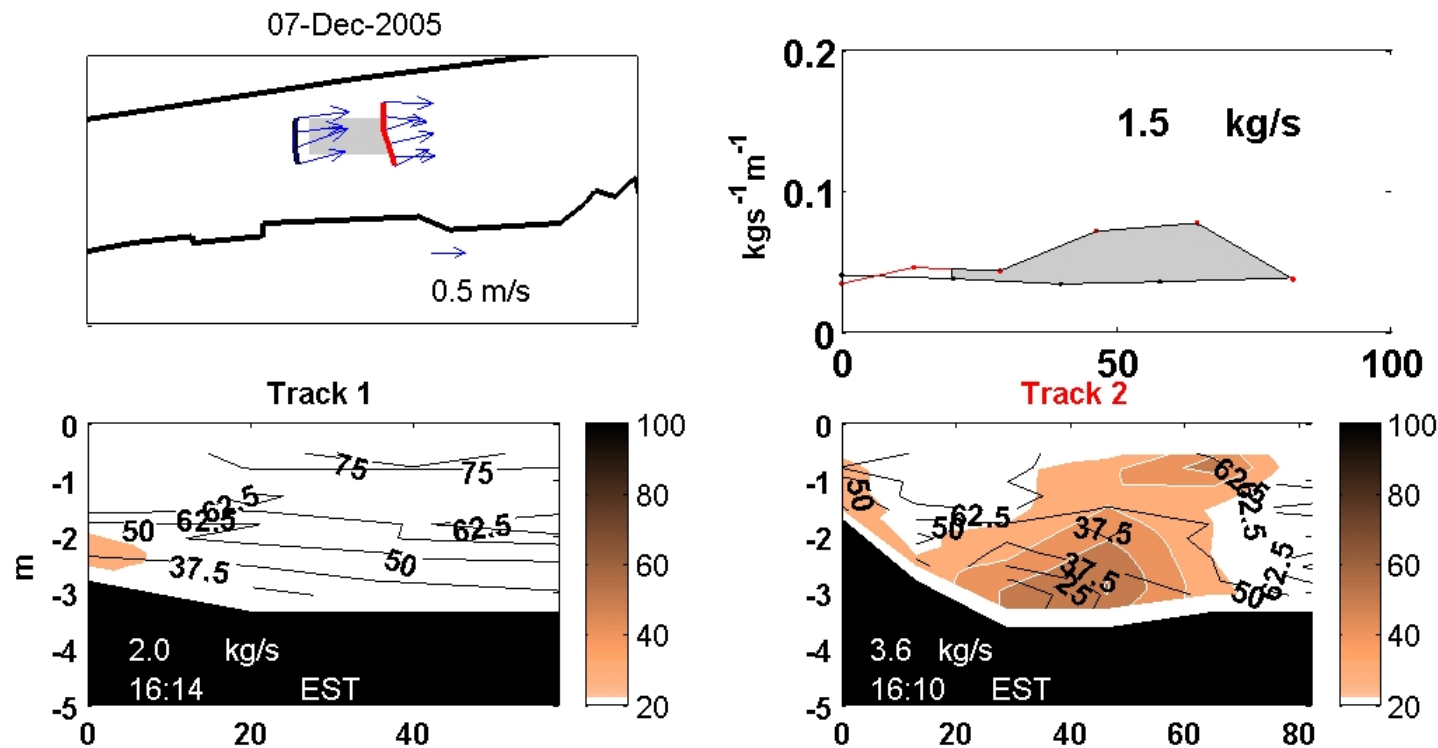


Figure 11-5 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of the difference between the red and the black line). The release rate estimated from this analysis is included in the panel. Lower two panels show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

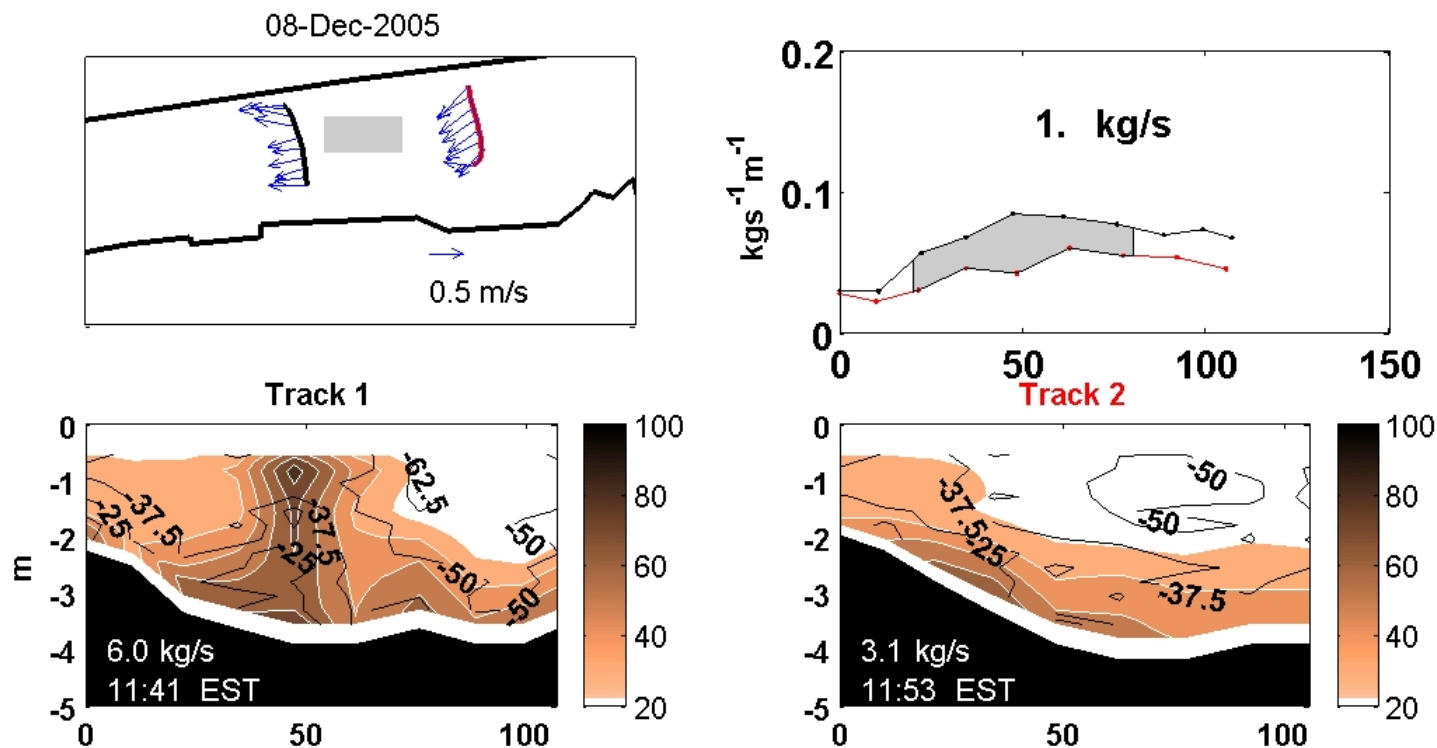


Figure 11-6 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of the difference between the red and the black line). The release rate estimated from this analysis is included in the panel. Lower two panels show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

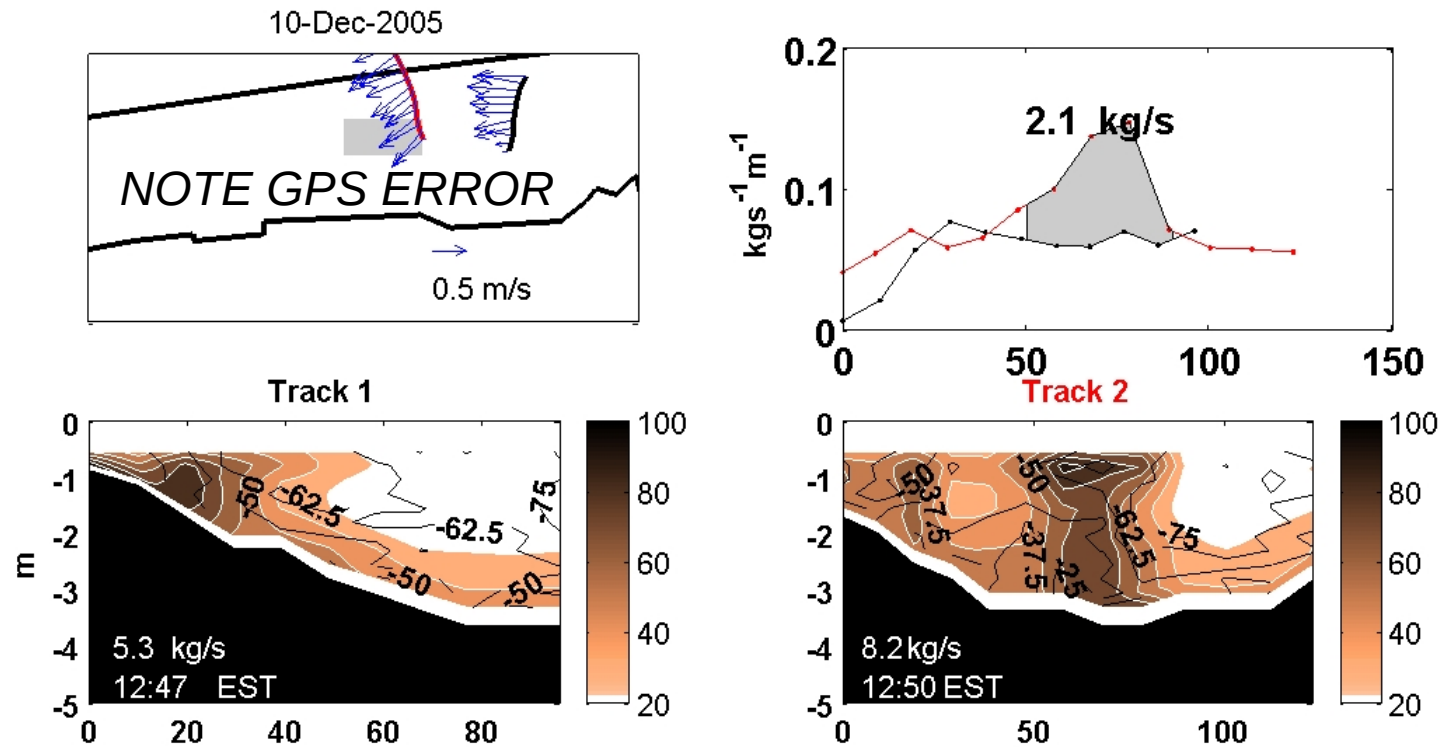


Figure 11-7 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) and mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum of the difference between the red and the black line). The release rate estimated from this analysis is included in the panel. Lower two panels show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of the TSS flux and time are indicated in white in lower left on each of these four panels.

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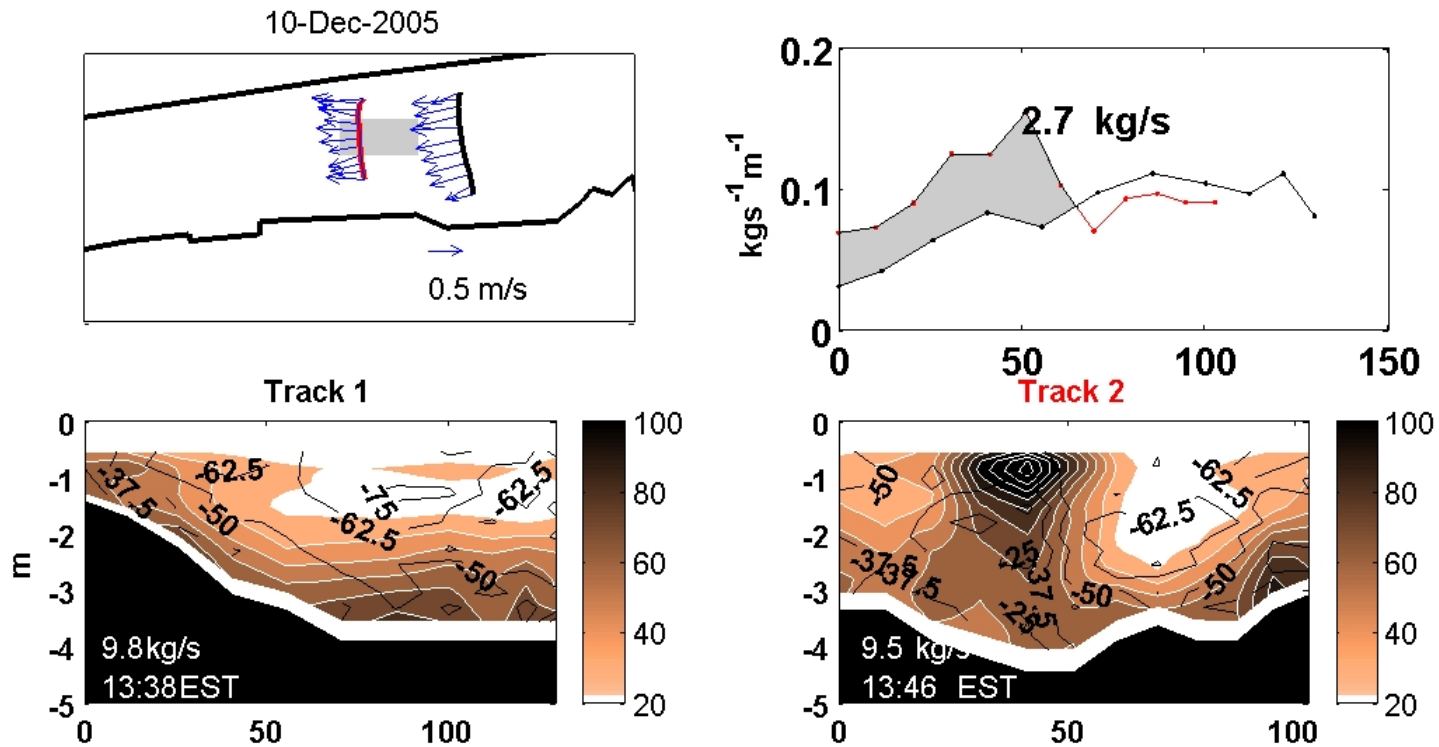


Figure 11-8 . Panel in upper left shows location of sections (colored lines) and surface currents (blue vectors), dredge location (grey) a mooring location (black dots). Upper right shows estimates of TSS transport per unit width from a section immediately upstream and down stream of the dredge during time that an obvious release of sediments occurred. The color of each line is consistent with the colors drawn on maps. The grey area shows the region of the dredge plume and the release of sediments is equal to this area (i.e. the sum difference between the red and the black line). The release rate estimated from this analysis is included in the panel Lower two pa show velocity (contours) and TSS (brown) for each of the four transects. TSS flux listed on these two lower figures are the same as shown in figures 10. Color used for the title of each of these graphs coincides with the color of the track drawn on the map. Estimate of th flux and time are indicated in white In lower left on each of these four panels.