Estuarine Suspended Sediment Loads and Sediment Budgets in Tributaries of Chesapeake Bay

Phase 1: York, Patuxent, and Potomac Rivers

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Abstract

Understanding the sources and sinks of suspended sediment in Chesapeake Bay tributaries is an important contribution to quantifying the Bay sediment budget, as well as an aid to management strategies. The purpose of the project was to identify estuarine sediment transport processes and estimate sediment loads and sediment budgets for the major tributaries of the Bay. The first phase included the York River, Va. and the Patuxent River, Md. Sediment transport processes, sediment loads, and a partial budget also were developed for the Potomac River, Md.

The results of this study represent the most comprehensive calculations to date of sediment loads for Bay tributaries. The three rivers exhibit different magnitudes and transport directions of sediment loads at individual stations. Average sediment loads for the rivers as a whole show the York, Patuxent, and Potomac all importing sediment.

Sediment budgets for the York and Patuxent show a sediment loss that is unaccounted for; i.e. more sediment is needed from sources, or sinks are too large. The York River is highly energetic, moving large amounts of sediment within the estuary. The Patuxent River is less energetic but more variable in redistributing sediment.

Important future work for a more comprehensive understanding of suspended sediment transport in the Chesapeake Bay includes completion of the sediment budget for the Potomac River and calculation of estuarine transport processes, sediment loads, and sediment budgets for the James and Rappahannock Rivers, Va.

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Introduction

Earlier studies laid the groundwork for understanding sediment transport and budgets in Chesapeake Bay (e.g. Hobbs and other, 1992 and 1990; Nichols and others, 1991). A sediment budget for the Bay did not include the tributaries because there was 'little specific data on net, long-term flux of material through the mouths of the tributaries' (Fig. 1) (Hobbs and others, 1990). Gaps in our understanding are still present. A Chesapeake Bay Program (CBP) Scientific and Technical Advisory Committee workshop emphasized the need for an improved understanding of sediment sources and how sediment is distributed in the Bay and tributaries (CBP, 2007). One of the recommendations for further research was to determine if tidal tributaries are a source or sink of fine-grained sediment to the Bay (CBP, 2007). Results from such a study could provide insights for sediment management to improve water quality and protect SAV and tidal wetlands.

Purpose

The purpose of this project is to calculate estuarine suspended sediment loads and sediment budgets for 10 tidal tributaries of Chesapeake Bay. Phase 1 included:

- Sediment loads and budget for the York River, VA
- Sediment loads and budget for the Patuxent River, MD
- Sediment loads and estuarine sediment accumulation for the Potomac River, MD (Fig. 2).

Background Information

Technical terms and units of measure are defined in the glossary. Terms included in the glossary are marked with an asterisk the first time they appear in the text.

Sediment Loads

Few studies have calculated sediment loads* in Bay tributaries. The most commonly used sediment loads for Virginia tributaries (Schubel and Carter, 1976) were based on a salt balance using a single year's worth of data at a station in the main stem of the Bay. A new methodology using sediment data from tributary water quality monitoring stations was developed previously (Herman, 2001) and improved upon here to estimate several important aspects of suspended sediments in estuaries*, including the magnitudes and directions of estuarine transport processes (gravitational circulation*, tidal pumping* and river flow*) and the calculation of suspended sediment loads (mean annual values) in the estuaries.

Sediment Budgets

Sediment budgets are a useful tool for a number of reasons. Budgets account for the sources (areas of erosion) and sinks (areas of deposition) of sediment. Sediment budgets identify types and locations of missing data, which could help direct future research. Budgets also may assist in management decisions.

The components of a sediment budget will vary depending upon spatial and temporal scales, local variables, and available data. Sources of sediment are affected by location of the estuary within Chesapeake Bay such as southern vs. northern tributaries or western vs. eastern shore tributaries (Cronin, 2007). Sources include sediment coming from the tidal freshwater portion of the river (head of the estuary), shoreline (bank) erosion, sediment from upland erosion (usually input through streams), *in situ* biogenic production, and possibly wetland erosion in some areas. Sinks of sediment include deposition in the estuary and in wetlands. Sediment may enter or exit from the estuary mouth, so the mouth may be a source or sink, depending upon conditions. A budget is constructed with these components in a mass balance equation of sediment loads. The components and equation used in this study are:

Head of estuary load + shoreline erosion load + biogenic production load + mouth of estuary load – deposited sediment load in estuary ± error term = 0

Study Areas

Three estuaries on the western side of Chesapeake Bay were studied for this phase of the project: York River, Virginia; Patuxent River, Maryland; and Potomac River, Maryland (Fig. 2). The York and Patuxent Rivers were chosen to represent Virginia and Maryland, respectively, because these well-studied river systems have the necessary data, and revealed problems unique to datasets for each state during the first phase of the project. With data issues resolved, the Potomac River was requested by the Corps because it is the largest estuary of the Bay (the Bay is the estuary for the Susquehanna River) and the focus of many state and federal agencies. Sediment data from CBP water quality monitoring stations in the tributaries were used to study sediment transport. Stations were chosen by location (Fig. 2). The 'original' stations were the head and mouth of the estuaries, and the 'additional' stations were added for a better understanding of sediment transport within the estuaries. The water quality monitoring stations have CBP identifications with the prefix LE denoting lower estuary and RET denoting river-estuary transition.

While the watersheds of these rivers differ greatly in relief, areal extent, soil type, land use, etc. the estuaries for all the systems are limited to the low-relief Coastal Plain. Water quality monitoring stations used to calculate estuarine loads were located only in the brackish part of each system (Fig. 3). All the systems have a main channel that varies in depth and tends to shallow upstream, flanked by broad shoals about 2m deep. The brief descriptions below include information pertinent to this study, specific to each river. Values for river lengths, bank erosion rates, and bank heights were calculated from geographic information system (GIS) data layers (references are detailed in the Methods chapter).

<u>York River</u>

The York River empties into the southern end of Chesapeake Bay. Land use in the watershed is predominantly forested.

The length of the York River included in this study is about 46 km long. Just above the upstream station the York receives freshwater from the confluence of its two major tributaries at the town of West Point: the Pamunkey and Mattaponi Rivers. The axis of the main channel varies in depth from about 24 m below LE4.2 to about 8 m at the upper station RET4.3.

The shoreline studied is about 110 km long. Bank erosion rates range from 0 to 1.3 m/yr, with a weighted average of about 0.5 m/yr. The original source of erosion rates came from Byrne and Anderson (1978) using data from topographic maps of the 1850's and 1940's, which were then used by Hardaway and others (1992). Bank heights range from 0 to 12 m (using CBP data) to a maximum of 29 m (using Virginia Base Mapping Program (VBMP) 2006-2007 data). The weighted average bank height for unprotected shoreline is about 3.7 m.

Patuxent River

The Patuxent River is the largest river completely in Maryland and empties into the Bay just north of the Potomac River. In the Patuxent River basin, land use is very mixed, and consists of high density and low density development and agriculture lands, with some forests and wetlands.

The portion of the river studied is approximately 32 km long. The axis of the main channel varies in depth from about 30 m at LE3.1 to about 10 m at the upper station RET1.1.

The shoreline studied is about 84 km long. Bank erosion rates range 0 and 0.9 m/yr, with a weighted average of about 0.15 m/yr (using MGS and CCRM data). Erosion rates represent shoreline positions between the years 1988 and 1995. Bank heights reach up to 25 m but more than half the reaches have average bank heights between 0 and 3 m (LIDAR data).

Potomac River

The Potomac River is the second largest tributary to Chesapeake Bay and empties into the mid-Bay. In the Lower Potomac River basin, land use is primarily forested land, with some agricultural and developed lands.

The portion of the Potomac River studied is about 107 km long. The axis of the main channel varies in depth from about 24 m between stations LE2.3 and LE2.2 to about 5 m at station RET2.1.

Shoreline erosion calculations for the Potomac were not part of phase 1 of this study.

Methods

Pre-existing datasets from a variety of federal and state agencies were used. Each budget component was calculated independently, and if possible, the results were verified with a different method.

Software

Several software programs were used extensively in this study. The geographic information system (GIS) software was ArcGIS ArcInfo v. 9.3. MatLab v. 2007 was used to process sediment transport data.

Estuarine Transport Processes and Sediment Loads

This section describes the methodology developed by Herman (2001) and improved upon in this study to calculate what proportion of sediment is contributed by each estuarine transport process. The results then were combined to determine a total estuarine sediment load at each water quality monitoring station.

Calculating suspended sediment transport and sediment loads in estuaries are problematic because of the complex nature of water movement in these systems. Multiple estuarine transport processes, such as gravitational circulation, tidal pumping, and river flow all contribute a portion of the suspended sediment load. In this text, for consistency, the processes are called gravitational transport*, tidal transport*, and river transport*, respectively.

A sediment load is the amount of sediment per unit time (e.g. g/s or Mt/yr). The basic concept is that concentration times velocity, integrated over the cross-sectional area equals the sediment load.

Q = integration of (u * c * dA)

where Q is load, u is velocity, c is concentration, A is cross-sectional area, and the expression dA represents the components of the total area over which the integration is summed.

For this study, it was assumed that the tributaries have a typical two-layer circulation in a partially stratified estuary (Haas, 1977; Owen, 1969; Lin and Kuo, 2001). In a tidal system with two-layer circulation, the load for the upper and lower layers must be integrated separately before combining into a total load. It is assumed that in each of the two layers it is reasonable to represent the velocity and concentration via representative layer-averaged values.

$$Q_{layer} = [(u_{tidal\ transport} * c) + (u_{gravitational\ transport} * c) + (u_{river\ transport} * c)] * A_{layer}$$

$$Q_{total} = Q_{upper\ layer} + Q_{lower\ layer}$$

where u, in m/s, was calculated from Chesapeake Bay hydrodynamic model output (1985-2005);
c, in mg/l (converted to g/m^3), is total suspended solids (TSS) concentrations from Virginia and Maryland water quality monitoring stations; and
A, in m^2, was calculated using bathymetric data (see next section on Estuarine Sediment Accumulation for details on bathymetric data).

In Virginia, approximately once per month at each CBP water quality monitoring station, TSS samples are collected 1m below the surface and between 1-2m above the bottom. In Maryland, TSS samples are collected approximately twice per month at each CBP station, and samples are collected at several depths through the water column. For consistency with Virginia, only the 'surface' and 'bottom' samples were used from the Maryland data. Including data from other depths is not always possible because sample depths do not always correspond with model depths and not all sample depths have values for all sample dates. Data distributed spatially throughout a layer's cross section would yield more accurate results, but such data is rarely collected over long time periods and would not necessarily be representative of longer temporal scale conditions. Some testing with short-term ADCP data would help determine how closely single samples characterize the layers. For both states, the samples are collected independently of the tidal phase.

The Chesapeake Bay hydrodynamic model output was acquired from ERDC in Vicksburg, MS (S-C. Kim and C. Cerco, pers. comm. 2008 and 2009). The model output spans 1985-2005. The monitoring stations for each river were chosen based on two criteria:

- Location—stations were intended to be downstream of each estuarine turbidity maximum* (ETM). The location of the main ETM in each river varies seasonally and annually, based on salinity (and therefore precipitation), and tends to 'mark' the transition from estuarine to tidal fresh water.
- TSS data availability—most stations had a period of record encompassing the entire hydrodynamic model output.

The TSS concentration data were separated into 'surface' and 'bottom' samples, representing the concentrations for the upper and lower layers of the cross-section, and were matched by date. The sample dates and times of TSS data for each station were used to obtain the CBP model velocities. The grid for the hydrodynamic model is comprised of numerous cells with varying numbers of layers, each 5 feet thick, depending upon the depth at the cell location. For each station the geographically corresponding model cell was chosen, and the velocity outputs from the surface cell and the cell one up from the bottom (to compensate for the effects of bottom friction) were used.

To estimate the tidal and subtidal velocity at times corresponding to each TSS sample, Chesapeake Bay model output at the location of the TSS collection was extracted for 25 hours, centered around the time of TSS collection. The average velocity over that 25 hour period was defined as the subtidal velocity at the time of the TSS sample collection, and the deviation from that average was defined as the tidal velocity at the time of the

TSS sample collection. To verify the accuracy of the output velocities, the cross-sectional areas of the estuary using the model grid cells were compared to cross-sectional areas of the estuary using bathymetric data. For some stations the cross-sectional areas based on the model and bathymetry differed by more than 10%, so the velocities were adjusted by the proportional difference. For example, at station LE4.2 in the York River, the cross-sectional area calculated from the model grid was 33% larger than the area calculated using bathymetric data, which results in the tidal velocities from the model being too small. Therefore the tidal velocities were increased by 33% to compensate, and verified by comparison with observed velocities (Wang and Johnson, 2000). The velocities were processed using a MatLab program that decomposed the velocities into a tidal component and a subtidal component (a combination of the contributions from all other processes besides tidal—in this study the subtidal transport* was attributed to gravitational transport and river transport) and determined a tidal phase for each sample. Over the long-term, the average magnitude of all tidal velocities was defined here to be of equal strength on flood and ebb. Thus once all the tidal observations had been distributed into flood and ebb phases, their speeds were weighted such that the average magnitude of all flood tide velocities equaled the magnitude of all ebb tide velocities.

River discharges (m^3/s) are collected by USGS from Fall Line stations of the Bay tributaries, and reported as mean daily values. The discharges were matched to the sample dates, and weighted by land area to account for additional sources of discharge along the river from the Fall Line to each water quality monitoring station. Previous calculations showed that correcting discharges based on land area or on total stream lengths were comparable (Herman, 2001). For example, the Mattaponi and Pamunkey Rivers are tributaries of the York River. The discharges at the two Fall Line stations were added together and increased by 53% for station LE4.2 in the York River. The discharge was divided by the cross-sectional area of the estuary at the monitoring station to convert to velocity.

For each station and layer, the sample TSS concentrations and the tidal, subtidal, and river velocities and transport were plotted vs. the tidal phase. The tidal cycle was divided into 4 phases: slack before ebb; ebb; slack before flood; and flood. Thus each graph contains the sampling data from 1985-2005 plotted over a single tidal phase. An arbitrary assignment was made of a negative sign to ebb-directed tidal phases and a positive sign to flood-directed tidal phases. Means and standard errors (SEs) for the ebb and flood phases and total means and SEs were calculated for each graph. In these calculations the slack phases were incorporated in the ebb and flood phases in order to include all data points, and because concentrations and velocities tend to be lower during slack.

The tidal transport was determined by multiplying the TSS concentration by the tidal velocity for each sample. The same was done for the subtidal and river transport using TSS concentration and subtidal and river velocity, respectively. Gravitational transport was calculated afterwards by subtracting the total river transport from the total subtidal transport for each layer (to avoid getting anomalous gravitational velocities).

The tidal, gravitational, and river transport means and SEs for the upper and lower layers were added together, multiplied by the cross-sectional area of the layer and a conversion factor (g/s to Mt/yr) to get sediment loads. Cross-sectional areas for the channel at each monitoring station were calculated using bathymetric data and ArcGIS. Only the cross-sectional area of the channel >2 m deep was used in the calculations, since the effects of the shoals are minimal. For example, at station LE4.2, the area of the shoals is only 13% of the estuary and the load in the shoals is two orders of magnitude smaller than the channel (Herman, 2001). The cross-sectional area was divided into upper and lower areas by mathematically estimating the level of no motion using the gravitational velocities and conservation of water mass for the upper and lower layers. The upper and lower loads were then added together to get a total sediment load.

Estuarine Sediment Accumulation

Sediment accumulation in estuaries was calculated using bathymetric data from two distinct time periods that differ for each river, because of bathymetric data availability. For the York River, the dates were 1857 and 1945; the Patuxent River was 1944 and 1985; the Potomac River was 1862 and 1955. The hydrographic surveys were conducted by the NOAA National Ocean Service and are available in digital format online (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html). Many of the older surveys (unavailable in digital format) were digitized previously by the Comprehensive Coastal Inventory (a division of CCRM at VIMS).

Multiple adjacent surveys were combined to maximize the areal extent covered. Most combined surveys had collection dates that only differed by a year or two. For each estuary or portion of estuary, the surveys from two time periods were clipped to the overlapping areal extent. The soundings for the older dataset were adjusted for the difference in relative sea level rise with the newer dataset. Sea level rise rates were used for the closest station available in the CO-OPS network (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). Discussions with NOAA experts (C. Zervas and S. Gill, pers. comm., 2009) confirmed that sea level rise rates calculated for the last 50 to 100 years could be used reliably on data from about 1850 until the present (Jevrejeva and others, 2008; Kearney, 1996).

After these adjustments, the two sets of surveys were each converted into a bathymetric surface with ArcGIS using an interpolation method that creates triangulated irregular networks (TINs). A study by the Corps (Byrnes and others, 2002) comparing different interpolation techniques to create bathymetric surfaces recommended using TINs. The two TINs were subtracted using a 'cut/fill' option in ArcGIS that identifies regions where sediment was eroded or deposited and calculates the volume change (m^3). The volume was then converted to a load (Mt/yr) using a bulk density conversion factor. Maryland uses a bulk density of 1.33 g/cm^3 (J. Halka, pers. comm., 2009). Another option is to use a water content of 60% and a specific gravity for quartz of 2.65 g/cm^3, which is equivalent to a bulk density of 1.06 g/cm^3.

To compare the results from the bathymetric survey method, the volume of accumulated material was divided by the area of an estuary to generate a vertical accumulation rate. This rate was compared to accumulation rates in the literature calculated from core data taken in that estuary (Cronin and others, 2003b; Karlsen and others, 2000) as well as to rates of relative sea level rise (using the assumption that the estuaries are filling at the local rate of rise).

Shoreline Erosion

Shoreline erosion (commonly called bank erosion or shore erosion) consists of two parts:

- fastland erosion – the subaerial portion of the bank
- nearshore erosion – the subaqueous portion of the bank.

Only fastland erosion was considered in this study because nearshore erosion often is a much smaller proportion of shoreline erosion (Hardaway and others, 2009). In addition, nearshore erosion is captured in part by the estuarine sediment accumulation term, and separating eroding sediment from resuspended sediment in the nearshore is problematic.

In order to improve bank erosion inputs for their modeling efforts, CBP collected datasets from Maryland and Virginia and distributed the bank erosion rates, bank heights, and reach lengths to shorelines for both states using GIS. The CBP results (K. Hopkins and J. Halka, pers. comm., 2009) were used to calculate initial loadings for both states. Where available for each state, new elevation data and erosion rates were incorporated using GIS to generate new loadings, and the results were compared to the CBP loadings.

Maryland

LIDAR (light detection and ranging) data, which are high resolution elevation data, are available for Maryland. A portion of the south shore of the Patuxent River was processed using LIDAR data for bank heights. Using ArcGIS, a buffer strip was created along the shoreline that encompassed a region 20-30m inland of the shoreline. This strip was meant to target the maximum elevations along the shoreline while excluding the lowlying beaches adjacent to cliffs. All portions of hardened shoreline were removed and the buffer strip, representing unprotected shoreline, was then divided into reach lengths based on where gaps occurred due to hardening. The average bank height for each reach was calculated using elevations from the LIDAR data. A volume (m^3) of eroded sediment was calculated using the resultant average bank heights, reach lengths, and bank erosion rates. The volume was converted to a load (Mt/yr) using a bulk density of 1.38 g/cm^3 (J. Halka, pers. comm., 2009).

For improved erosion rates, a Maryland Geological Survey (MGS) study (http://www.mgs.md.gov) using various historical shoreline locations was combined with information from Maryland shoreline surveys conducted by CCI (http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/index.html).

Virginia

The Virginia Base Mapping Program (http://www.vita.virginia.gov/isp/default.aspx?id=8412) produced digital terrain models

(DTMs) from high resolution aerial photography. The data for the York River bank heights were processed similarly to Maryland, except that a buffer strip that encompassed a region 50-100m inland of the shoreline was used, due to scarcity of elevation data in some areas. Bank erosion rates were based on work done by Hardaway and others (1992).

Biogenic Production

Biogenic sediments are generated in the estuary by organisms, and include materials such as diatom tests (silica), foraminifera shells (calcium carbonate), dinoflagellates, sponge spicules, fish scales and bones, etc. Literature values were used to estimate the contribution from biogenic production (Anderson, 1982).

Sediment Budgets

The components for the sediment budget of an estuary, described above, were combined in a mass balance equation (sediment sources – sediment sinks ± error = 0). An arbitrary assignment was made in the equation of a positive sign to represent a sediment source (erosion) and a negative sign to represent a sediment sink (deposition or movement out of the estuary, either upstream or downstream of the system).

Results and Discussion

<u>Estuarine Transport Processes and Sediment Loads</u>

Transport Processes

Sediment transport processes and sediment loads were calculated for the 14 stations in three tributaries—the York, Patuxent, and Potomac Rivers (Fig. 2). As an example, graphs of estuarine transport processes for York River station LE4.2 are shown in Figures 4-8. Individual graphs of all estuarine transport processes, including TSS concentrations, tidal velocities and transport, subtidal velocities and transport, and river velocities and transport vs. tidal phase for all monitoring stations and layers are included in Appendix 1.

Results show that, in general, TSS concentrations are higher in the lower layer, indicative of resuspended sediment (Fig. 4). Within the lower layer, higher concentrations near peak ebb and flood, and lower concentrations near slack are consistent with higher velocity water and more turbulence during peak stages. TSS concentrations multiplied by the tidal velocities (Fig. 5) yield tidal transport (Fig. 6). Likewise, concentrations times subtidal velocities yield subtidal transport (Fig. 7) and concentrations times river velocities yield river transport (Fig. 8). Summary graphs of velocities, transport, and loads for each river are shown in Appendix 2.

The net direction of tidal transport varies between stations in all the rivers, due to factors such as the cross-sectional area of the river and location in the Bay (closer or farther from the Bay mouth). For most stations, as expected, gravitational transport is ebb-directed in the upper layers and flood-directed in the lower layers. River transport is small for all stations because their contribution is spread over the larger cross-sectional areas of the estuaries.

The Patuxent River stations tend to show the most variability and deviation from expected transport directions. One factor may be the intermittent three-layer circulation that exists at certain times at the mouth of the Patuxent (Owen, 1969). This idea was tested by extracting the velocities at a mid-depth layer for station LE1.4 and calculating transport values for this depth. The results were inconclusive. Since the three-layer circulation only occurs intermittently, usually in April, the long-term dataset might mask this phenomenon. In addition, the correct combination of TSS data and velocity data for the proper depth to illustrate the three-layer circulation may be unavailable.

Sediment Loads

The three rivers show very different magnitudes and transport directions of sediment loads (Figures 9-10 and Tables 1-3). The channel cross-sections, used to calculate sediment loads, were determined using bathymetric data and are shown in Figures 11-13. Literature values for sediment loads in the Bay tributaries are rare (e.g. Schubel and Carter, 1976), and the results presented here represent the most comprehensive calculations of sediment loads for Bay tributaries.

All loads in the York River are directed upstream, except for the load at the mouth, (station LE4.3). These results generally support the traditional thinking that tributaries are sinks of sediment from the Bay. The large difference in loads between LE4.3 and LE4.2 in the York suggests a tendency for erosion between these two stations. However, there is not enough shoreline erosion, the most plausible long-term source of sediment, to account for the difference. The York River, in particular, is highly energetic, with high levels of resuspended sediment (Dellapenna and others, 1998) that may account for a substantial portion of the calculated load. Thus bed sediment may be exported from between these two stations during the non-storm conditions captured by monitoring.

The uppermost station (RET4.3) for the York River was only three cells deep. To confirm the results, a load was calculated using the deepest cell and compared to the load from the cell one up from the bottom. The results from the bottom cell were oriented in the same direction as the cell one up from the bottom but smaller in magnitude. For consistency, the value from one cell up from the bottom was used.

The direction of loads in the Patuxent River fluctuated between stations. It is possible that this phenomenon was due, in part, to a sampling bias. For several of the monitoring stations in the Patuxent, most samples were collected on the ebb phase of the tide, unlike the other rivers where samples were more evenly distributed between the ebb and flood phases. The impact of a sampling bias was lessened by correcting tidal velocities so that average ebb and flood magnitudes were equal.

Loads in the Potomac varied in direction, as well, although there is no noticeable sampling bias. Overall, the total load along the Potomac generally decreases with distance upstream. From the salinity distribution (Fig. 3) and the location of the ETM (Fig. 14) it is arguable whether stations RET2.1 and RET2.2 should be included in the sediment budget for the Potomac River estuary.

Interestingly, averaging all the loads for each river (Fig. 15) shows a net input of sediment into each estuary. In addition, the absolute value of the total average load for each river decreases from south to north in the Bay especially when normalized by river cross-sectional area. Total average loads from the James and Rappahannock Rivers are needed to confirm or challenge this pattern. This tendency for decreasing absolute load to the north is consistent with decreasing tidal range along this portion of the Bay mainstem, and thus, decreasing magnitude of tidal resuspension.

Another possible issue is with the loads at three stations: RET4.3 in the York, and LE1.4 and LE1.2 in the Patuxent. The cross-sectional areas for the upper and lower layers were not calculated based on a level of no motion because the gravitational velocities were not directed in the typical manner (Fig. 10). Instead, the cross-sectional area of the channel was divided in half for these three stations. The results using the level of no motion for cross-sectional areas are substantially different from just dividing the areas in half (Fig. 16).

Estuarine Sediment Accumulation

An example of the soundings and TINs for two surveys in the York River is shown in Figure 17. The resultant volume differences created by subtracting the two TIN surfaces for each estuary are shown in Figures 18-20. Based on the area of overlap for two bathymetric datasets for each river, the results indicate sediment accumulation in all three estuaries.

Sediment accumulation in an estuary calculated using bathymetric data is highly dependent upon the factor used to convert sediment volume to sediment mass. The values of 1.33 g/cm^3 and 1.06 g/cm^3 were used to produce two values for comparison. In addition, a comparison of vertical accumulation rates (calculated from the volumes) to rates from core data and sea level rise showed the results were reasonably close.

The areal extent of overlap for the Patuxent datasets was small. An older set of hydrographic surveys (circa 1908) was not available in digital form, but covers a wider extent and may improve the accumulation load.

Shoreline Erosion

Bank heights, hardened shoreline reaches, and erosion rates for the York River are shown in Figures 21-22. A comparison of the loads in the York using the CBP data and the VBMP elevation data shows that the VBMP data produced a load ~ 37% higher. In addition, a project to recalculate shoreline erosion rates in Virginia using newer techniques and multiple datasets of historic shorelines is underway for some Virginia counties (Shoreline Studies Program, VIMS) and would greatly improve any studies using shoreline erosion rates.

Bank heights, hardened shoreline reaches, and erosion rates for the Patuxent River are shown in Figures 23-24. A comparison of loads in the Patuxent using CBP data vs. LIDAR elevation data, shows that the LIDAR data produced a load ~15% higher. The average erosion rates used by CBP seem low in some areas (≤ 0.16 m/yr). For example, the combined erosion rate shoreline created by work from the Maryland Geological Survey and CCRM (http://ccrm.vims.edu/gis_data_maps/interactive_maps/erosion_vulnerability/index.html) has average rates up to 0.9 m/yr in a few areas on the Patuxent and many reaches with rates of 0.3 m/yr. Using these rates would increase the contribution from shoreline erosion.

The time spans of estuarine sediment accumulation discussed in the previous section do not necessarily coincide with the time span of shoreline hardening. Presumably, most shorelines in the Bay, especially along residential stretches, were hardened after World War II. To roughly gauge how the difference in time spans might affect shoreline erosion loads, shoreline erosion loads were estimated assuming no shoreline hardening. These estimates were calculated only for the portions of each river that were used in this study. For the York River 21% of the shoreline is hardened. The shoreline erosion load assuming no hardening increases the current load by 32%. For the Patuxent River 37% of the shoreline is hardened. The shoreline erosion load assuming no hardening increases the current load by 34%. These values reduce the error of the sediment budget by 5% and 7% respectively, so the difference in time spans does not appear to be a problem.

Biogenic Production

Currently, it is thought that biogenic production may be a substantial portion of sediment sources in mid-Bay estuaries (Cronin and others, 2003a). The literature reports on concentrations of biogenic material in the sediment (e.g. Colman and Bratton, 2003), but the concentration of biogenic material in the water column is needed. Using the fixed portion of TSS is not adequate, because it would be necessary to distinguish biogenic material (which does not separate during ignition) from organic material.

Biogenic silica values were collected from numerous samples in the Rappahannock River (Anderson, 1982). Concentrations for all stations in the estuary for all seasons were averaged to obtain a mean concentration of 0.15 mg/l. The contribution from biogenic production using this mean concentration is quite small (in the Patuxent, it is less than 1% of the smallest source). Another important consideration is that the use of TSS data already incorporates most or all of the biogenic production, so that a separate term in the sediment budget was deemed unnecessary.

Sediment Budgets

The sediment budgets were constructed using the best estimates for each component (Fig. 25 and Table 4). The proportions for the two budgets differ noticeably. The budgets for the York and Patuxent Rivers both show a sediment loss that is unaccounted for, i.e. to balance the budget so the error term is zero, more sediment is needed from sources, or the sinks are too large and need to be reduced.

Calculating sediment loads for stations within the estuary, as well as at the head and mouth of the estuary has highlighted one problem with using a traditional budget for the estuary. A better way to illustrate these dynamic systems is to include all the estuarine stations (Figs. 26-28). For example, in the York River the intermediate loads show that large amounts of sediment are being redistributed in system. This phenomenon would not be evident if the loads from only the head and mouth of the estuary were used.

Constructing sediment budgets presents several important challenges when using pre-existing datasets. Differences in spatial scales, temporal scales, and sediment types (e.g. TSS vs. fixed suspended solids) may introduce errors. All efforts were made to recognize these differences and the effects they may have on the results. One way to help separate out the inconsistencies is to generate a value for each component of the sediment budget, so that no components were calculated by subtraction. This puts the errors from all the components into one term, which then can be analyzed and apportioned to possible causes. For example, as discussed previously, improving shoreline erosion rates would probably increase the load and reduce the error. The loads accumulating in the estuary are very large—it is possible that the % water content is too low. A higher percentage would reduce the size of this sink.

Sediment from upland erosion in the Coastal Plain usually is input through streams. It is thought that the significance of upland erosion in this type of sediment budget is minimal because of the low relief (Gellis and others, 2007). The relative contribution of the erosion of sediment from the land surface rather than from stream corridors is not well understood in the Chesapeake Bay basin (Gellis and others, 2007). These factors were not included in this study. However, future work to estimate the cumulative input of the numerous small tributaries of an estuary may yield additional information. For example, in the Potomac River, a load calculated at station SMT.07 (at the mouth of the St. Mary's River) would give a general idea of the contribution from estuary tributaries as well as add to the understanding of sediment transport in the Potomac River.

Errors and Uncertainty

Many factors contribute to the error term in the sediment budget mass balance equation. The main causes are due to spatial scales, temporal scales, and missing data.

Spatial Scales

Extrapolating data to different spatial scales is one source of error. For example, using a single monitoring station to represent the entire cross-sectional area was required in order to benefit from the valuable long-term record of TSS concentrations. Another example is extrapolating sediment accumulation from one portion of the estuary to the entire estuary.

Temporal Scales

Using long-term datasets and calculating them to an average annual value affects the magnitudes of rates. Shorter time periods tend to produce higher rates than if the same processes were studied over a longer time period. An example would be sediment accumulation rates in the estuaries.

Using datasets from different time periods also may introduce error. The bathymetric surveys were collected between the mid 1800's to mid 1900's. The monitoring station data is from the late 1900's to early 2000's.

Missing or Dissimilar Data

The use of TSS for the sediment concentrations introduces some discrepancies. Due to laboratory processing, TSS samples are skewed towards finer sediments, compared to SCC (suspended sediment concentrations). While they are not precisely comparable, and there is no easy conversion factor (Gray and others, 2000; Glysson and others, 2000), TSS are measured Bay-wide, and many stations have a long period of record (10's of years). So, due to data availability and for consistency, TSS were used everywhere. In addition, TSS contains inorganic sediment (e.g. sand, silt, and clay), organic material from runoff (e.g. leaves, peat) and *in situ* biogenic production (e.g. diatoms, foraminifera). Fixed suspended solids (FSS) are the remains when TSS samples are heated to remove the volatile organic material. Although the volatile material is burned off, the organic tests of the microorganisms remain. Material eroded from river banks, because of its age, is probably mostly FSS, whereas, material depositing in estuaries is probably a mixture of TSS and FSS, depending on depth of accumulation.

The more accurate shoreline erosion rates that are currently being developed for Virginia using newer technology would help reduce error in shoreline erosion loading estimates. In addition, including nearshore erosion as part of shoreline erosion may somewhat increase the sediment input calculated from shoreline erosion.

The contribution from estuary tributaries may be more than current thinking, which would be an additional source of sediment to reduce the budget error.

Uncertainty

All measurements have limitations in accuracy and contain a certain amount of error. In addition, formulation of a sediment budget usually requires estimation of quantities that are not well known. See Kraus and Rosati (1998) for a discussion of uncertainty in sediment budgets. The values reported in the present study were calculated from the raw data and were not rounded. The accuracies range from one to three significant figures depending upon the source of the data. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

Despite these issues, the results in this study are based on the best data currently available. As new data become available, iterations of the budgets will improve.

Summary

Conclusions

The results of this study represent the most comprehensive calculations to date of sediment transport processes and loads for Bay tributaries. The three rivers exhibit different magnitudes and transport directions of sediment loads at individual CBP water quality monitoring statons. Average sediment loads for the rivers as a whole show the York, Patuxent, and Potomac all importing sediment, with an overall decrease in loads from south to north in the Bay.

Sediment budgets for the estuaries are complex. Loads at the head and mouth of the estuary do not represent the complete picture—intermediate stations provide additional information about the amount and direction of sediment movement. The York River is highly energetic, moving large amounts of sediment within the estuary even during non-storm conditions captured by monitoring. The Patuxent River is less energetic but more variable at individual stations in terms of the local direction of redistributing sediment. Sediment budgets for the York and Patuxent show a sediment loss that is unaccounted for; i.e. more sediment is needed from sources, or sinks are too large. Sediment input from tributaries of the estuaries is another source that may improve budget calculations. The sediment budget for the Potomac River needs the shoreline erosion component for completion.

If the necessary data are available, the methods developed and used in this study are transferable to other areas.

Future Work

There are many areas of study that would add significant contributions. In particular, finishing the sediment budget for the Potomac River and continuing to calculate transport processes, loads, and budgets for the rest of the Bay tributaries, especially the James and Rapphannock Rivers in Virginia.

With a more complete picture of sediment transport in the Bay tributaries, the results could be incorporated into an existing Chesapeake Bay sediment budget (e.g. Hobbs and others, 1992).

The role of storms is integral to sediment transport. Storm conditions are rarely captured by the existing monitoring protocol, due in part, to safety issues during data collection.

The tidal freshwater regions of the Bay tributaries are extensive. Little is known about these systems in terms of sediment processes and the quantification of sediment sources and sinks.

Glossary

Estuaries are the portions of drowned river mouths with tidal influence that contain regions with fresh water, and with a mixture of fresh and salt water (brackish water). The fresh water portions with tidal influence are called tidal rivers or tidal fresh estuaries. In this report, 'estuary' is the portion with brackish water and occurs below the estuarine turbidity maximum.

Estuarine turbidity maximum (ETM) is a region of elevated suspended solids concentrations that occurs near the landward limit of salt intrusion in estuaries.

Gravitational circulation is the pattern of water movement in estuaries due to the density differences between fresh and salt water.

Gravitational transport is gravitational circulation expressed as mass/area/time. In this study it was calculated from subtidal transport minus river transport.

River flow is the input of fresh water from the river into the estuary, usually reported as discharge. Discharge is converted to velocity by dividing by the cross-sectional area of the channel.

River transport is river flow expressed as mass/area/time.

Sediment load is the amount of sediment per time (e.g. g/s or Mt/yr).

Subtidal transport is the combination of contributions from all other processes besides tidal transport. In this study the subtidal component was attributed to gravitational circulation and river flow.

Tidal pumping is used here to mean the net movement of sediment due to a correlation between tidal velocity and concentration. If concentration is higher during flood than ebb, then tidal pumping moves sediment landward. Conversely, if concentration is higher during ebb, tidal pumping moves sediment seaward.

Tidal transport is tidal pumping expressed as mass/area/time.

Units

Area is length squared (e.g. m^2).

Concentration is mass/unit volume (e.g. mg/L or g/cm^3). In this study it was converted to Mt/m^3.

Discharge is volume/time (e.g. m^3/s).

Load is mass/time (e.g. g/s). This study used Mt/yr. It is the result of transport divided by area.

Transport is velocity times concentration (e.g. $g/m^2/s$).

Velocity is length/time (e.g. m/s).

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Figures and Tables

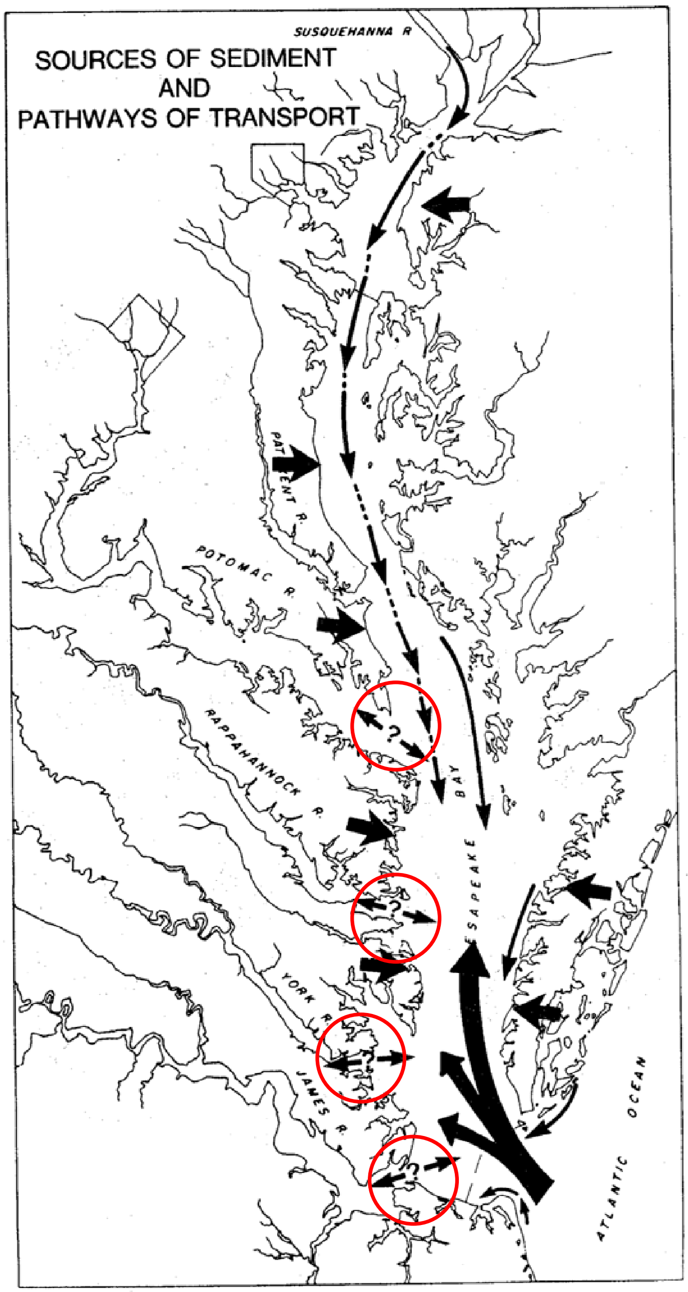


Figure 6: A map depicting the sources and pathways of transport of sediment deposited in Chesapeake Bay.

Figure 1: From Hobbs and others, 1990. A 100-year Sediment Budget for Chesapeake Bay.

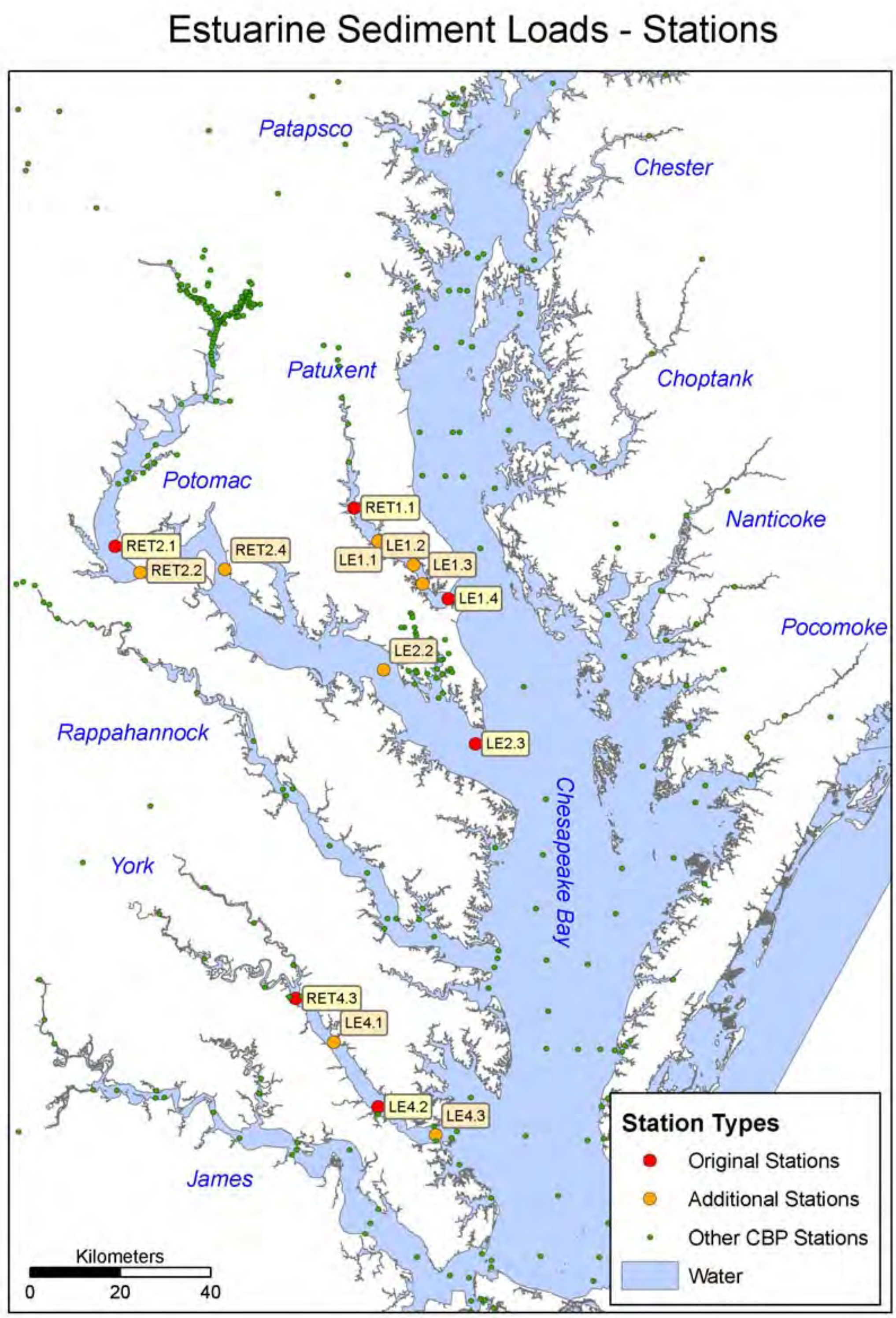


Figure 2: Estuaries and monitoring stations. Locations for Phase 1 of project. LE denotes lower estuary and RET denotes river-estuary transition.

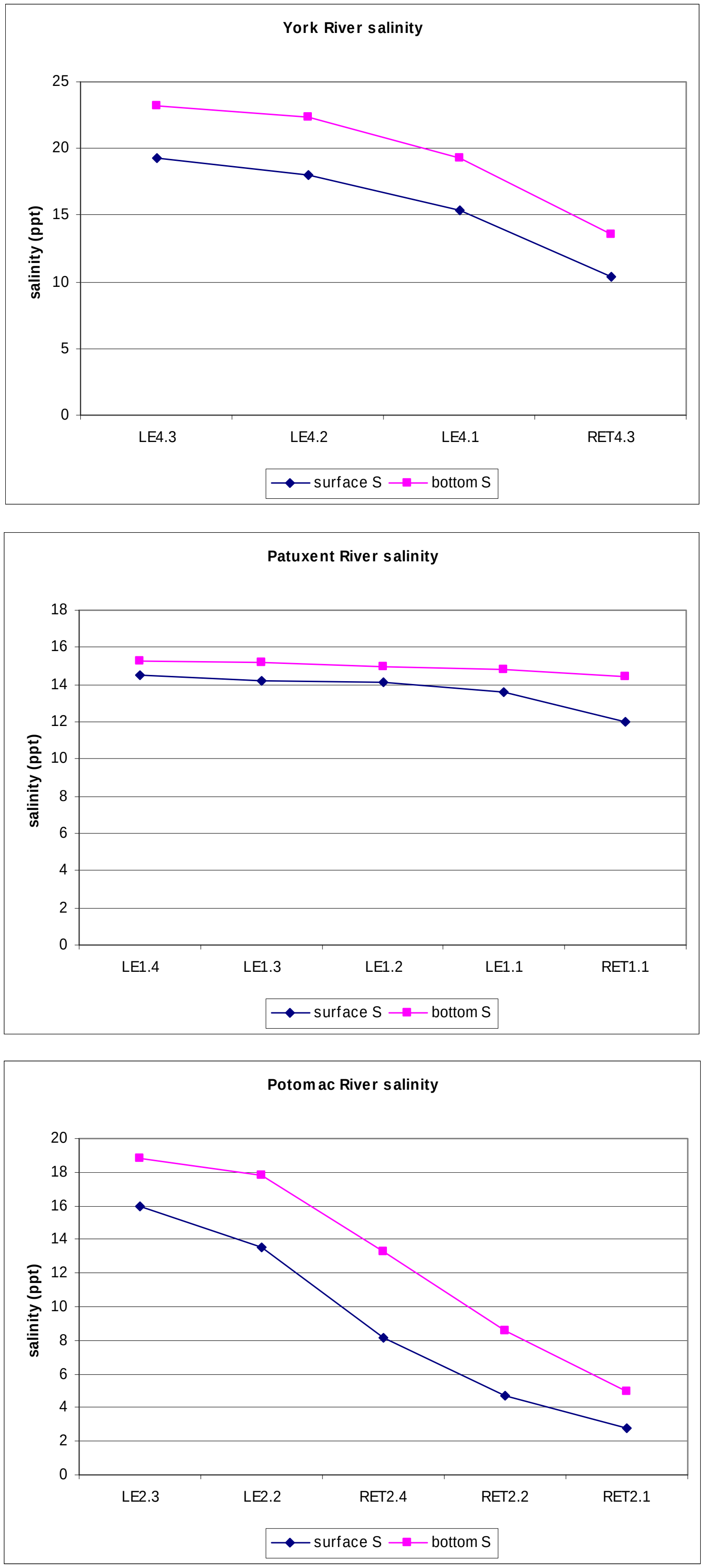
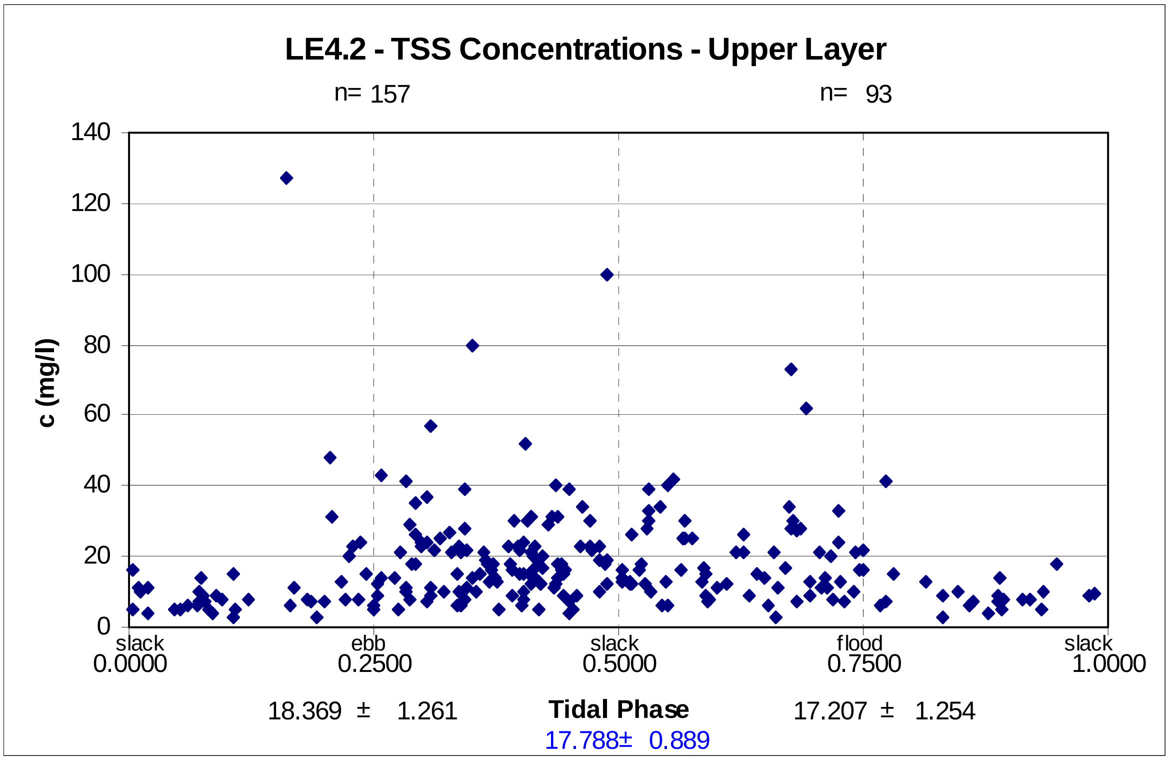


Figure 3. Salinity profiles from downstream to upstream.



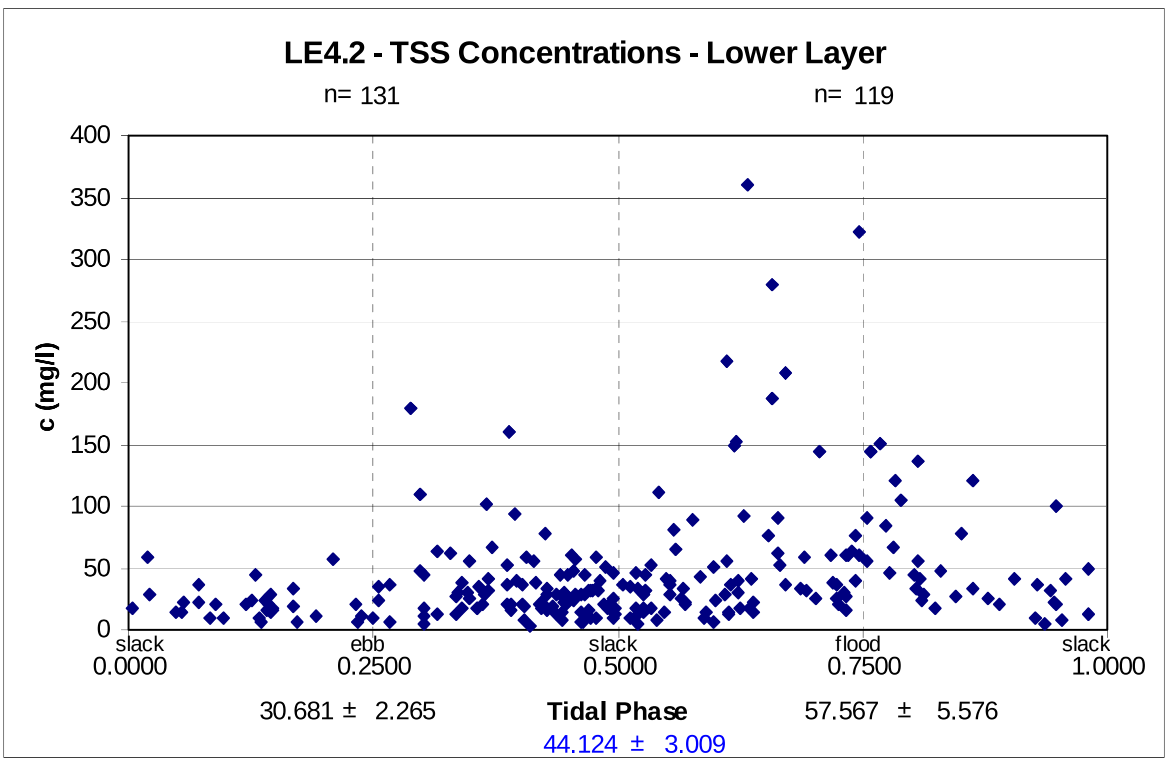


Figure 4. TSS concentrations for LE 4.2. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

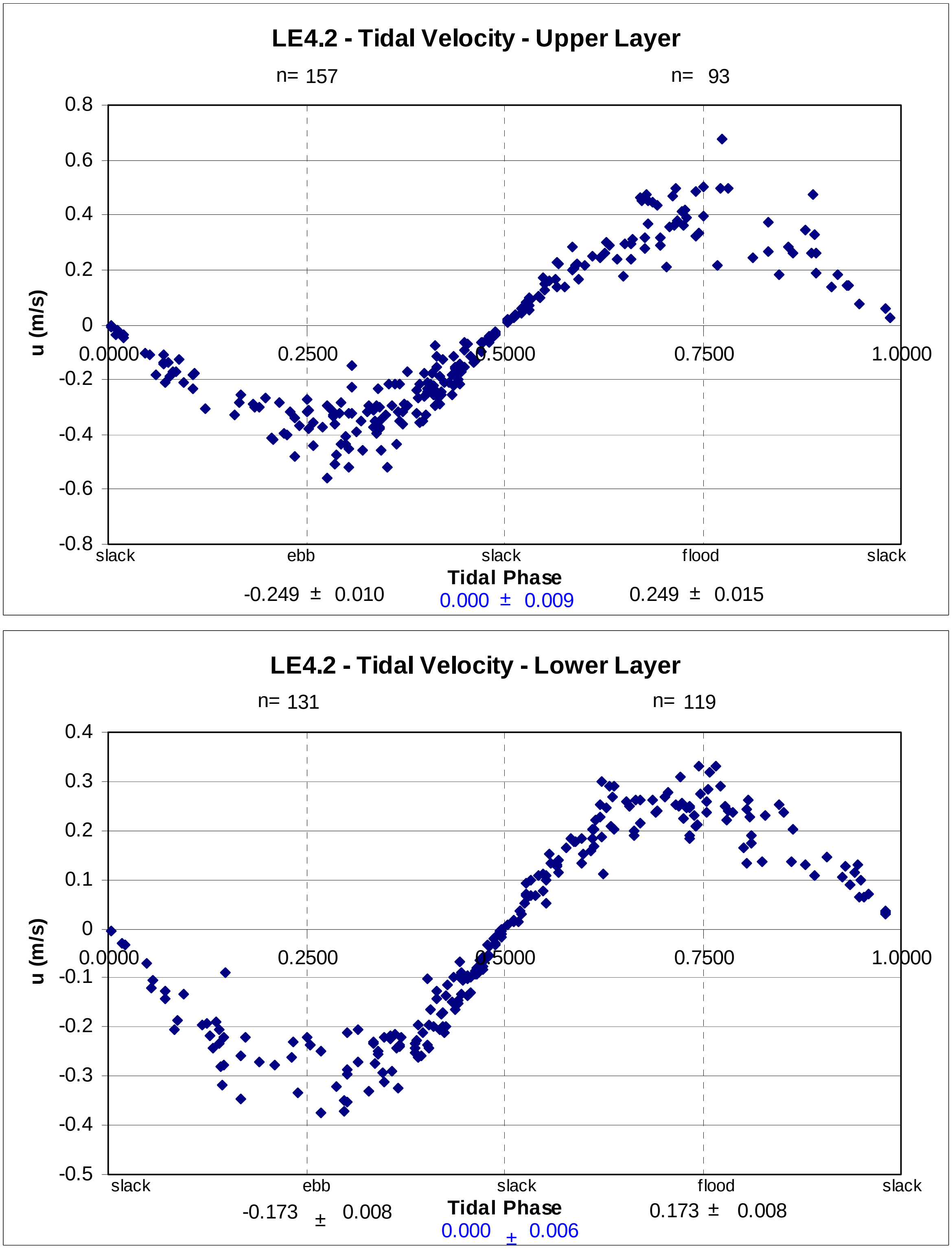


Figure 5. Tidal velocities for LE4.2. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

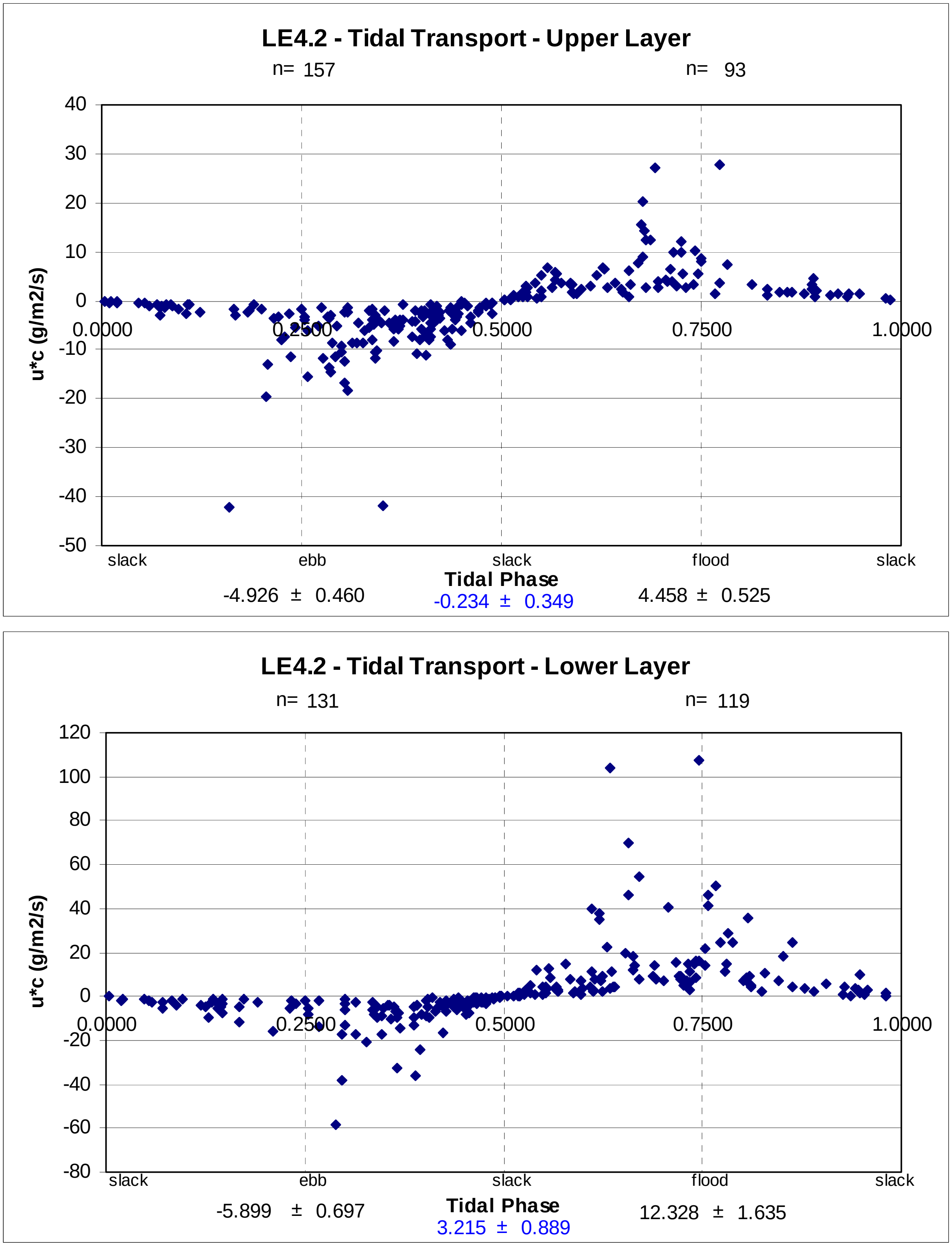


Figure 6. Tidal transport for LE4.2. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

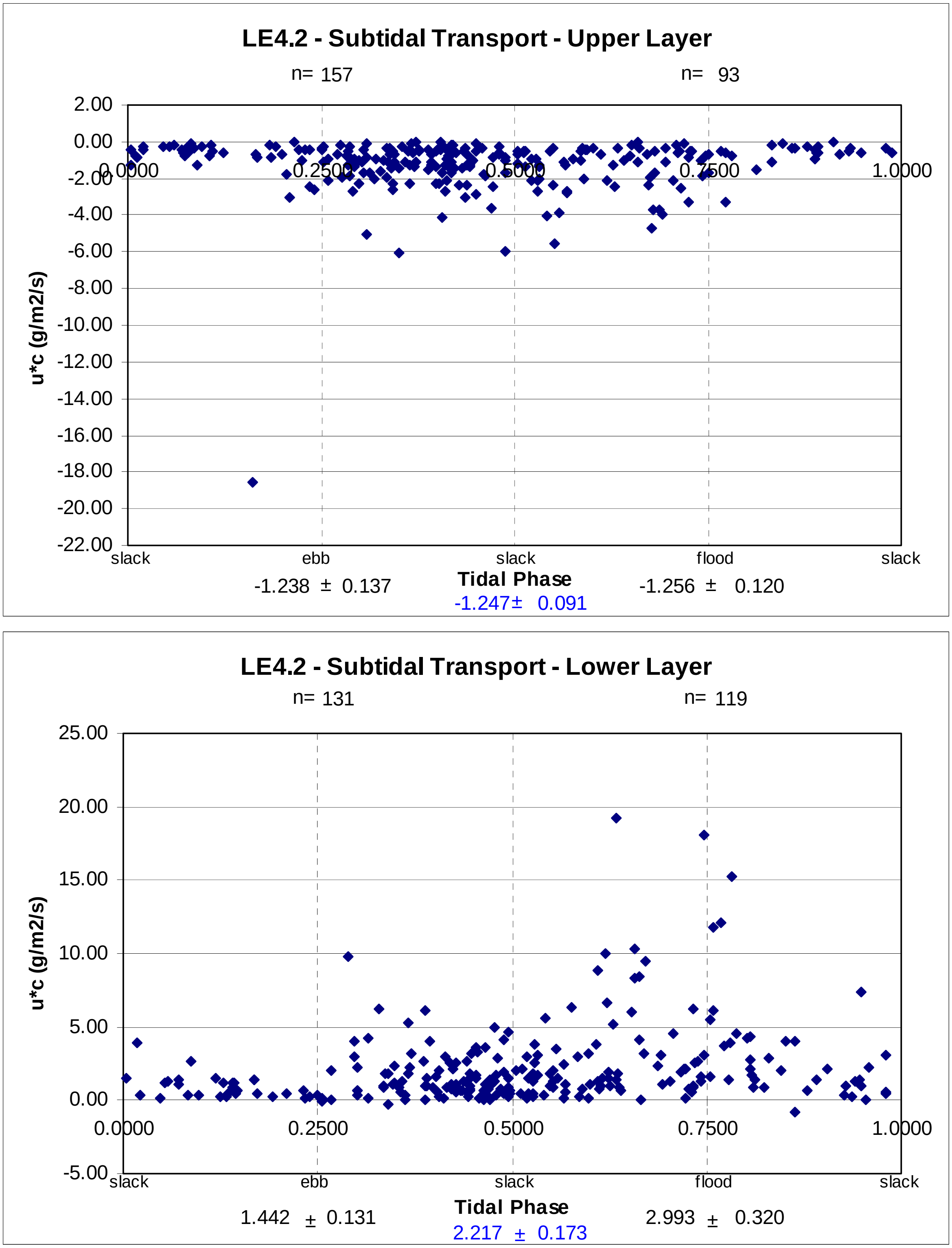


Figure 7. Subtidal velocities and transport for LE4.2. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

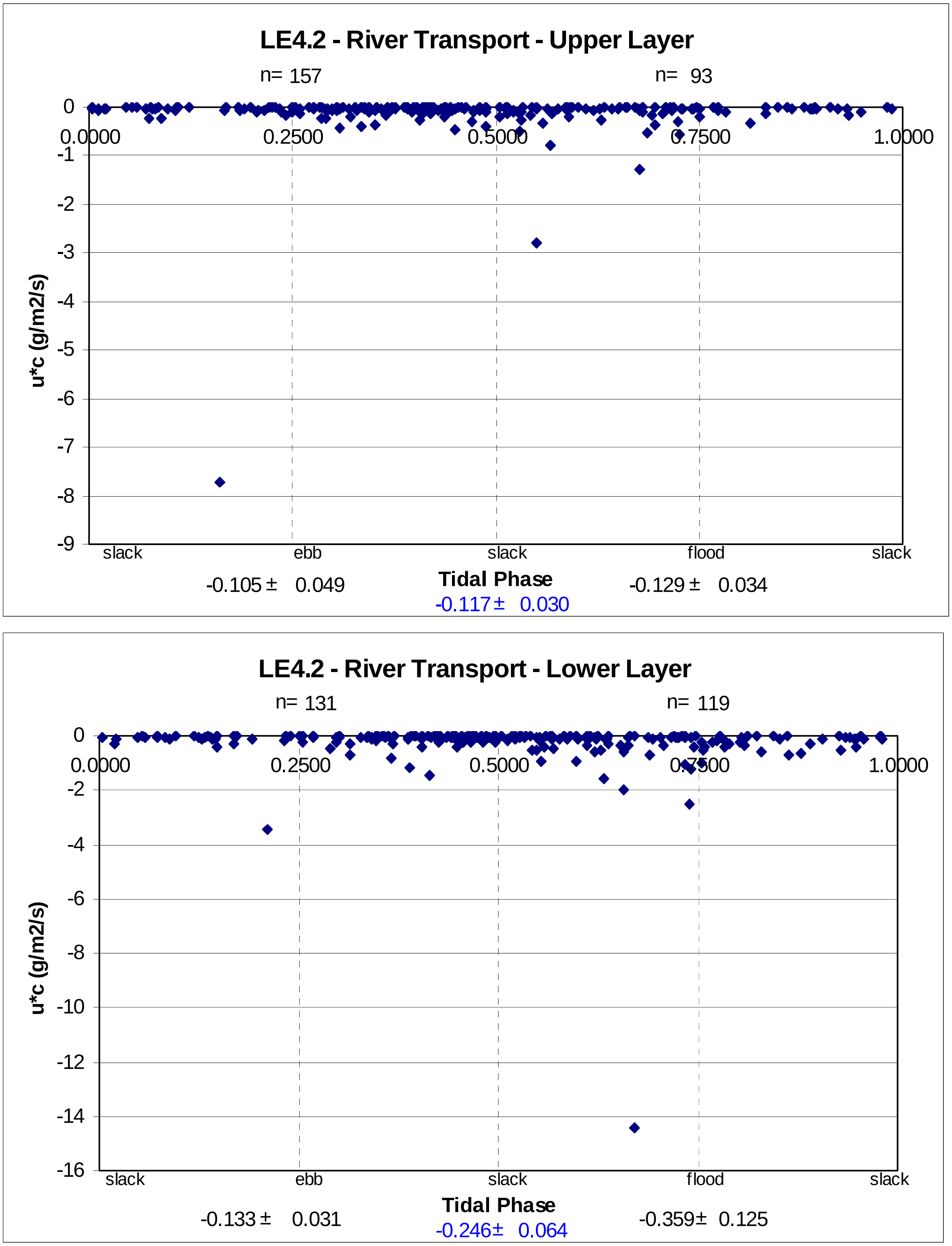


Figure 8. River transport for LE4.2. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

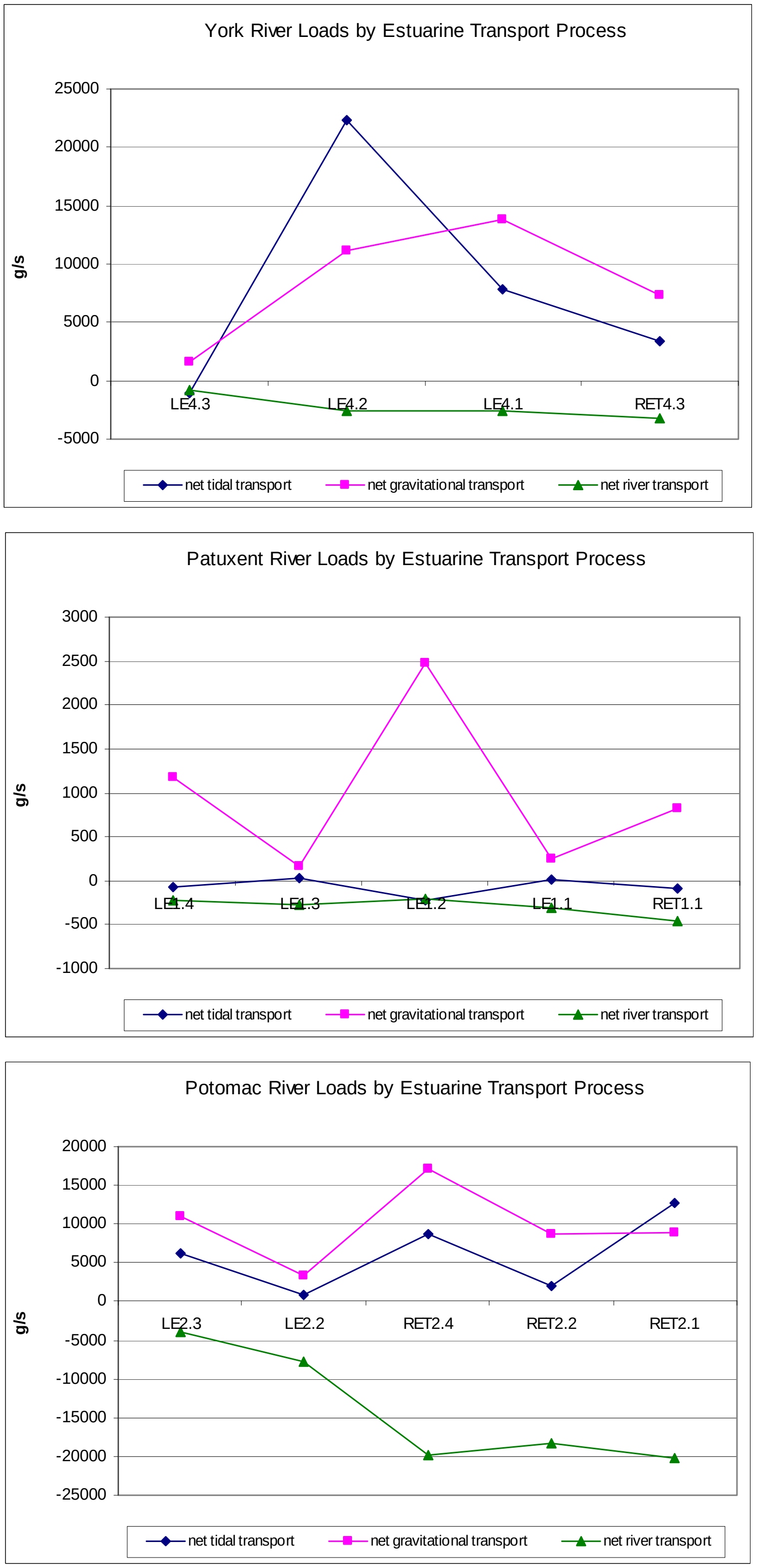
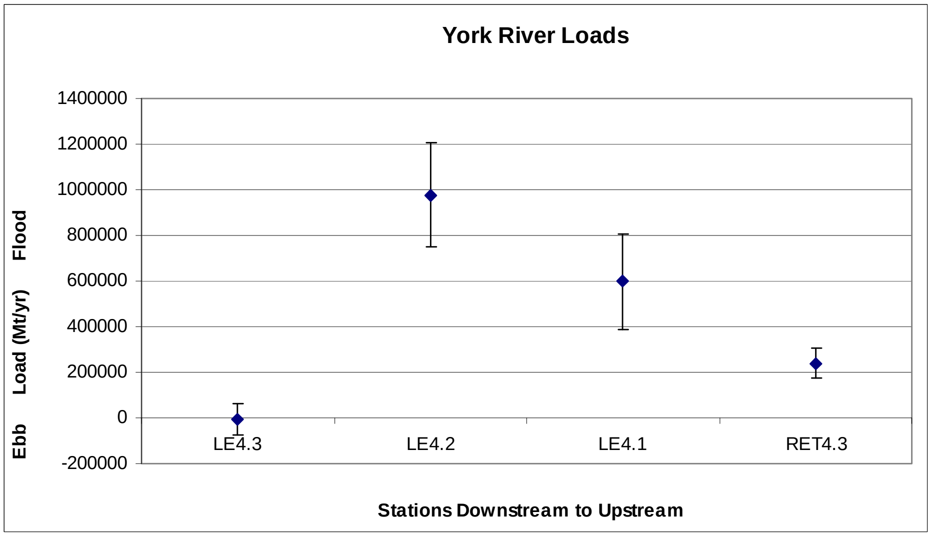
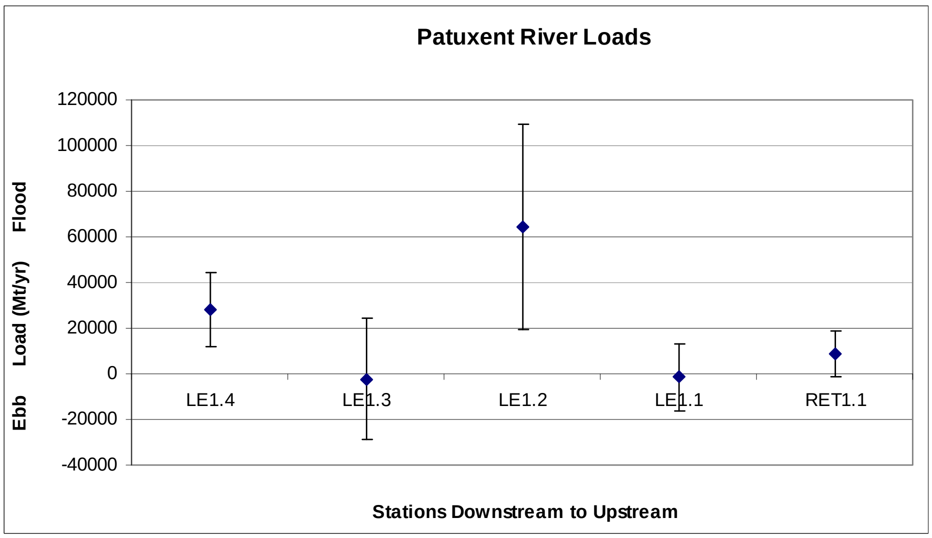


Figure 9. Sediment loads by estuarine transport process for each station from downstream to upstream. Positive numbers are flood-directed; negative numbers are ebb-directed.





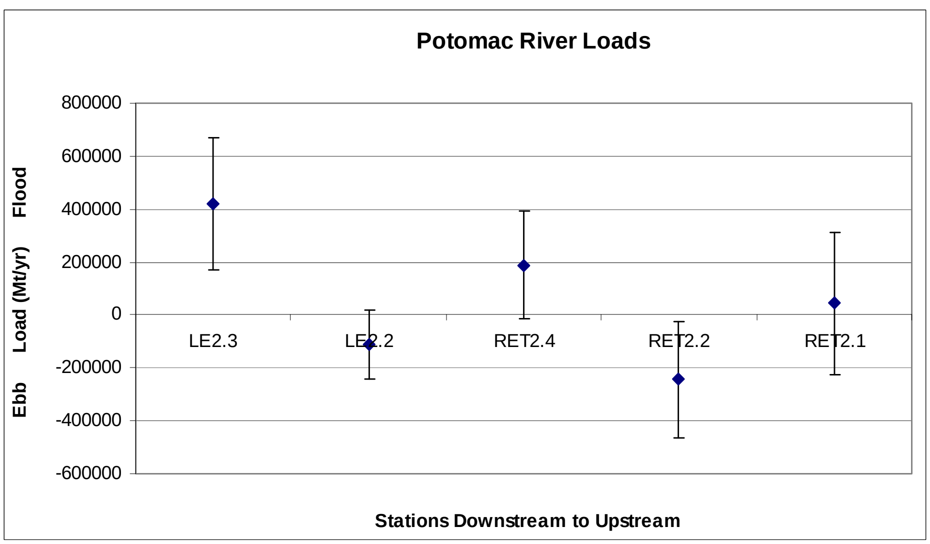


Figure 10. Estuarine sediment loads for each station—magnitude and direction (flood is positive, ebb is negative).

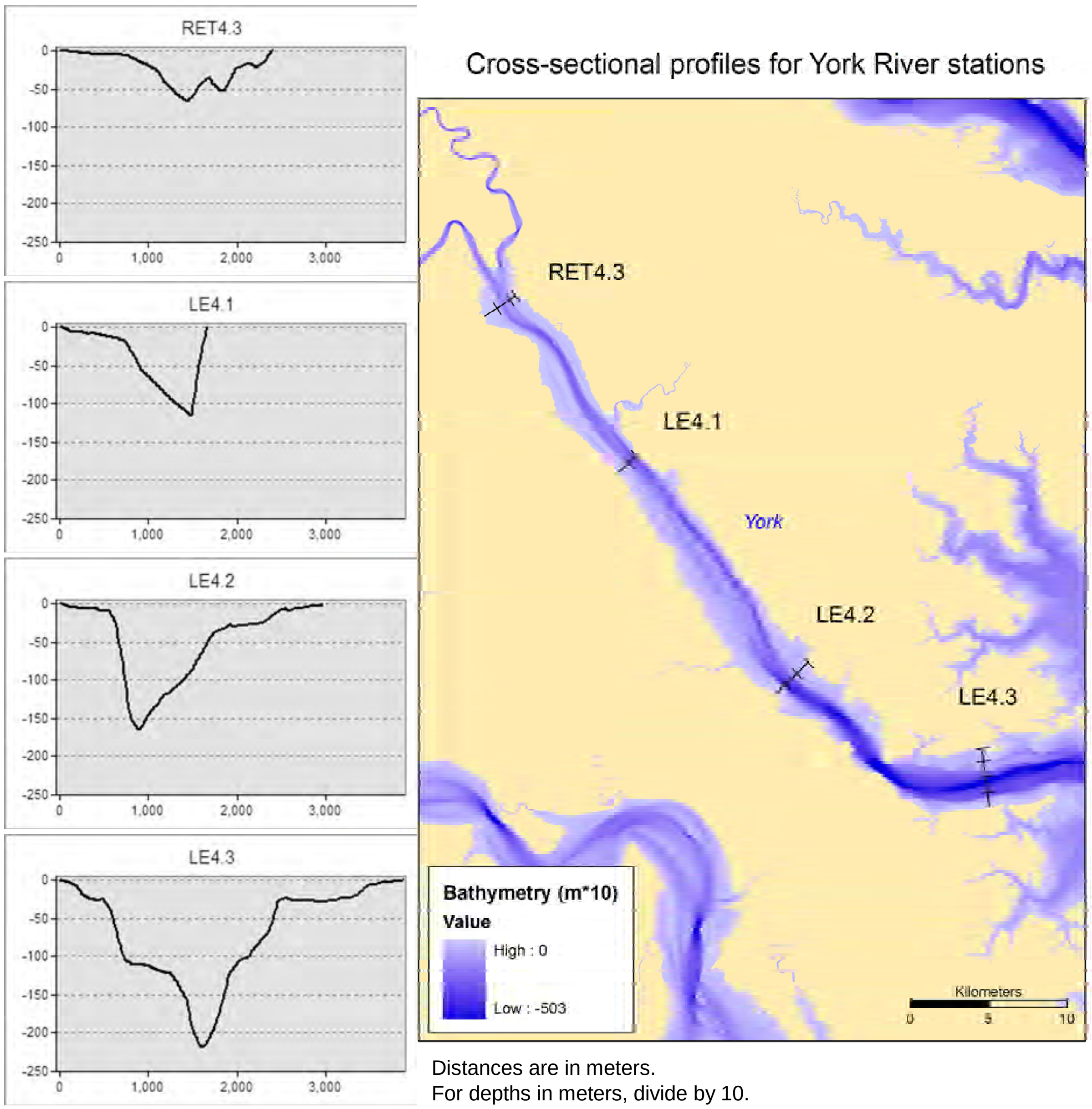


Figure 11. York River bathymetry and cross sections. Profiles are drawn from south shore to north shore (view looks upstream). Distances are in meters. For depths in meters, divide by 10. Tic marks on cross sections correspond to divisions on x-axis of profiles and are spaced 1000m apart.

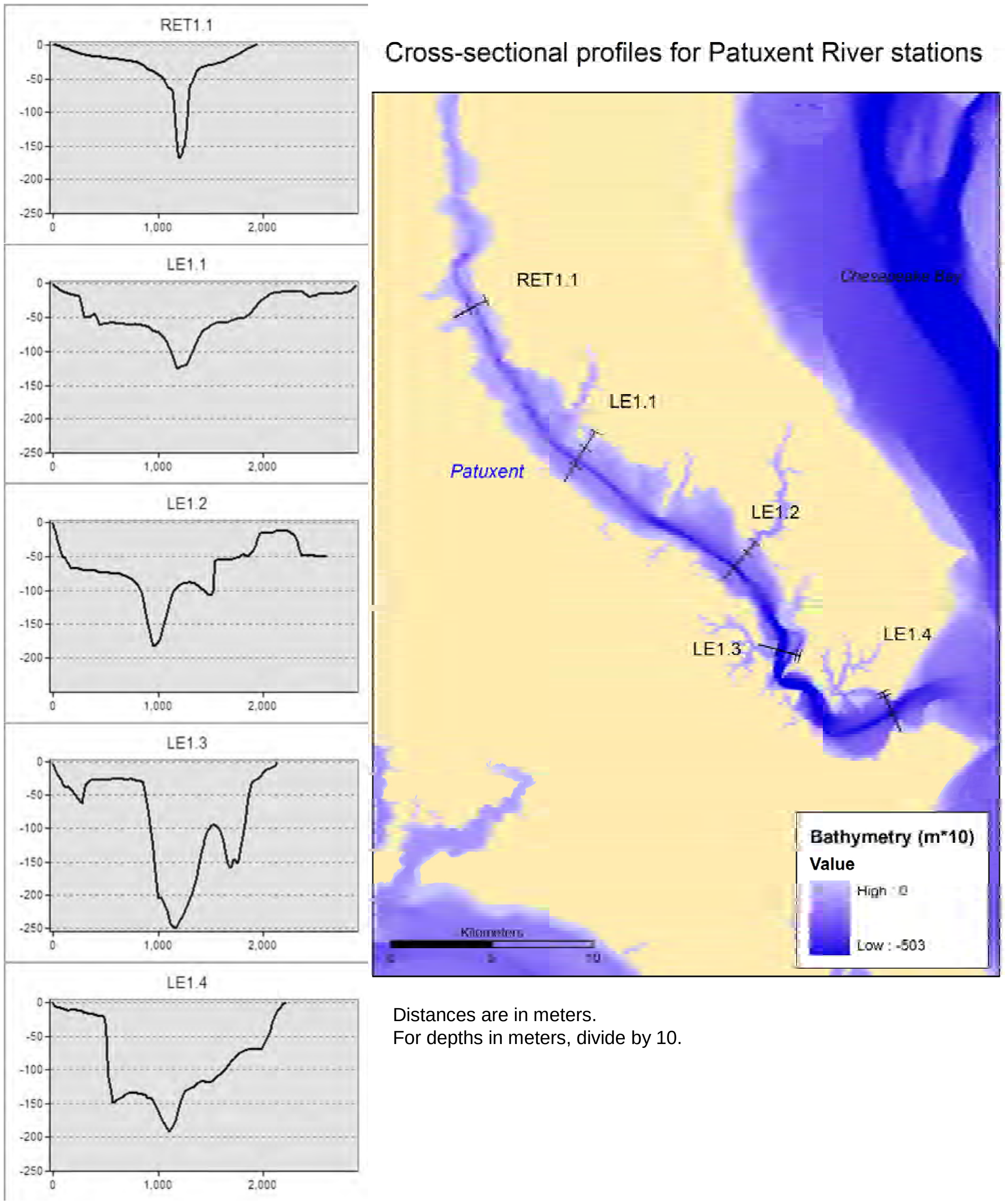


Figure 12. Patuxent River bathymetry and cross sections. Profiles are drawn from south shore to north shore (view looks upstream). Distances are in meters. For depths in meters, divide by 10. Tic marks on cross sections correspond to divisions on x-axis of profiles and are spaced 1000m apart.

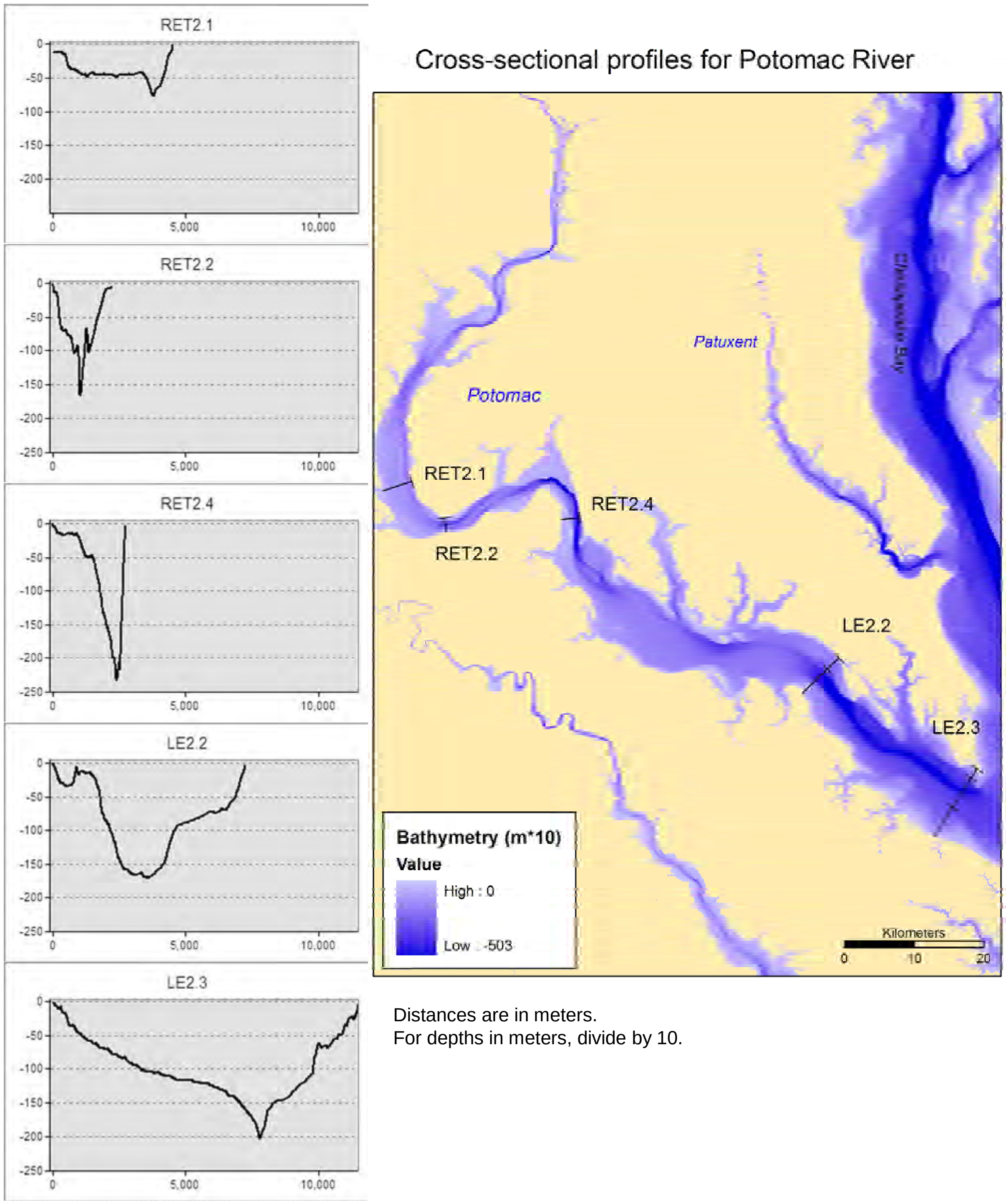


Figure 13. Potomac River bathymetry and cross sections. Profiles are drawn from south shore to north shore (view looks upstream). Distances are in meters. For depths in meters, divide by 10. Tic marks on cross sections correspond to divisions on x-axis of profiles and are spaced 5000m apart.

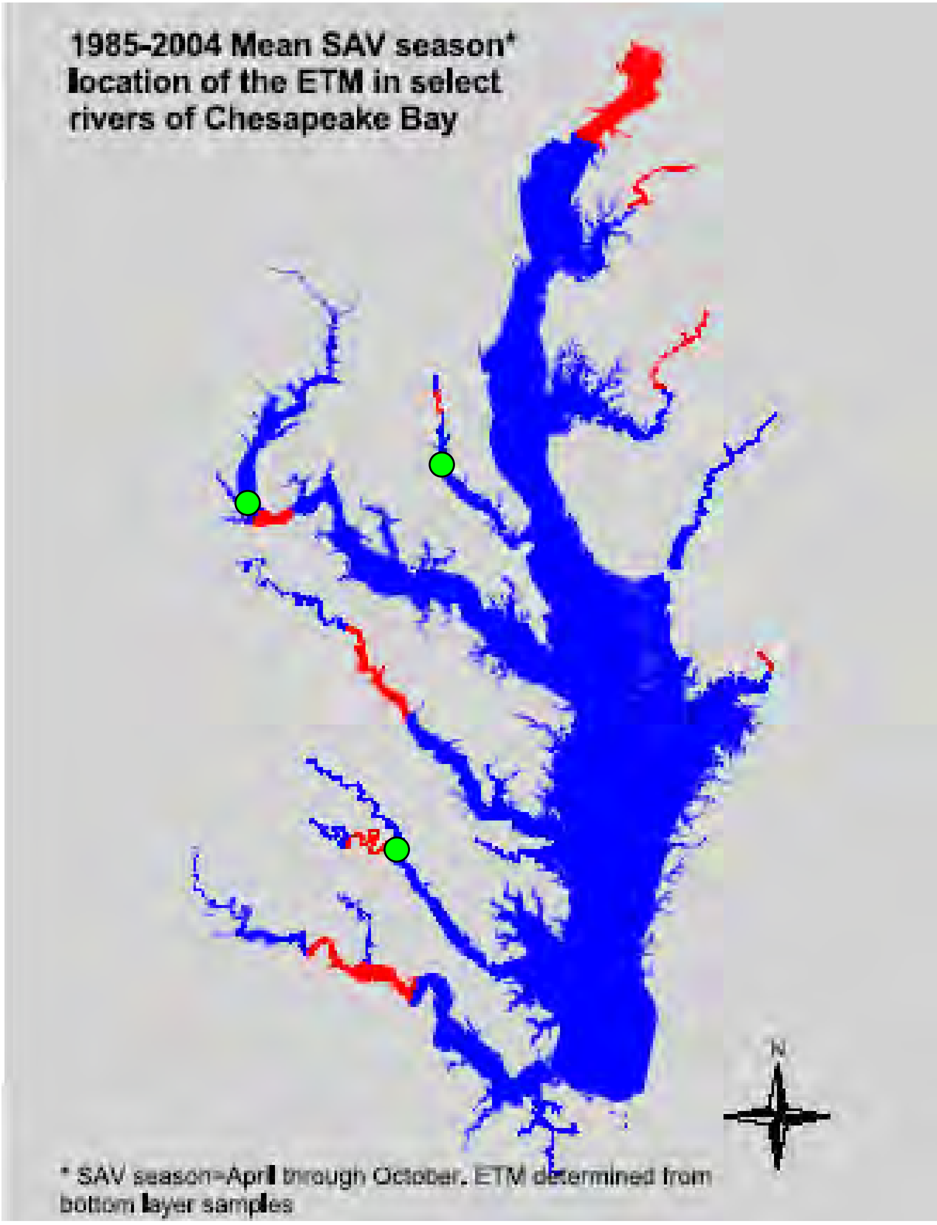


Figure 14: Location of estuarine turbidity maximum (ETM) for Chesapeake Bay tributaries. The Green dots on figure are locations of 'head of estuary' stations used in this study. The ETM migrates seasonally and annually, based on precipitation and its effect on salinity.

This is Figure 4-3 SAV growing season ETM locations from Currey and others, 2007. The source of the figure is David Jasinski, UMCES, 2006.

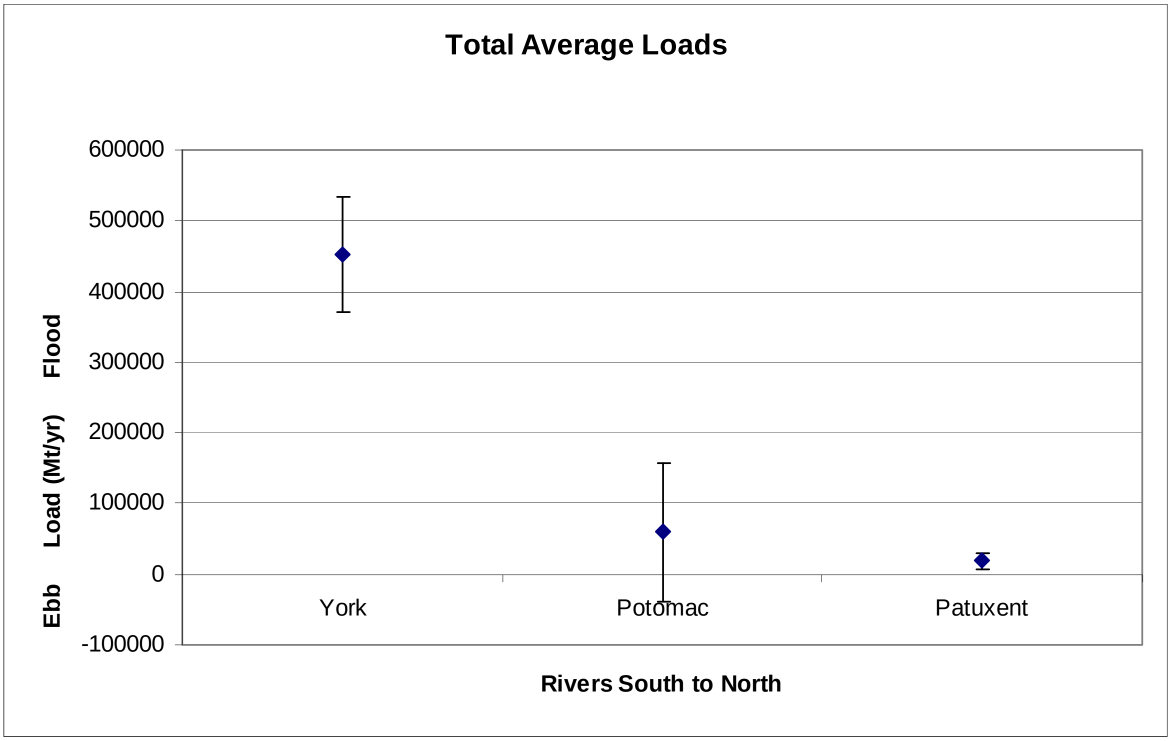


Figure 15. Total average estuarine sediment loads for each river—magnitude and direction (flood is positive, ebb is negative).

River	Station	Total cross-sectional area (m2)	Upper layer cross-sectional area (m2)	Lower layer cross-sectional area (m2)		Percent ratio of upper area: lower area
York						
	LE4.3	-26531	-22251	-4279		84:16
	LE4.2	-13683	-6274	-7409		46:54
	LE4.1	-6464	-4845	-1618		75:25
	RET4.3	-5073	-2537	-2537		50:50
Patuxent						
	LE1.4	-18993	-9496	-9496		50:50
	LE1.3	-18244	-7581	-10663		42:58
	LE1.2	-13190	-6595	-6595		50:50
	LE1.1	-11031	-2845	-8185		26:74
	RET1.1	-5150	-2771	-2379		54:46
Potomac						
	LE2.3	-110083	-49365	-60718		45:55
	LE2.2	-53390	-20100	-33291		38:62
	RET2.4	-19103	-3867	-15237		20:80
	RET2.2	-13789	-11882	-1908		86:14
	RET2.1	-18514	-11893	-6621		64:36

Figure 16. Cross-sectional areas of estuaries at water quality monitoring stations. The percent ratio of upper area:lower area shows that the proportion of cross-sectional area of the layers based on the 'level of no motion' varies widely from being half the total. Cross-sectional areas for stations RET4.3 in the York and LE1.4 and LE1.2 in the Patuxent were half the total because of gravitational transport anomalies. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

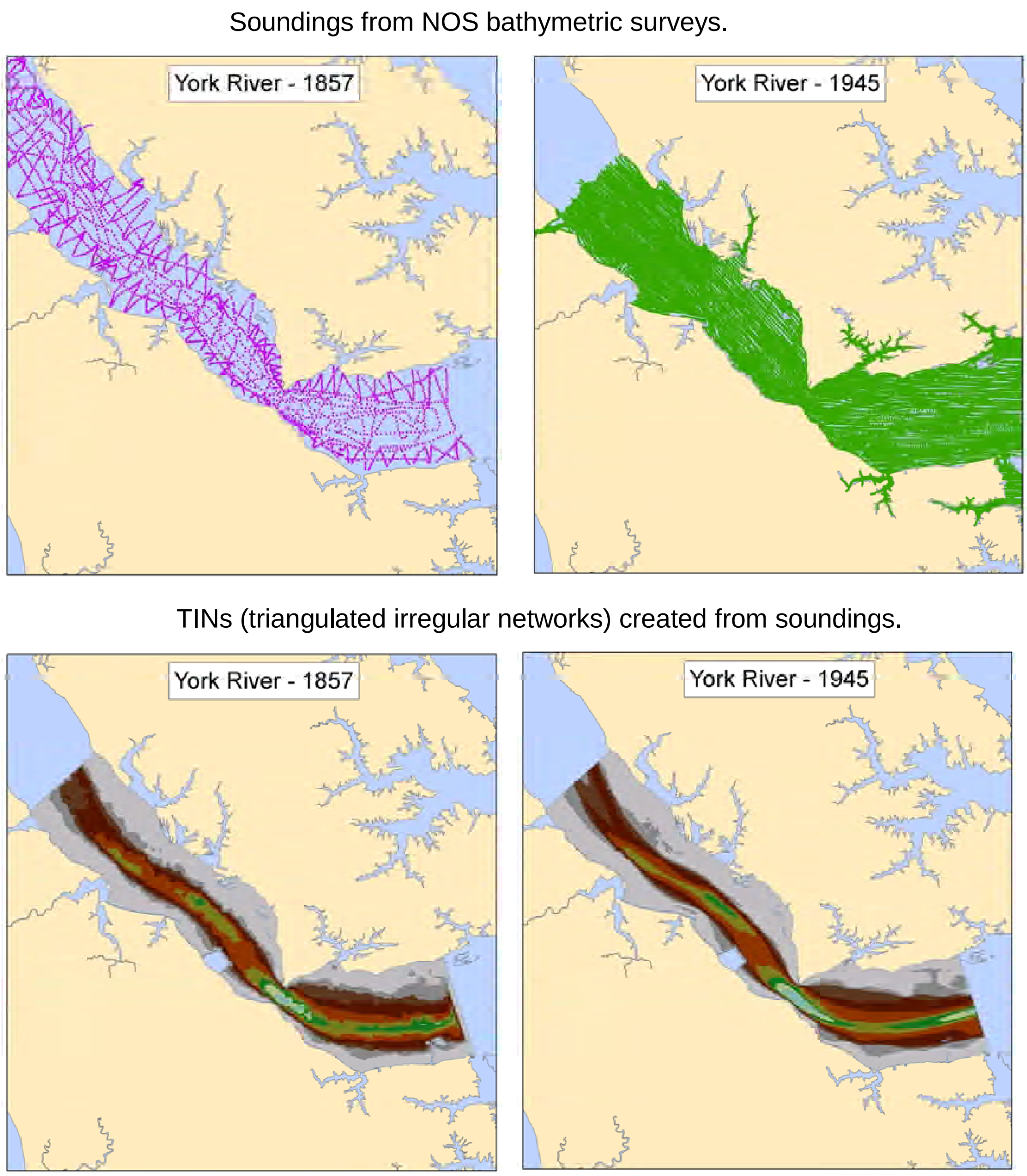


Figure 17. Bathymetric soundings and TINs for 2 surveys in the York River.

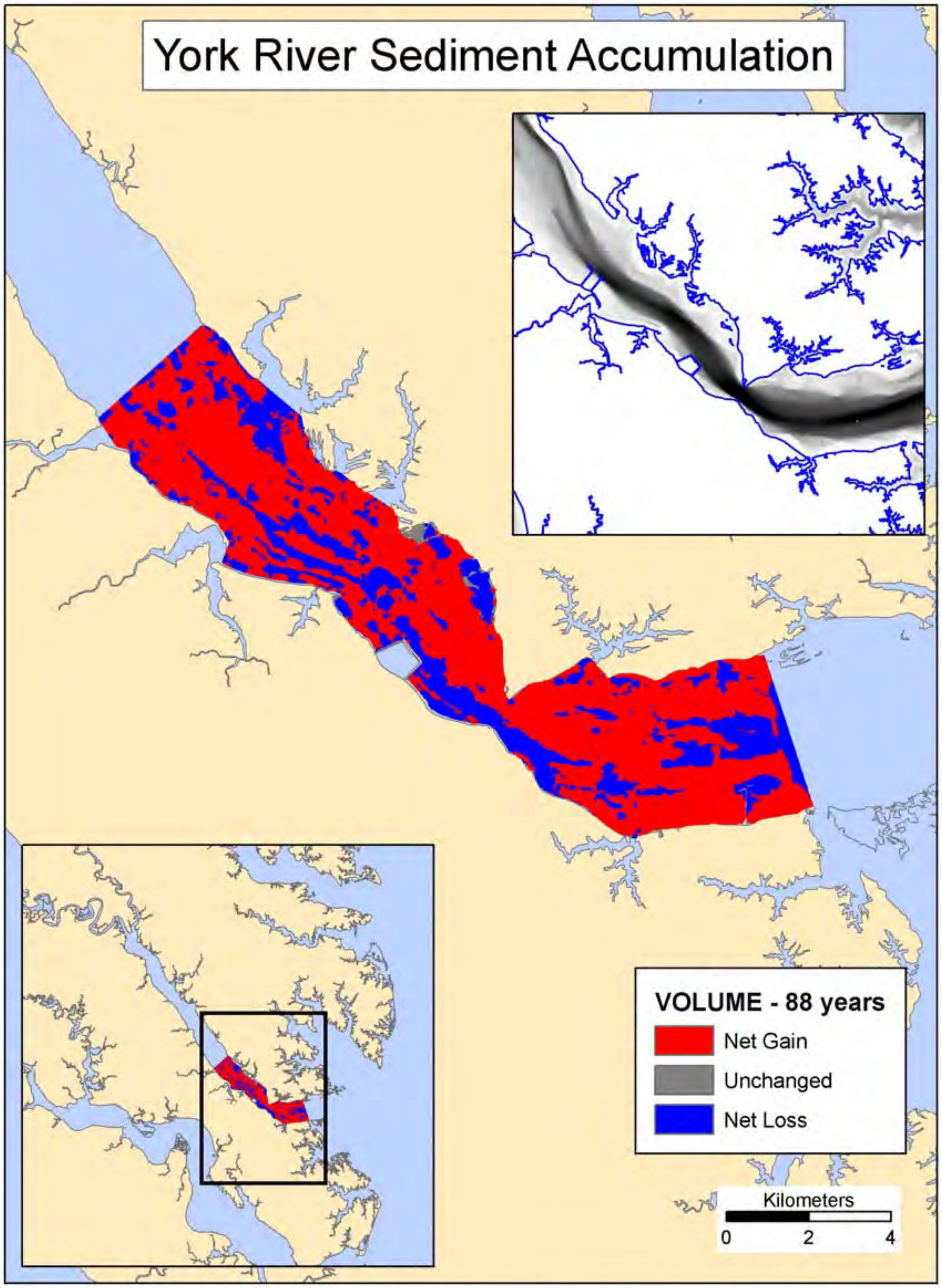


Figure 18. Estuarine sediment accumulation in the York River using TINs created with bathymetry from 1857 and 1945.

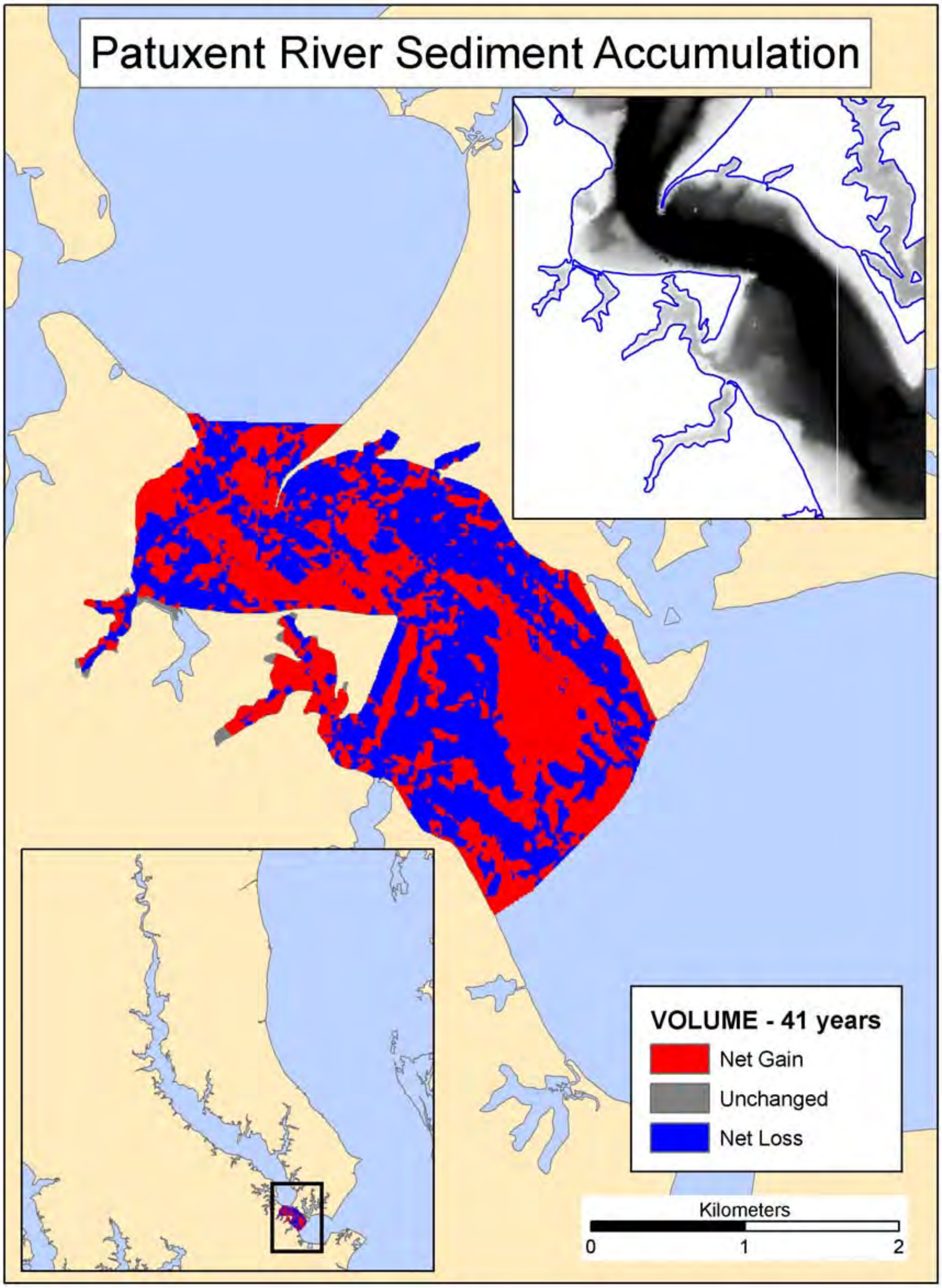


Figure 19. Estuarine sediment accumulation in the Patuxent River using TINs created with bathymetry from 1944 and 1985.

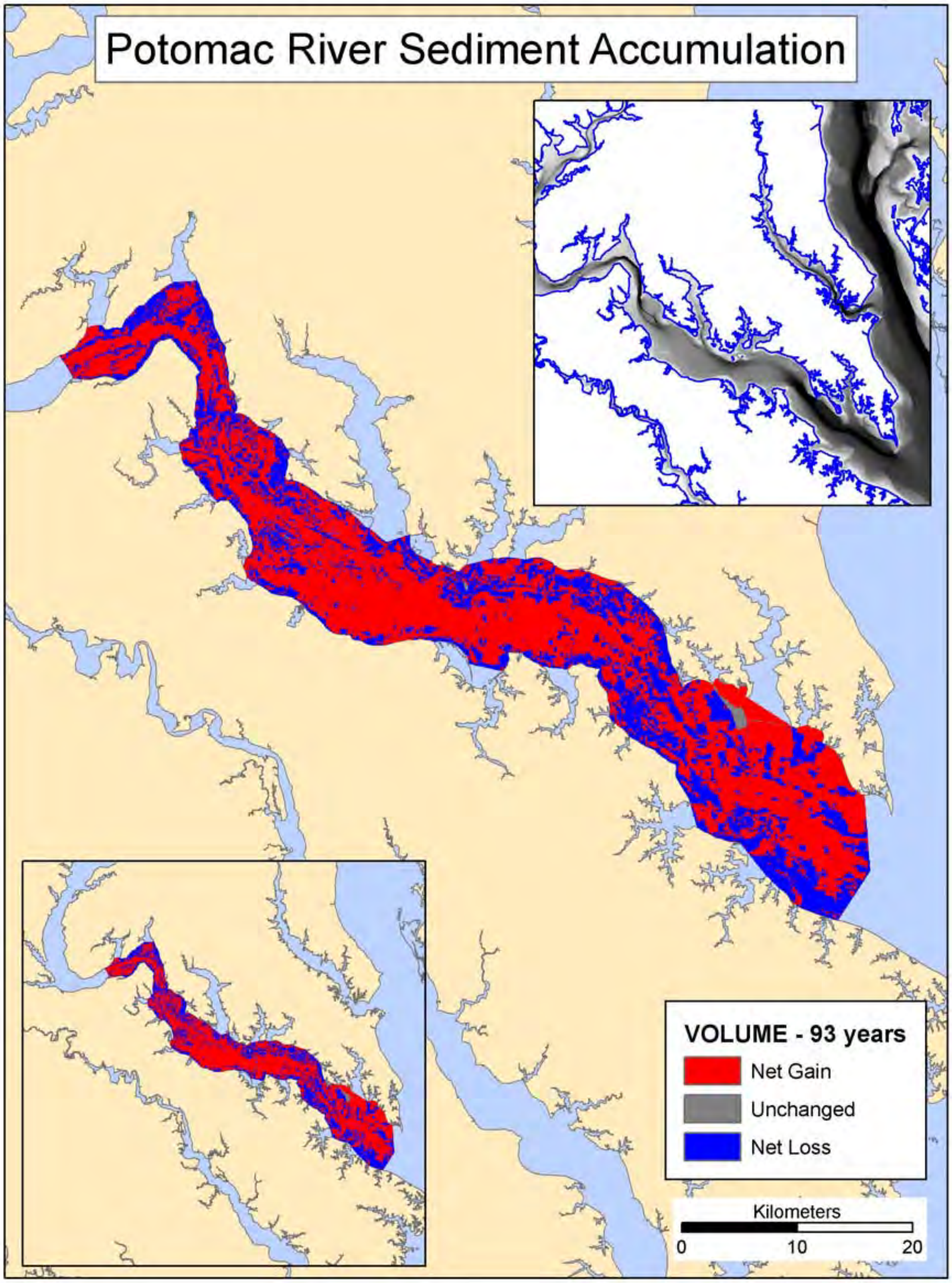


Figure 20. Estuarine sediment accumulation in the Potomac River using TINs created with bathymetry from 1862 and 1955.

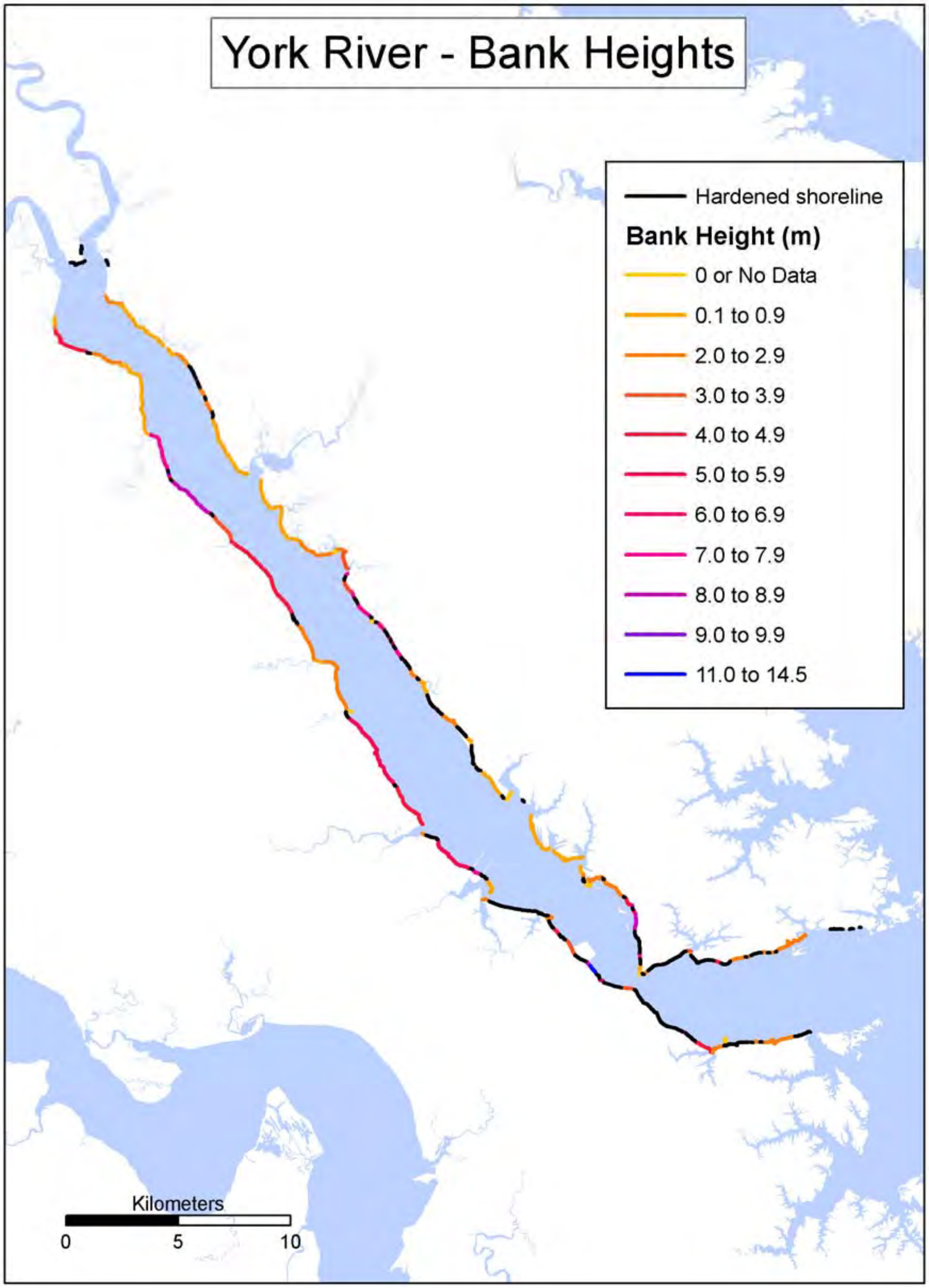


Figure 21. York River bank heights (meters) for reaches accessible to erosion (i.e. shoreline that is not hardened) using VBMP (2006-2007) data. Only mainstem reaches were used.

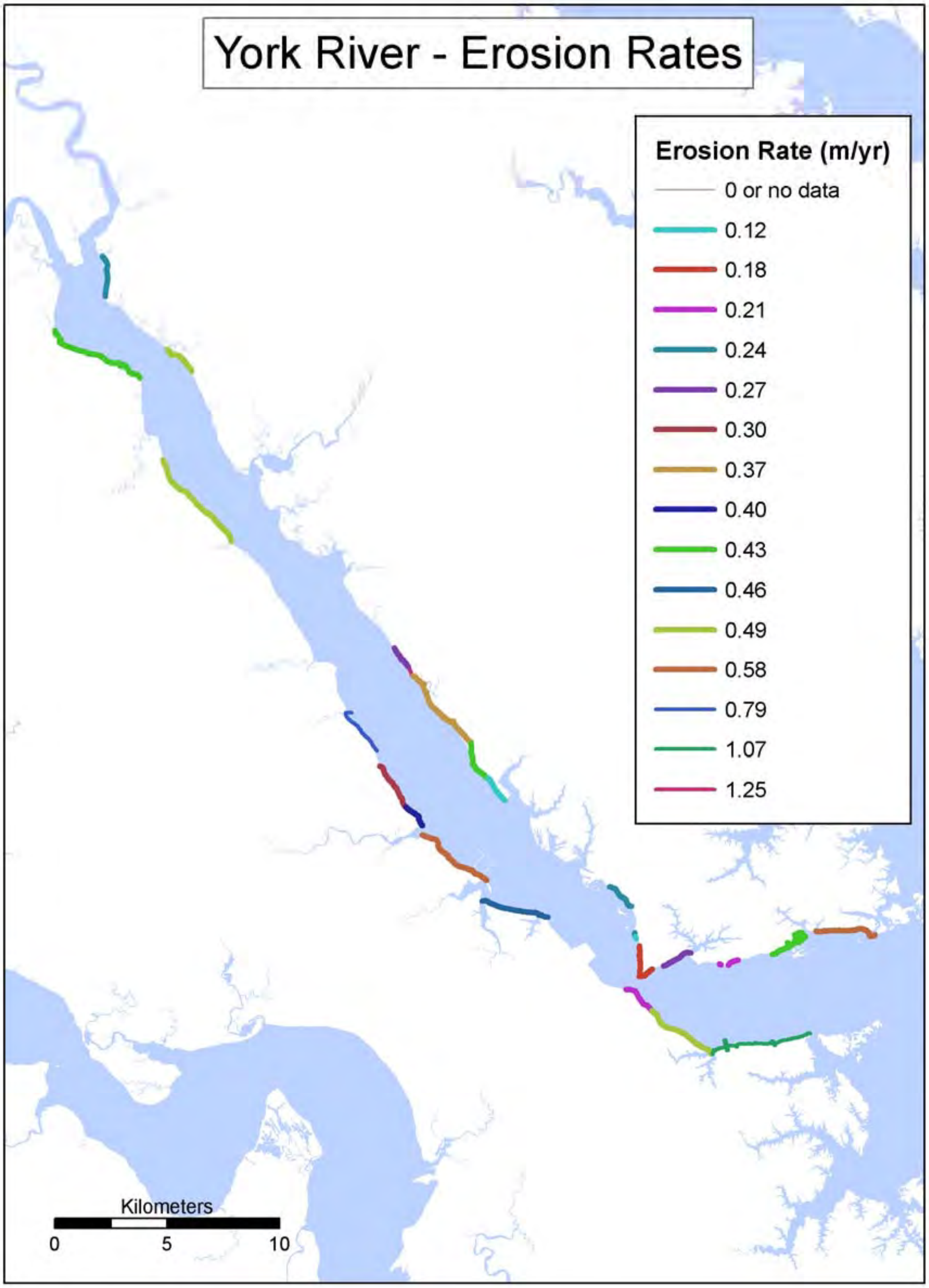


Figure 22. York River shoreline erosion rates (meters/year) using CBP analysis of Hardaway and others (1992). Only mainstem reaches were used.

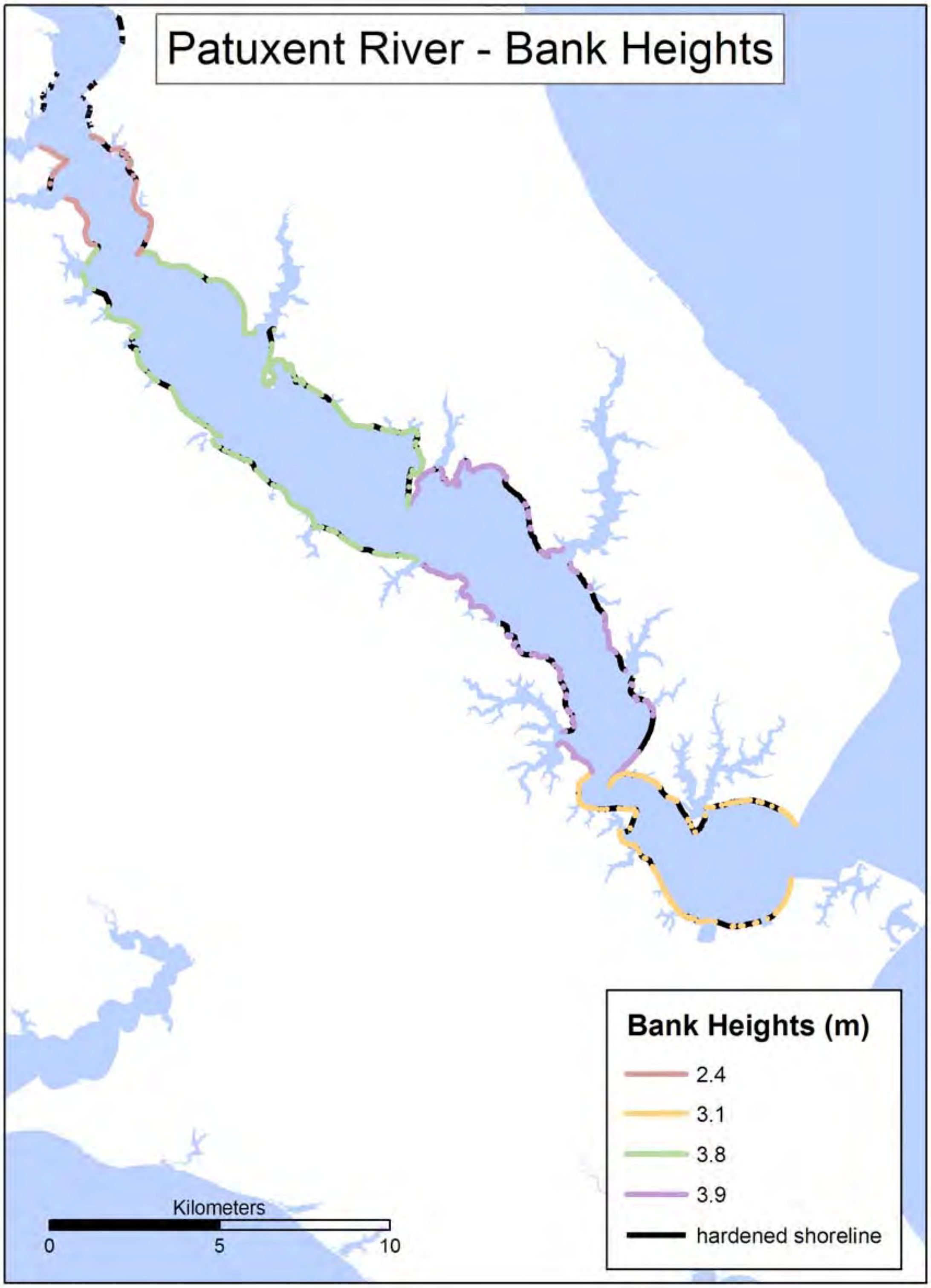


Figure 23. Patuxent River bank heights (meters) for reaches accessible to erosion (i.e. shoreline that is not hardened) using CBP analysis of Maryland Geological Survey data, and CCI shoreline inventory data. Only mainstem reaches were used.

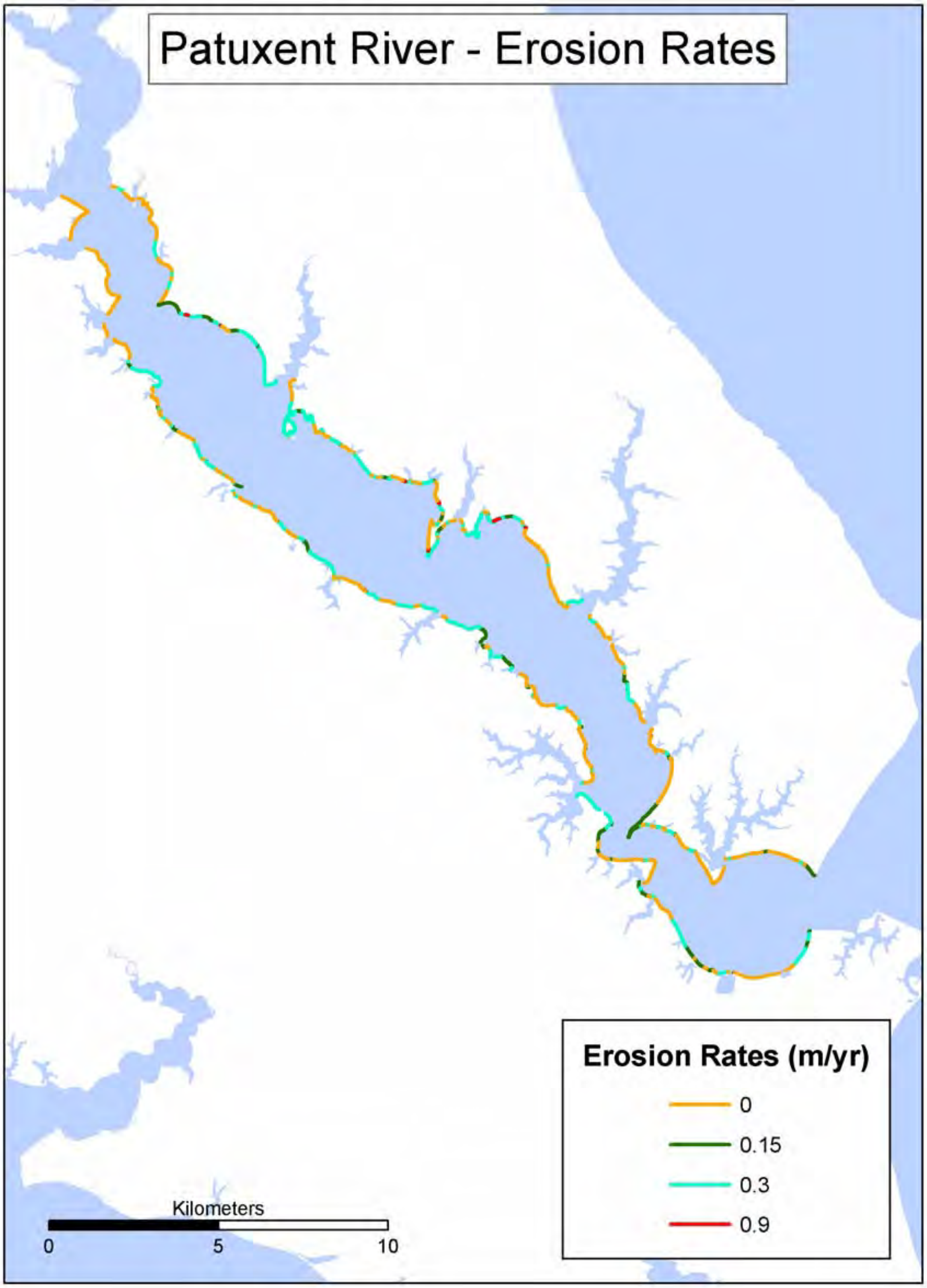


Figure 24. Patuxent River shoreline erosion rates (meters/year) using VIMS analysis of Maryland Geological Survey data and CCI shoreline inventories. Only mainstem reaches were used.

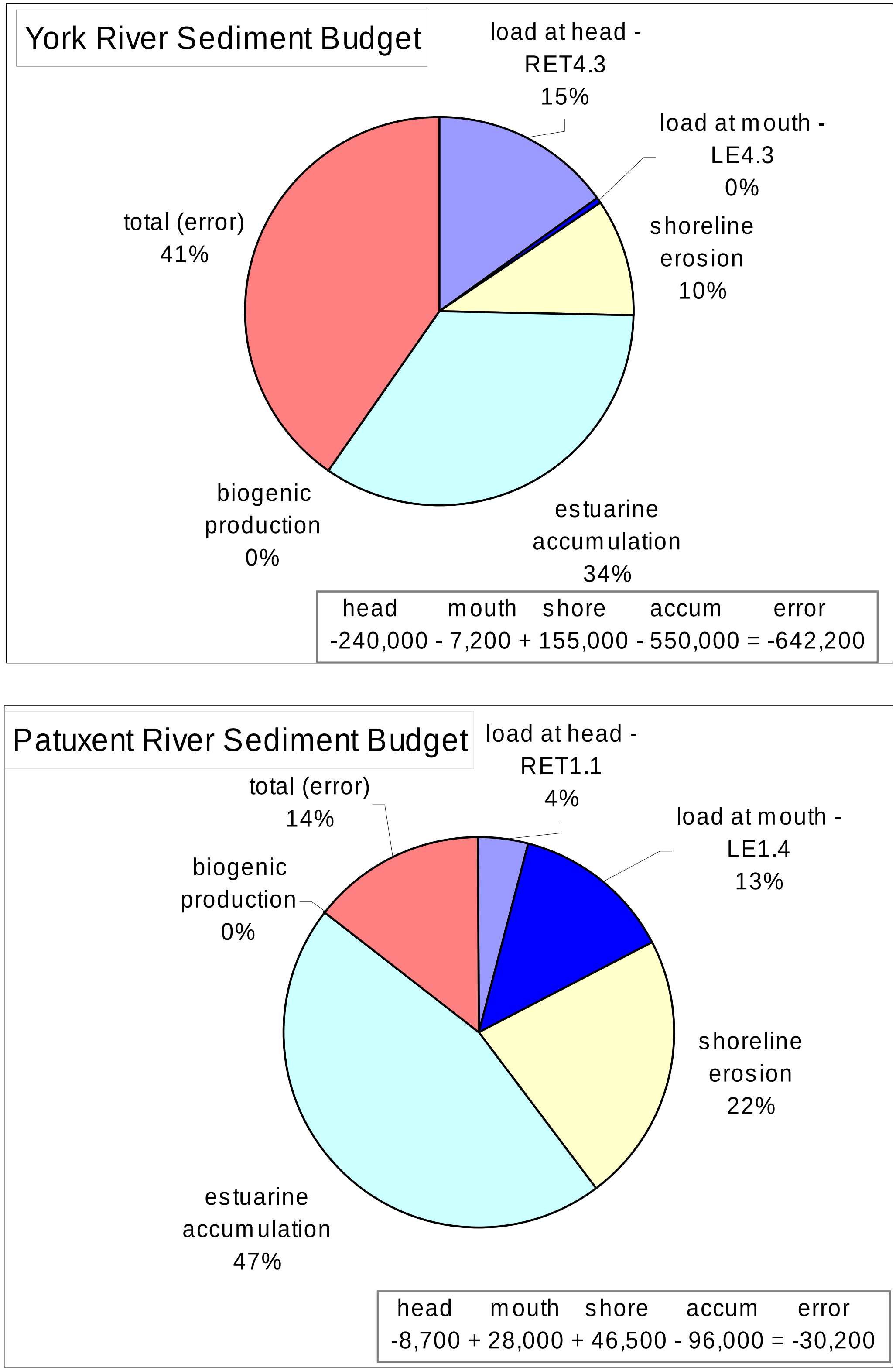


Figure 25. Sediment budgets for York and Patuxent Rivers—pie diagrams. Loads are in Mt/yr.

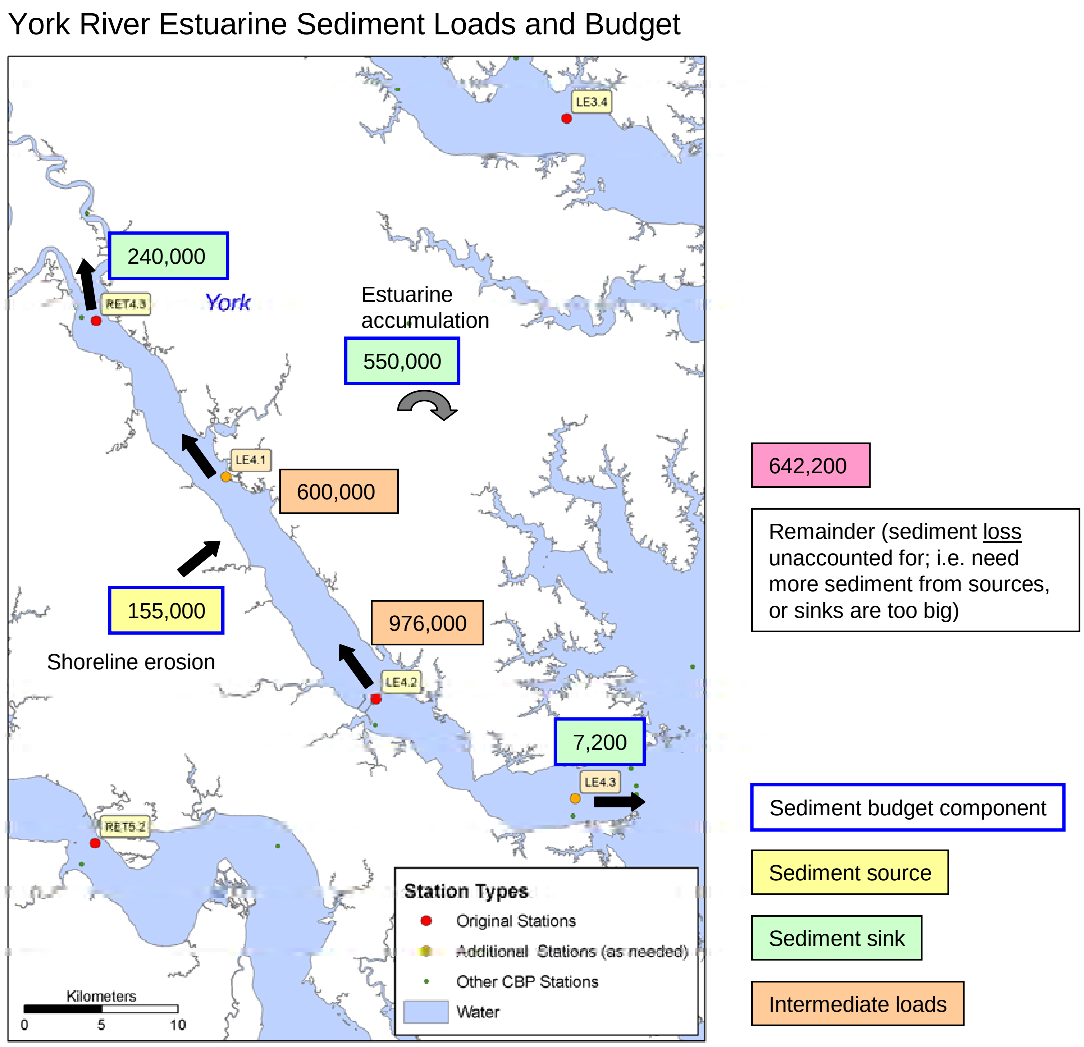


Figure 26. Sediment loads and budget for York River. Loads are in Mt/yr.

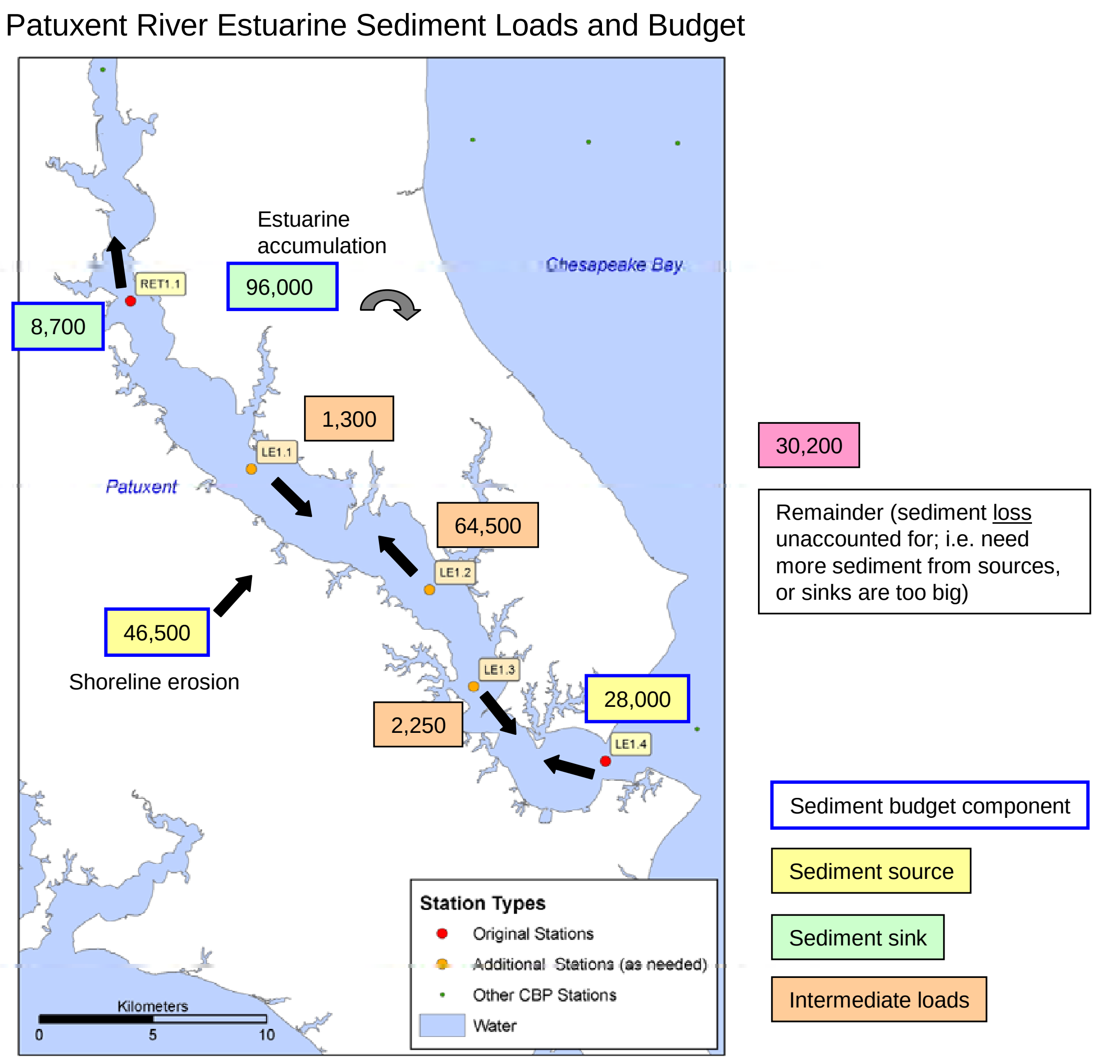


Figure 27. Sediment loads and budget for Patuxent River. Loads are in Mt/yr.

Potomac River Estuarine Sediment Loads

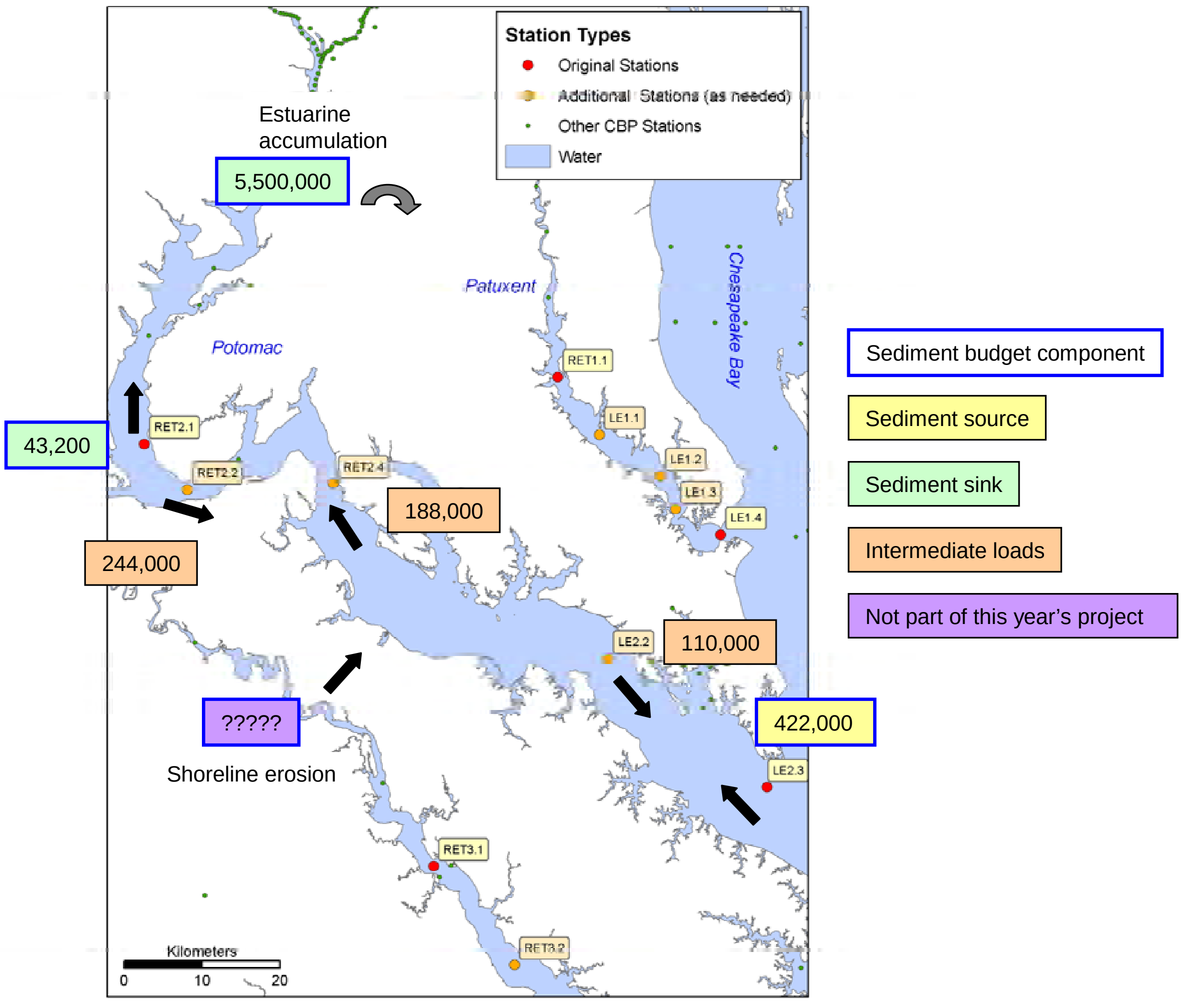


Figure 28. Sediment loads and partial budget for Potomac River. Loads are in Mt/yr.

York		In order from downstream to upstream										
LE4.3												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-1.404	0.139	0.260	0.050	-0.037	0.007	-1.181	0.148				
flood	2.288	0.316	0.592	0.103	-0.071	0.011	2.810	0.333				
Totals	0.442	0.173	0.426	0.057	-0.054	0.006	0.814	0.182	-4279	31.54	109888	24584
LE4.2												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-5.899	0.697	1.575	0.162	-0.133	0.031	-4.457	0.716				
flood	12.328	1.635	3.352	0.445	-0.359	0.125	15.321	1.699				
Totals	3.215	0.889	2.463	0.237	-0.246	0.064	5.432	0.922	-7409	31.54	1269187	215431
LE4.1												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-22.312	3.248	9.274	1.102	-0.509	0.131	-13.546	3.433				
flood	32.934	5.074	14.968	2.127	-1.244	0.325	46.658	5.512				
Totals	5.311	3.012	12.121	1.198	-0.877	0.175	16.556	3.247	-1618	31.54	844929	165691
RET4.3												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-6.898	0.762	2.191	0.254	-0.688	0.139	-5.394	0.815				
flood	9.055	1.067	2.907	0.350	-0.960	0.188	11.002	1.138				
Totals	1.079	0.655	2.549	0.216	-0.824	0.117	2.804	0.700	-2537	31.54	224298	55994

Table 1. Estuarine transport processes and sediment loads for the York River. For upper layers and totals, see next page. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

York															
LE4.3															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-1.207	0.117	0.009	0.030	-0.026	0.005	-1.224	0.121							
	0.945	0.125	-0.027	0.030	-0.028	0.008	0.891	0.129							
	-0.131	0.086	-0.009	0.021	-0.027	0.005	-0.167	0.088	-22251	31.54	-117095	61981	-7207	66679	925
LE4.2															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-4.926	0.460	-1.133	0.187	-0.105	0.049	-6.165	0.499							
	4.458	0.525	-1.127	0.154	-0.129	0.034	3.202	0.549							
	-0.234	0.349	-1.130	0.121	-0.117	0.030	-1.481	0.371	-6274	31.54	-293097	73327	976090	227568	23
LE4.1															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-10.632	0.829	-1.525	0.195	-0.219	0.033	-12.377	0.852							
	10.335	1.436	-0.895	0.247	-0.283	0.070	9.157	1.459							
	-0.148	0.829	-1.210	0.157	-0.251	0.039	-1.610	0.845	-4845	31.54	-245980	129106	598948	210052	35
RET4.3															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-4.495	0.344	0.330	0.107	-0.410	0.077	-4.575	0.368							
	5.056	0.635	0.385	0.155	-0.485	0.108	4.956	0.663							
	0.281	0.361	0.358	0.094	-0.448	0.066	0.191	0.379	-2537	31.54	15240	30325	239538	63679	27
												AVERAGE	451842	80781	18

Table 1—continued. Estuarine transport processes and sediment loads for the York River. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

Patuxent		In order from downstream to upstream										
LE1.4												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-0.151	0.007	0.052	0.011	-0.013	0.001	-0.112	0.013				
flood	0.158	0.023	-0.021	0.029	-0.012	0.002	0.124	0.037				
Totals	0.003	0.012	0.016	0.016	-0.013	0.001	0.006	0.020	-9496	31.54	1835	5903
LE1.3												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-0.420	0.021	0.151	0.022	-0.015	0.002	-0.285	0.031				
flood	0.367	0.043	0.087	0.053	-0.017	0.002	0.437	0.068				
Totals	-0.027	0.024	0.119	0.029	-0.016	0.001	0.076	0.037	-10663	31.54	25488	12541
LE1.2												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-1.176	0.170	0.493	0.139	-0.017	0.002	-0.700	0.220				
flood	0.915	0.108	0.010	0.155	-0.015	0.002	0.910	0.189				
Totals	-0.130	0.101	0.251	0.104	-0.016	0.001	0.105	0.145	-6595	31.54	21815	30127
LE1.1												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-0.542	0.031	0.122	0.030	-0.026	0.004	-0.446	0.043				
flood	0.572	0.055	0.127	0.035	-0.034	0.004	0.665	0.065				
Totals	0.015	0.032	0.125	0.023	-0.030	0.003	0.110	0.039	-8185	31.54	28276	10098
RET1.1												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-1.286	0.105	0.953	0.058	-0.083	0.008	-0.417	0.121				
flood	1.444	0.126	1.094	0.061	-0.130	0.014	2.408	0.140				
Totals	0.079	0.082	1.024	0.042	-0.107	0.008	0.996	0.093	-2379	31.54	74728	6948

Table 2. Estuarine transport processes and sediment loads for the Patuxent River. For upper layers and totals, see next page. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

Patuxent															
LE1.4															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-0.507	0.018	0.078	0.010	-0.010	0.001	-0.440	0.020							
	0.485	0.079	0.140	0.061	-0.011	0.002	0.615	0.100							
	-0.011	0.040	0.109	0.031	-0.011	0.001	0.087	0.051	-9496	31.54	26174	15210	28009	16315	58
LE1.3															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-0.875	0.034	-0.087	0.020	-0.011	0.001	-0.973	0.040							
	0.960	0.179	-0.203	0.070	-0.016	0.003	0.741	0.192							
	0.042	0.091	-0.145	0.036	-0.013	0.001	-0.116	0.098	-7581	31.54	-27738	23494	-2250	26632	1183
LE1.2															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-0.802	0.033	0.052	0.025	-0.012	0.001	-0.762	0.041							
	0.993	0.252	0.199	0.193	-0.020	0.004	1.172	0.318							
	0.095	0.127	0.125	0.097	-0.016	0.002	0.205	0.160	-6595	31.54	42662	33303	64477	44908	70
LE1.1															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-0.867	0.033	-0.198	0.041	-0.021	0.002	-1.086	0.052							
	0.790	0.138	-0.342	0.185	-0.021	0.005	0.427	0.231							
	-0.039	0.071	-0.270	0.095	-0.021	0.003	-0.330	0.118	-2845	31.54	-29576	10621	-1300	14655	1128
RET1.1															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-1.341	0.056	-0.631	0.051	-0.081	0.007	-2.053	0.076							
	1.145	0.131	-0.538	0.054	-0.065	0.007	0.542	0.142							
	-0.098	0.071	-0.584	0.037	-0.073	0.005	-0.756	0.081	-2771	31.54	-66025	7034	8702	9887	114
												AVERAGE	19528	11497	59

Table 2—continued. Estuarine transport processes and sediment loads for the Patuxent River. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

Potomac		In order from downstream to upstream										
LE2.3												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-0.886	0.087	0.413	0.097	-0.036	0.005	-0.509	0.130				
flood	1.054	0.081	0.443	0.157	-0.054	0.006	1.443	0.177				
Totals	0.084	0.059	0.428	0.092	-0.045	0.004	0.467	0.110	-60718	31.54	894440	210569
LE2.2												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-0.711	0.082	0.394	0.058	-0.140	0.021	-0.457	0.103				
flood	0.726	0.076	0.476	0.091	-0.225	0.062	0.977	0.133				
Totals	0.007	0.056	0.435	0.054	-0.182	0.033	0.260	0.084	-33291	31.54	273052	88411
RET2.4												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-2.431	0.248	1.404	0.413	-1.048	0.378	-2.076	0.612				
flood	3.596	0.349	1.800	0.278	-1.305	0.236	4.091	0.504				
Totals	0.582	0.214	1.602	0.249	-1.176	0.223	1.008	0.396	-15237	31.54	484240	190514
RET2.2												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-10.138	0.948	4.118	1.252	-2.766	0.764	-8.786	1.747				
flood	15.469	1.137	5.679	0.541	-2.565	0.271	18.583	1.288				
Totals	2.666	0.740	4.898	0.682	-2.666	0.405	4.899	1.085	-1908	31.54	294706	65282
RET2.1												
lower layer	tidal transport	SE	gravitational transport	SE	river transport	SE	lower transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	lower load (Mt/yr)	lower SE
ebb	-9.508	0.937	2.475	1.409	-2.164	0.922	-9.196	1.927				
flood	11.776	0.732	1.977	0.304	-1.166	0.123	12.587	0.802				
Totals	1.134	0.595	2.226	0.721	-1.665	0.465	1.695	1.044	-6621	31.54	353943	217952

Table 3. Estuarine transport processes and sediment loads for the Potomac River. For upper layers and totals, see next page. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

Potomac															
LE2.3															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-0.831	0.061	-0.078	0.084	-0.022	0.004	-0.931	0.104							
	0.875	0.073	-0.528	0.113	-0.024	0.002	0.324	0.135							
	0.022	0.048	-0.303	0.071	-0.023	0.002	-0.303	0.085	-49365	31.54	-472402	132569	422038	248824	59
LE2.2															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-1.433	0.146	-0.294	0.195	-0.093	0.020	-1.820	0.244							
	1.497	0.100	-0.806	0.151	-0.078	0.009	0.613	0.181							
	0.032	0.088	-0.550	0.123	-0.086	0.011	-0.604	0.152	-20100	31.54	-382677	96341	-109625	130760	119
RET2.4															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-3.059	0.572	-1.965	0.908	-0.582	0.232	-5.606	1.098							
	2.995	0.232	-1.826	0.237	-0.422	0.072	0.747	0.339							
	-0.032	0.309	-1.895	0.469	-0.502	0.122	-2.429	0.574	-3867	31.54	-296246	70054	187995	202986	108
RET2.2															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-5.793	0.517	-0.110	0.755	-1.340	0.432	-7.243	1.012							
	5.262	0.375	0.001	0.244	-0.895	0.121	4.368	0.464							
	-0.265	0.319	-0.055	0.397	-1.117	0.224	-1.438	0.557	-11882	31.54	-538650	208553	-243944	218532	90
RET2.1															
upper layer	tidal transport	SE	gravitational transport	SE	river transport	SE	upper transport (g/m2/s)	SE	cross-sectional area (m2)	conversion (g/s to Mt/yr)	upper load (Mt/yr)	upper SE	TOTAL LOAD (Mt/yr)	TOTAL SE	% error
	-4.419	0.402	-0.498	0.533	-0.855	0.240	-5.772	0.710							
	5.294	0.342	-0.478	0.197	-0.700	0.091	4.115	0.405							
	0.438	0.264	-0.488	0.284	-0.778	0.129	-0.828	0.409	-11893	31.54	-310707	153213	43236	266416	616
												AVERAGE	59940	97765	163

Table 3—continued. Estuarine transport processes and sediment loads for the Potomac River. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

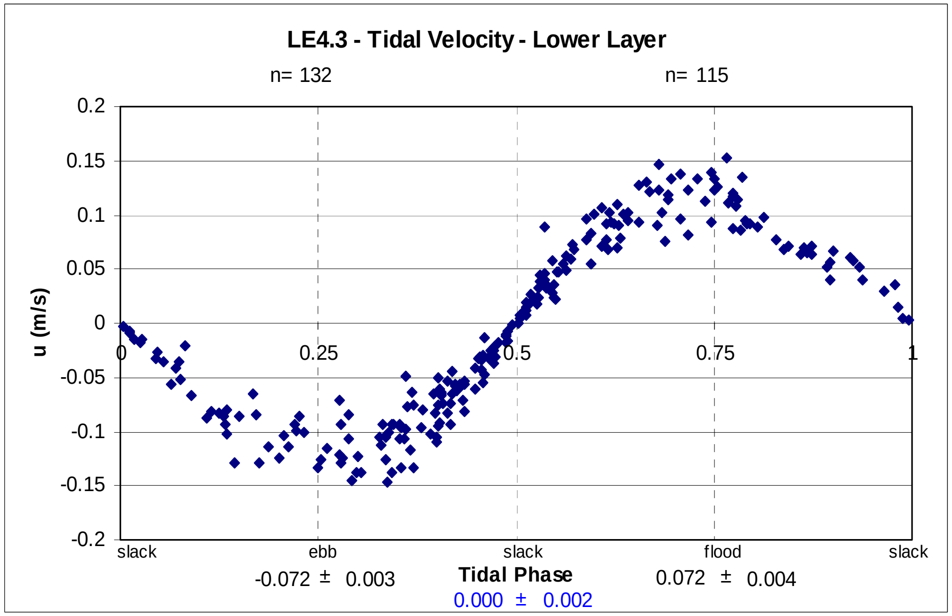
Sediment Loads in Mt/yr	**load at head**	**shoreline erosion**	**estuarine accumulation**	**in situ biogenic production**	**load at mouth**
York River					
This study	-239,538			0	-7,207
CBP		97,894			
VBMP		154,478			
Bulk density (1.33) - Halka, pers. comm.			-689,126		
Specific gravity (2.65) and 60% water content			-549,228		
Patuxent River					
This study	-8,702			0	28,009
CBP/MGS		29,322			
Lidar		34,694			
MGS/VIMS		46,467			
Bulk density (1.33) - Halka, pers. comm.			-120,398		
Specific gravity (2.65) and 60% water content			-95,957		
Anderson, 1982				200	
Potomac River					
This study	-43,236			0	422,038
Bulk density (1.33) - Halka, pers. comm.			-6,920,948		
Specific gravity (2.65) and 60% water content			-5,515,943		
Cronin and others, 2003b			-2,574,161		
Cronin and others, 2003b			-657,891		

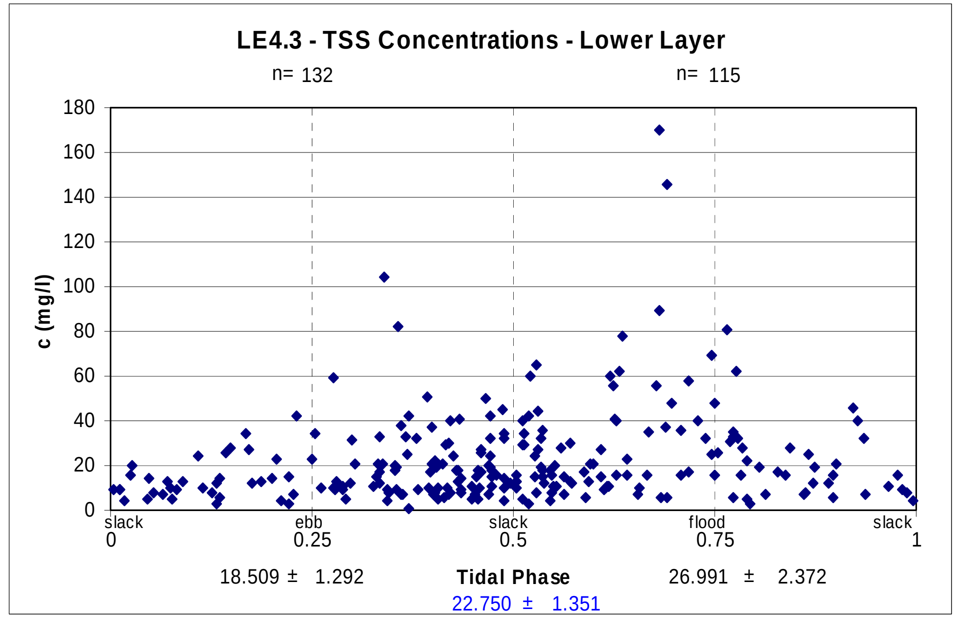
positive = source
negative = sink

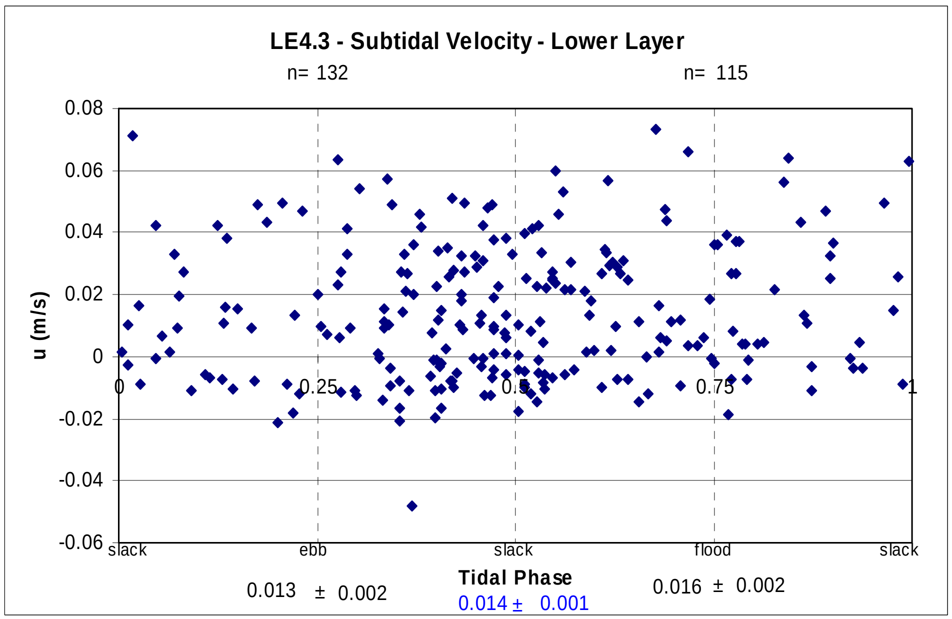
Table 4. Sediment loads in Mt/yr. Where possible, more than one load was calculated for each component for comparison. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

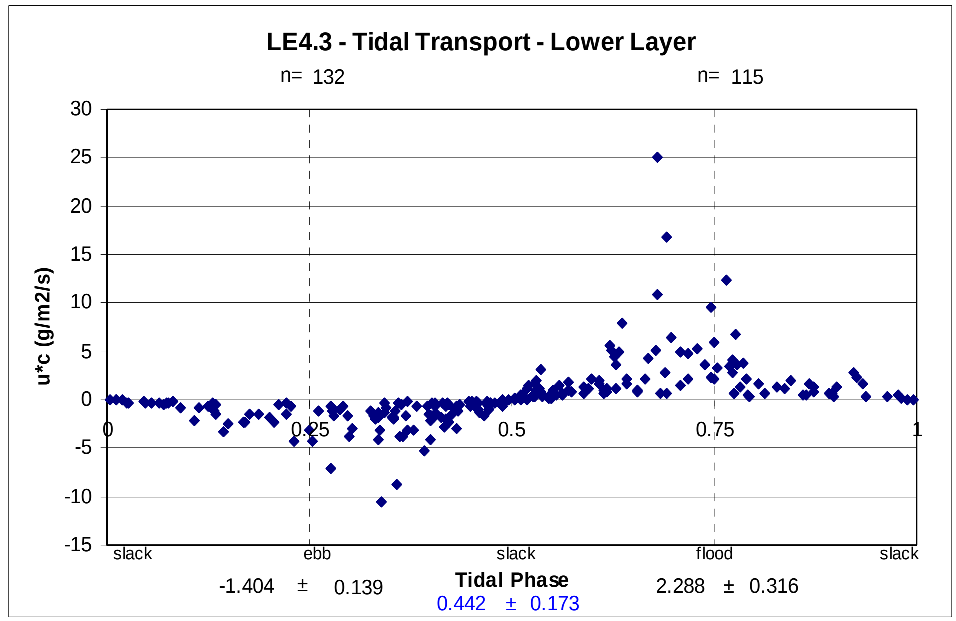
Appendix 1

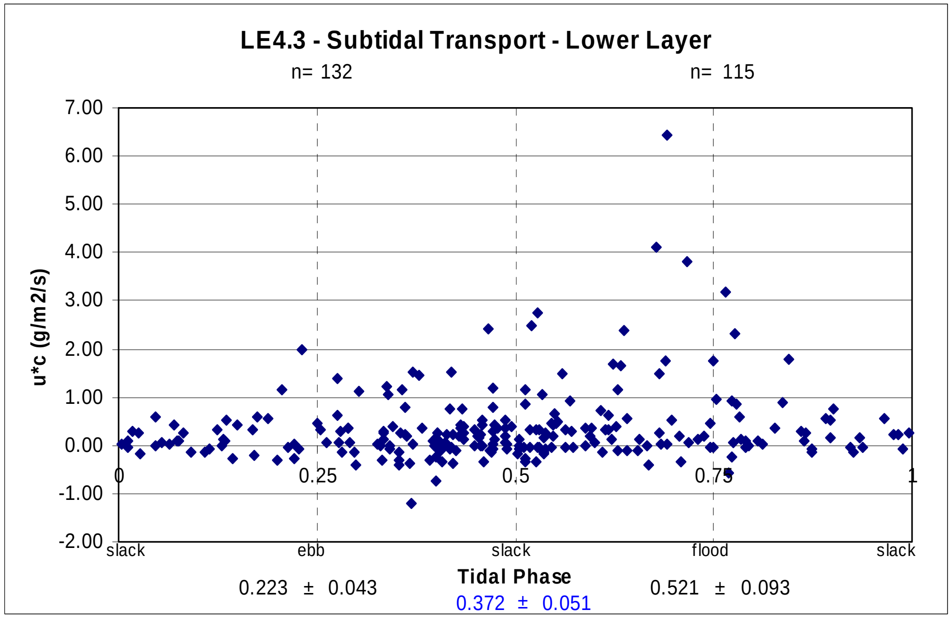
Graphs of TSS concentrations, tidal velocities and transport, subtidal velocities and transport, and river velocities and transport for upper and lower layers for all water quality monitoring stations. Each graph contains the sampling data from 1985-2005 plotted over a single tidal phase. n = number of samples. Values in black below the ebb and flood phases are means and standard errors for that phase. Values in blue at the bottom of each graph are the total means and standard errors for that layer. An arbitrary assignment was made of a negative sign to ebb-directed tidal phases and a positive sign to flood-directed tidal phases. When applying the results of this study, it is recommended that all values be rounded to two significant figures.

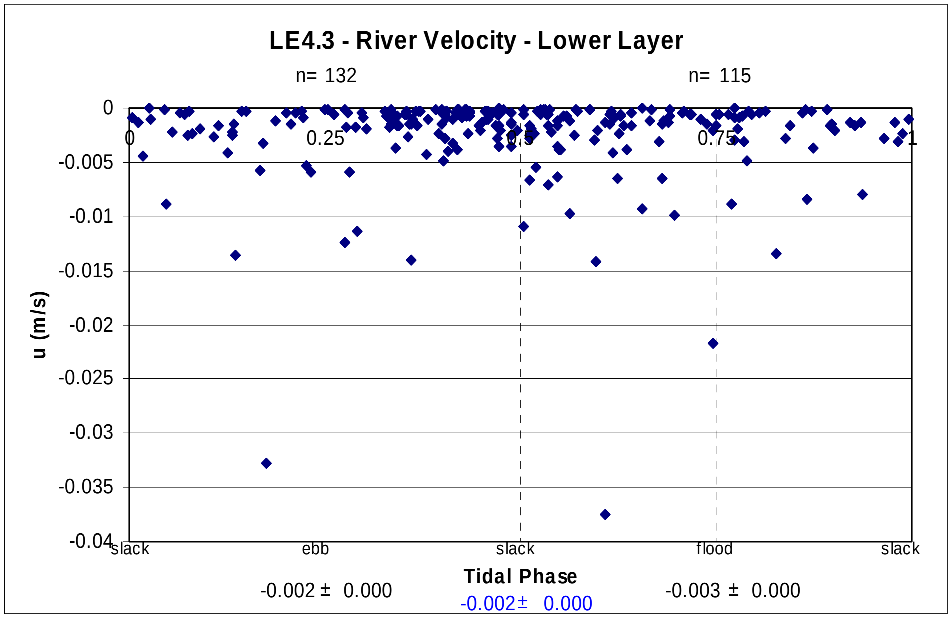

LE4.3 - Tidal Velocity - Lower Layer
n= 132
n= 115
u (m/s)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.072 ± 0.003
Tidal Phase
0.072 ± 0.004
0.000 ± 0.002

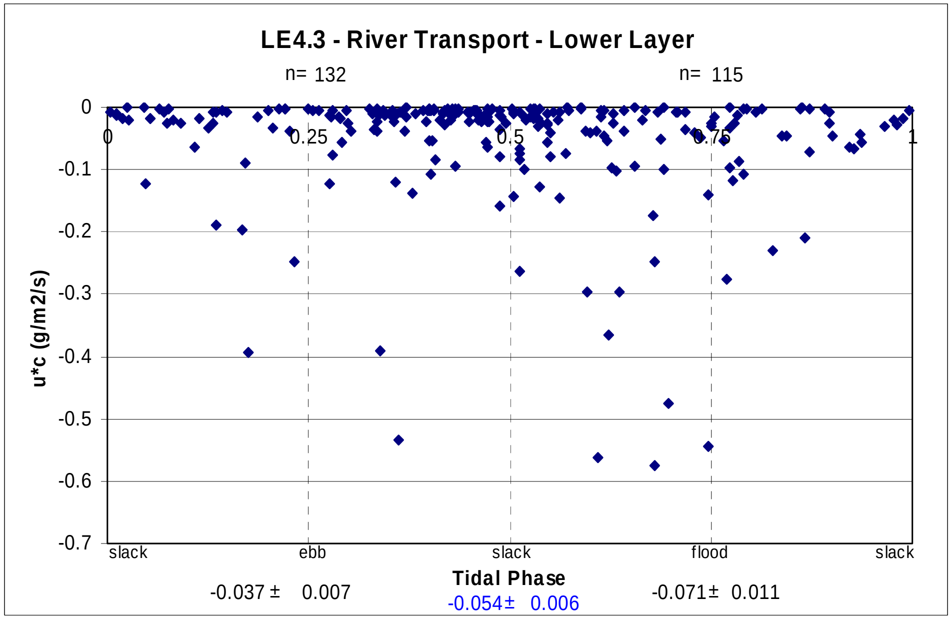

LE4.3 - TSS Concentrations - Lower Layer
n= 132
n= 115
c (mg/l)
180
160
140
120
100
80
60
40
20
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
18.509 ± 1.292
Tidal Phase
26.991 ± 2.372
22.750 ± 1.351

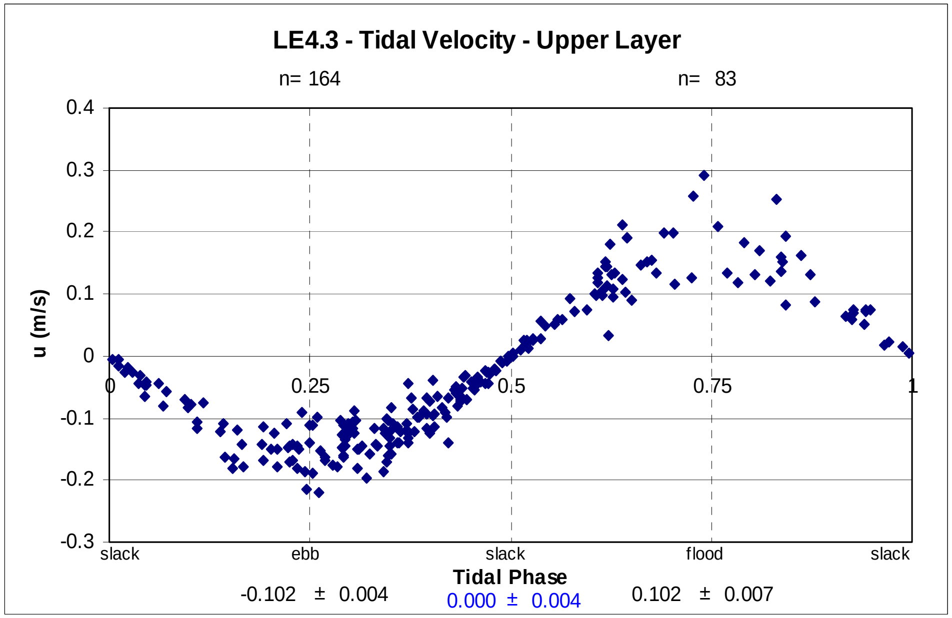

LE4.3 - Subtidal Velocity - Lower Layer
n= 132
n= 115
u (m/s)
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.013 ± 0.002
Tidal Phase
0.016 ± 0.002
0.014 ± 0.001

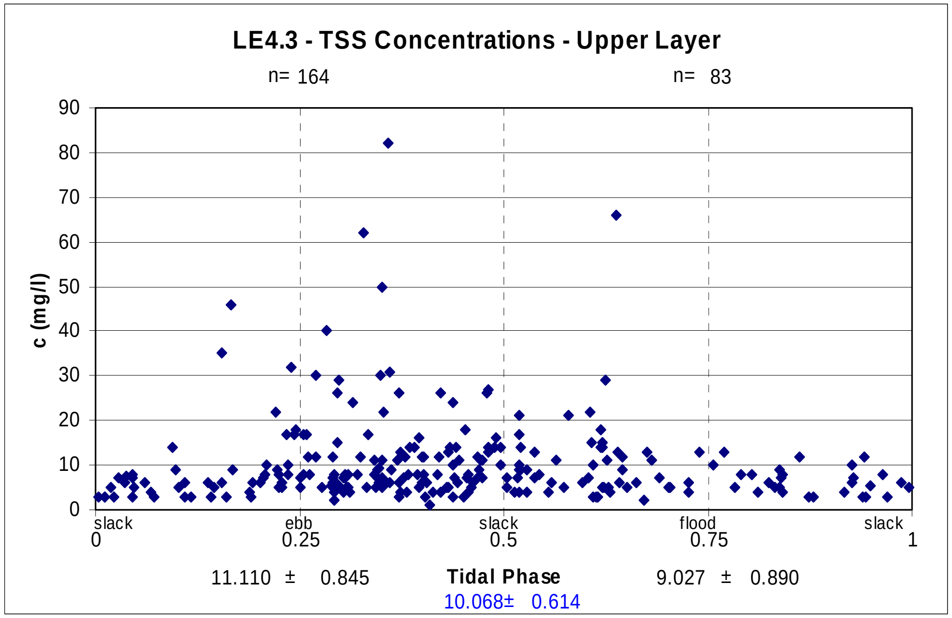

LE4.3 - Tidal Transport - Lower Layer
n= 132
n= 115
u*c (g/m2/s)
30
25
20
15
10
5
0
-5
-10
-15
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-1.404 ± 0.139
Tidal Phase
2.288 ± 0.316
0.442 ± 0.173

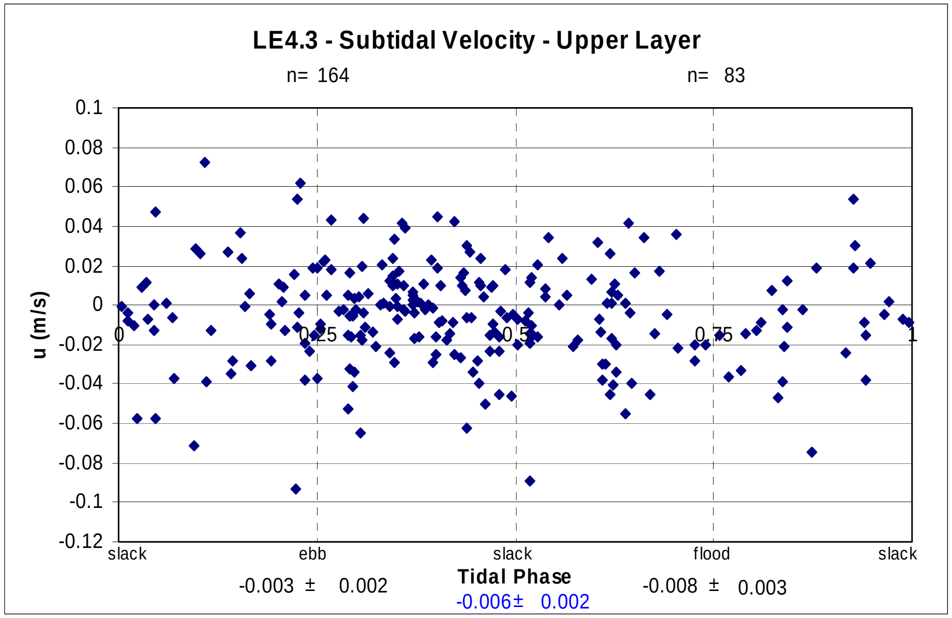

LE4.3 - Subtidal Transport - Lower Layer
n= 132
n= 115
u*c (g/m2/s)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.223 ± 0.043
0.372 ± 0.051
0.521 ± 0.093

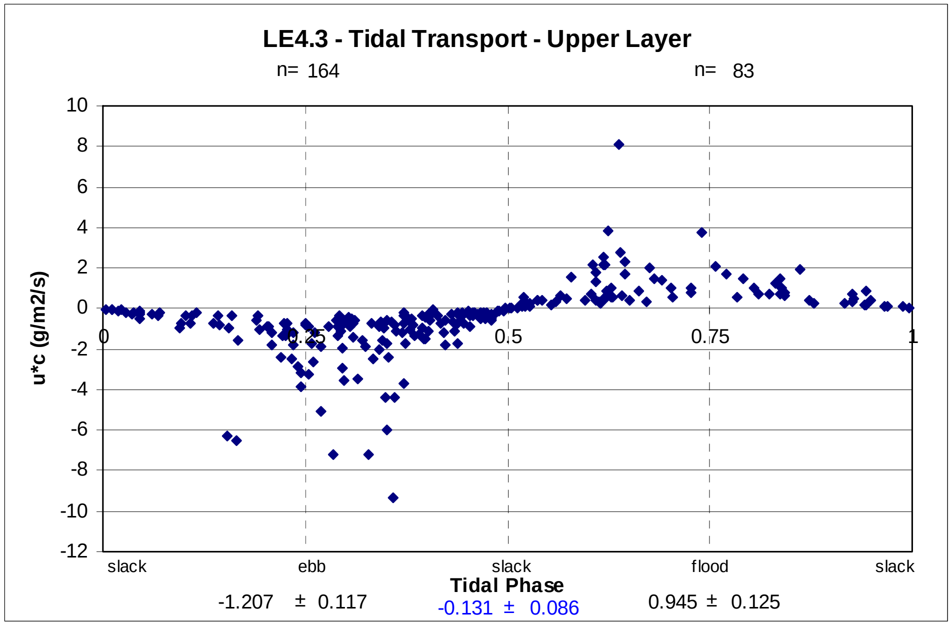

LE4.3 - River Velocity - Lower Layer
n= 132
n= 115
u (m/s)
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.002 ± 0.000
-0.002± 0.000
-0.003 ± 0.000

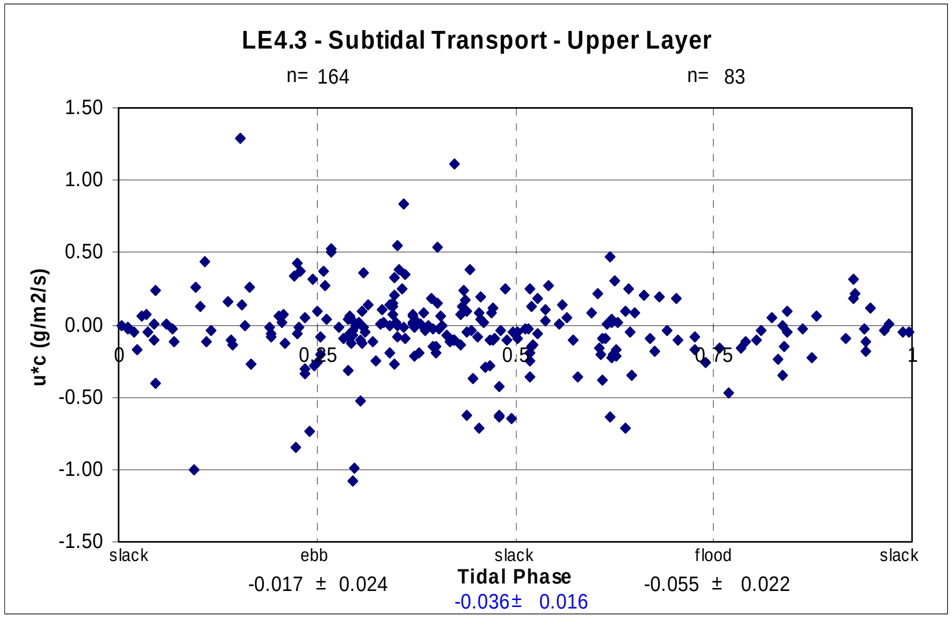

LE4.3 - River Transport - Lower Layer
n= 132
n= 115
u*c (g/m2/s)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.037 ± 0.007
-0.054± 0.006
-0.071± 0.011


LE4.3 - Tidal Velocity - Upper Layer
n= 164
n= 83
u (m/s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.102 ± 0.004
0.000 ± 0.004
0.102 ± 0.007

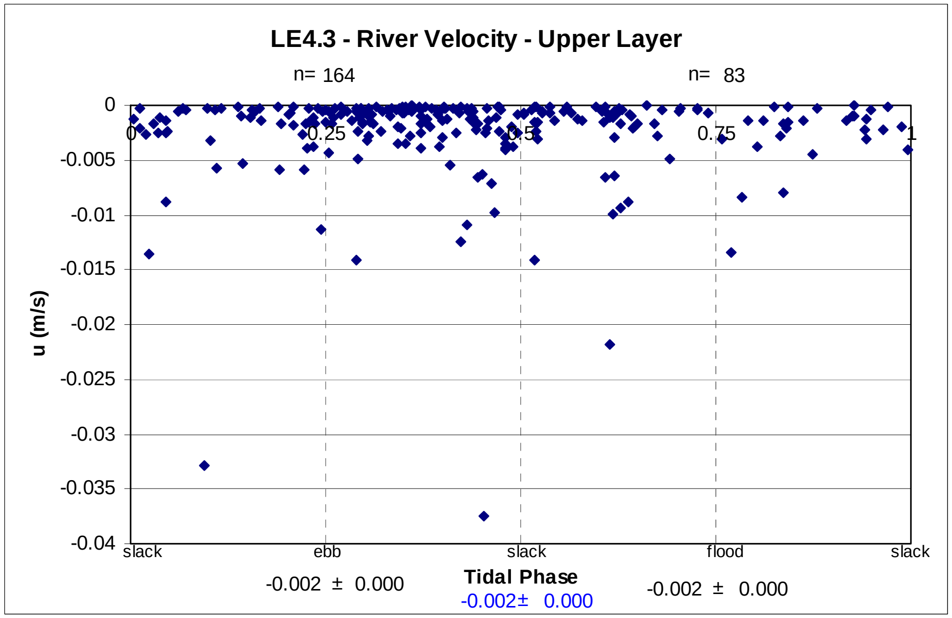

LE4.3 - TSS Concentrations - Upper Layer
n= 164
n= 83
c (mg/l)
90
80
70
60
50
40
30
20
10
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
11.110 ± 0.845
Tidal Phase
10.068± 0.614
9.027 ± 0.890


LE4.3 - Subtidal Velocity - Upper Layer
n= 164
n= 83
u (m/s)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.003 ± 0.002
-0.006± 0.002
-0.008 ± 0.003

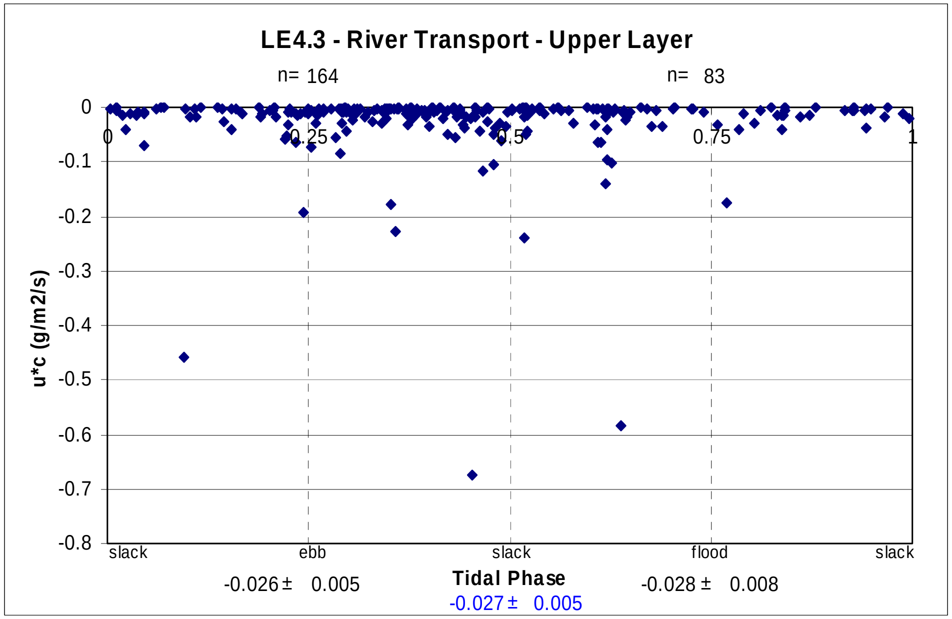

LE4.3 - Tidal Transport - Upper Layer
n= 164
n= 83
u*c (g/m2/s)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.207 ± 0.117
-0.131 ± 0.086
0.945 ± 0.125



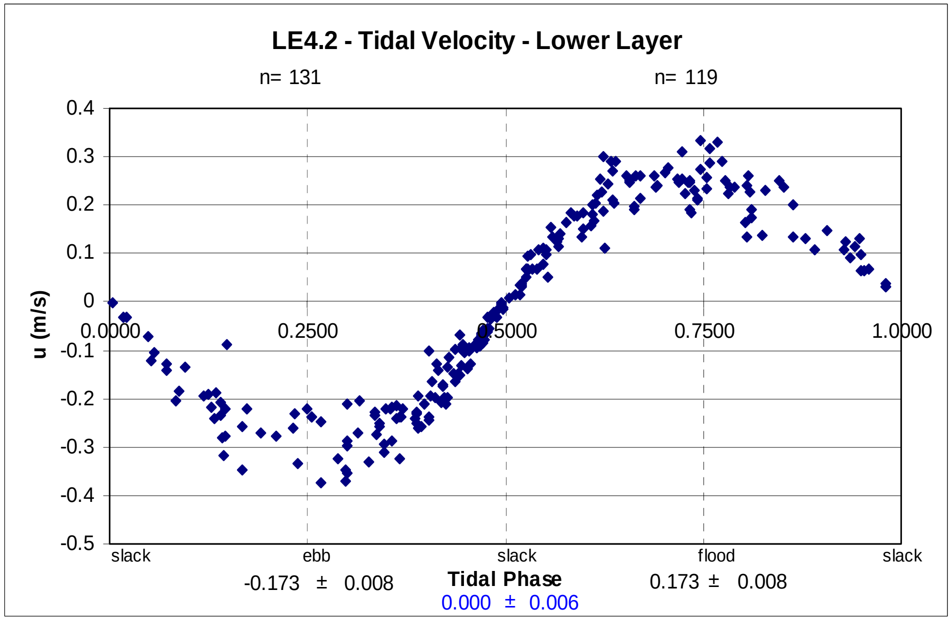
LE4.3 - Subtidal Transport - Upper Layer
n= 164
n= 83
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.017 ± 0.024
Tidal Phase
-0.036± 0.016
-0.055 ± 0.022

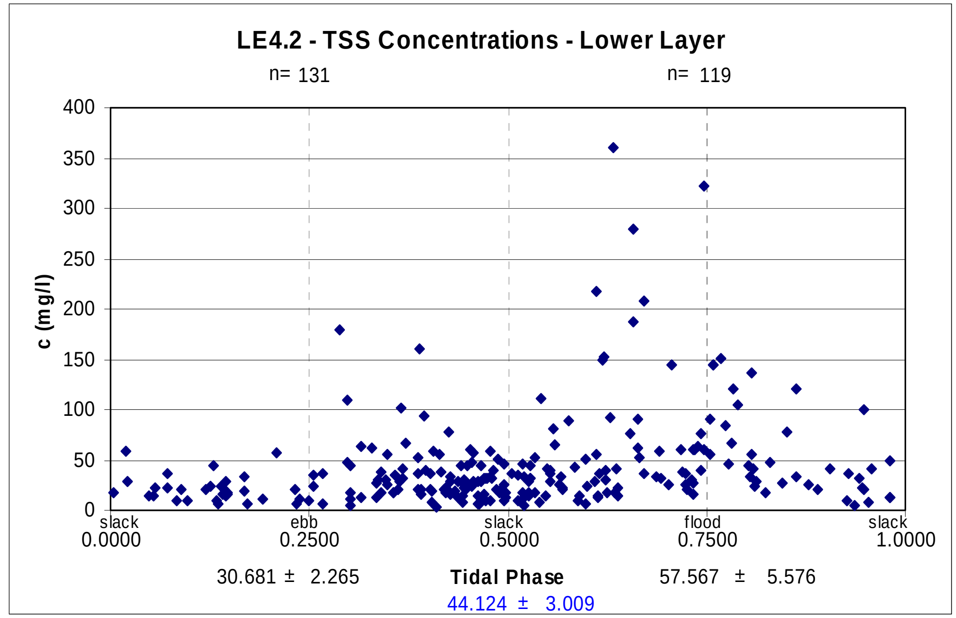


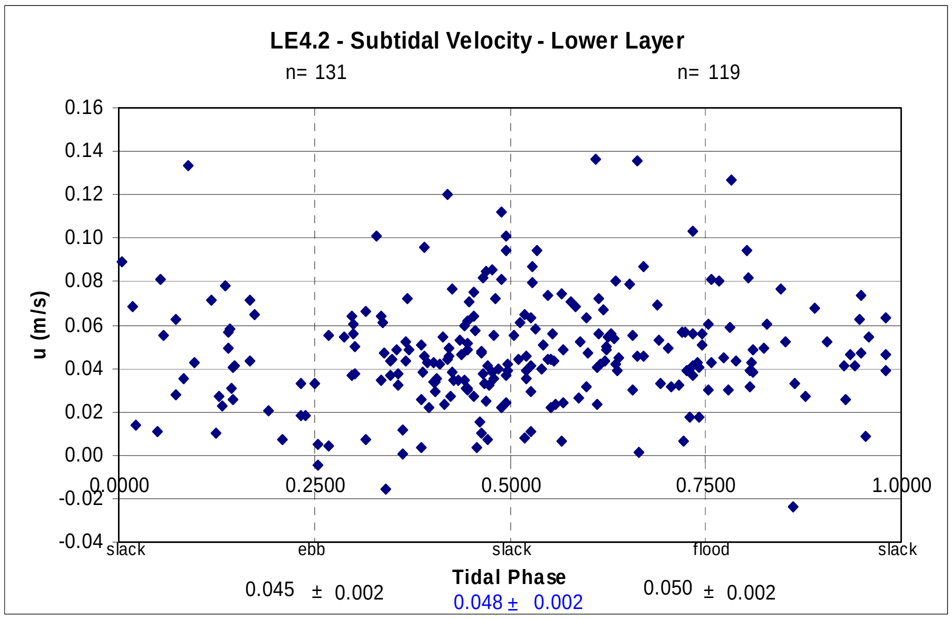
LE4.3 - River Velocity - Upper Layer
n= 164
n= 83
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.002 ± 0.000
Tidal Phase
-0.002± 0.000
-0.002 ± 0.000

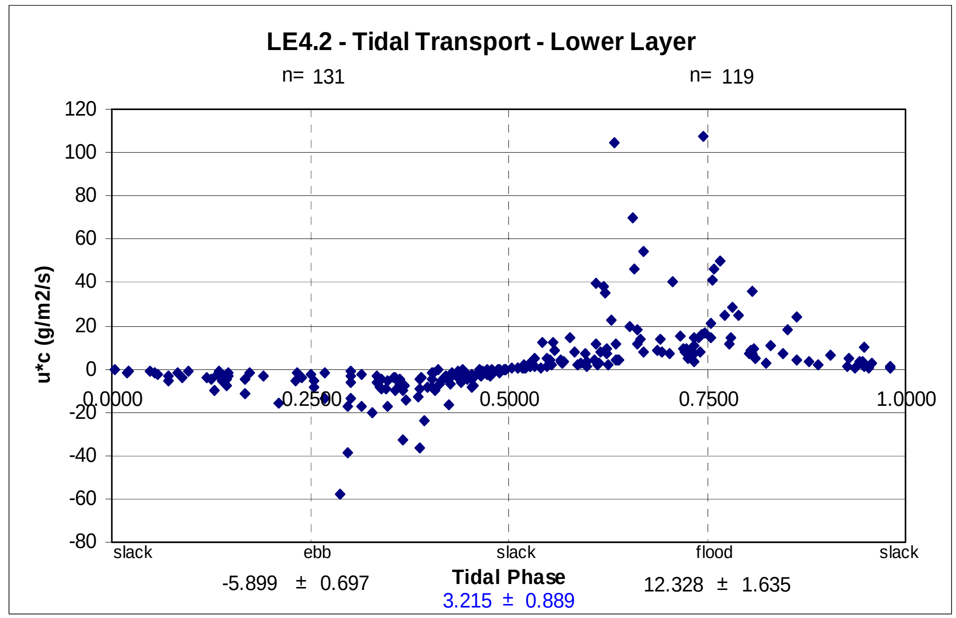


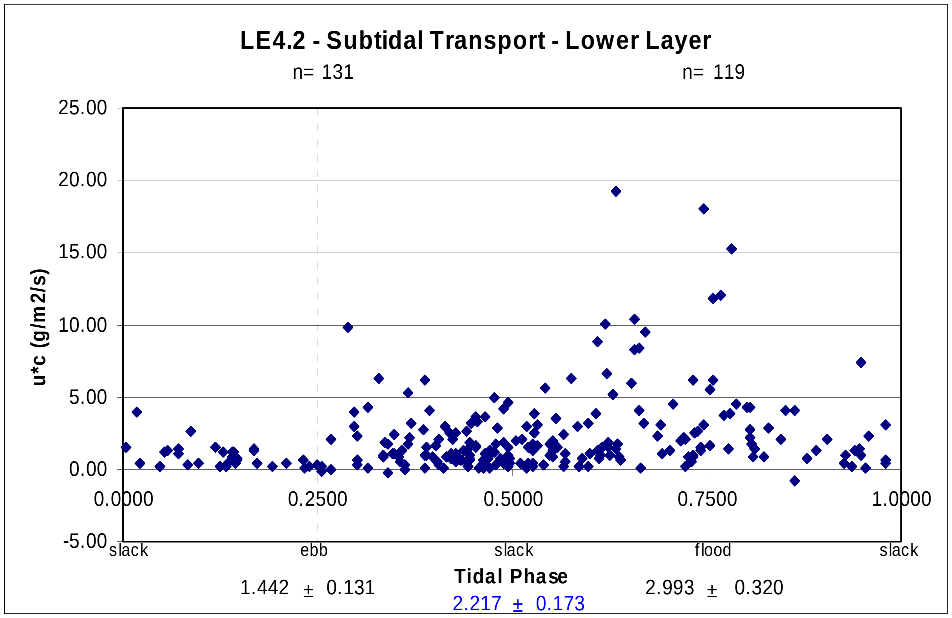
LE4.3 - River Transport - Upper Layer
n= 164
n= 83
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.026 ± 0.005
Tidal Phase
-0.027 ± 0.005
-0.028 ± 0.008

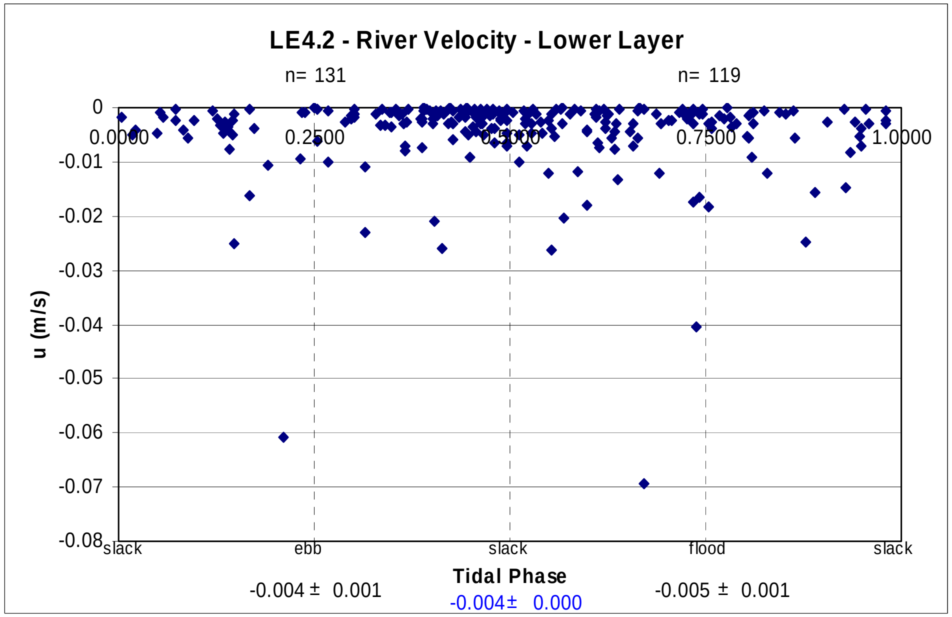

LE4.2 - Tidal Velocity - Lower Layer
n= 131
n= 119
u (m/s)
slack
ebb
slack
flood
slack
-0.173 ± 0.008
Tidal Phase
0.173 ± 0.008
0.000 ± 0.006

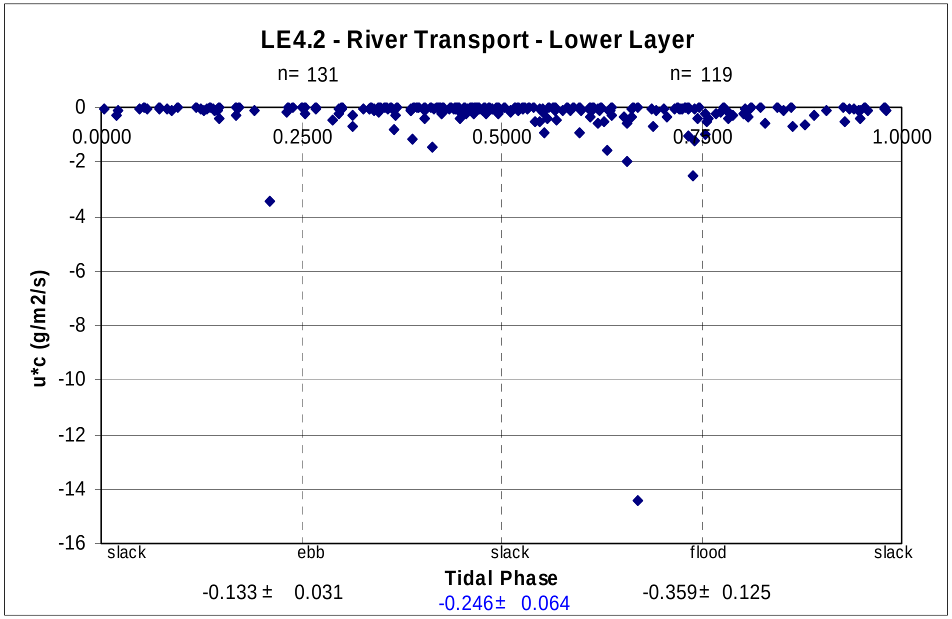

LE4.2 - TSS Concentrations - Lower Layer
n= 131
n= 119
c (mg/l)
slack
ebb
slack
flood
slack
30.681 ± 2.265
Tidal Phase
57.567 ± 5.576
44.124 ± 3.009

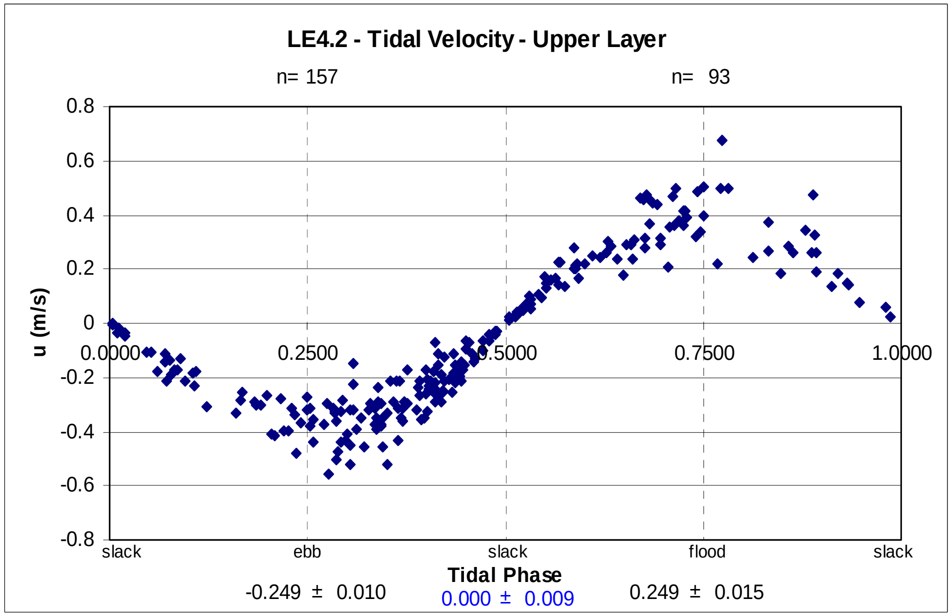

LE4.2 - Subtidal Velocity - Lower Layer
n= 131
n= 119
u (m/s)
slack
ebb
slack
flood
slack
0.045 ± 0.002
Tidal Phase
0.050 ± 0.002
0.048 ± 0.002

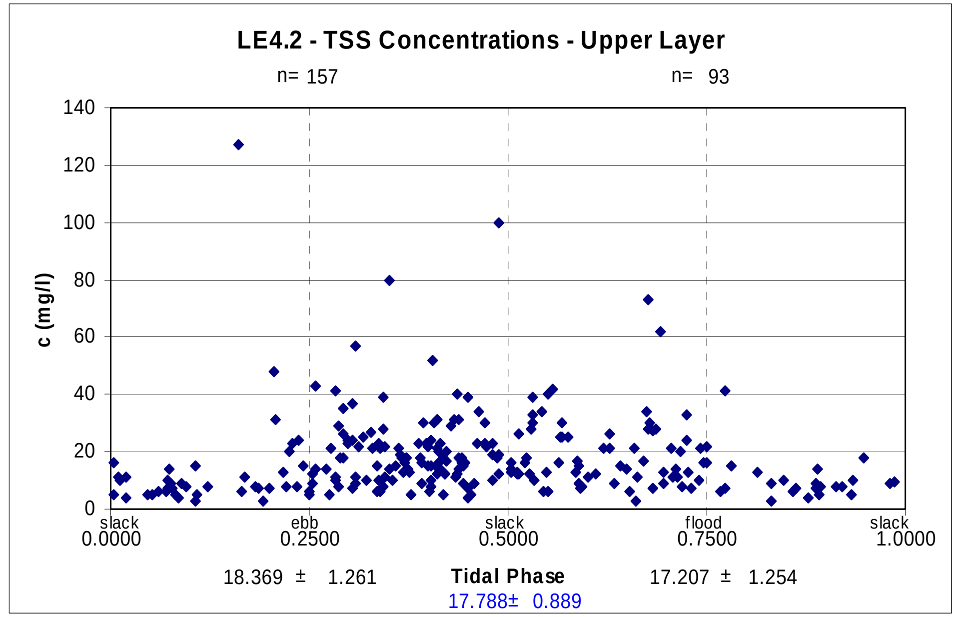

LE4.2 - Tidal Transport - Lower Layer
n= 131
n= 119
u*c (g/m2/s)
slack
ebb
slack
flood
slack
-5.899 ± 0.697
Tidal Phase
12.328 ± 1.635
3.215 ± 0.889

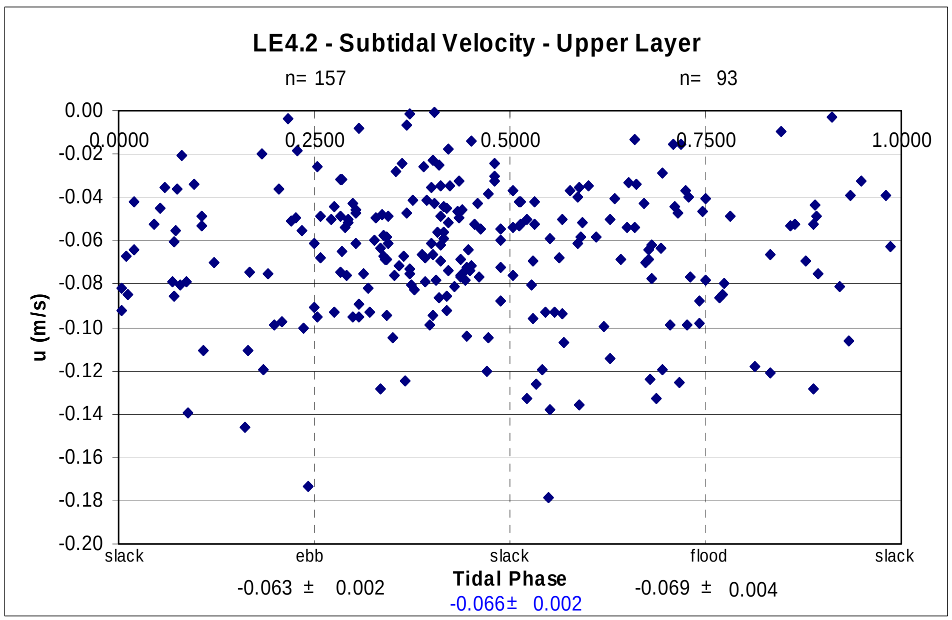

LE4.2 - Subtidal Transport - Lower Layer
n= 131
n= 119
u*c (g/m2/s)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
0.0000
0.2500
0.5000
0.7500
1.0000
slack
ebb
slack
flood
slack
Tidal Phase
1.442 ± 0.131
2.217 ± 0.173
2.993 ± 0.320

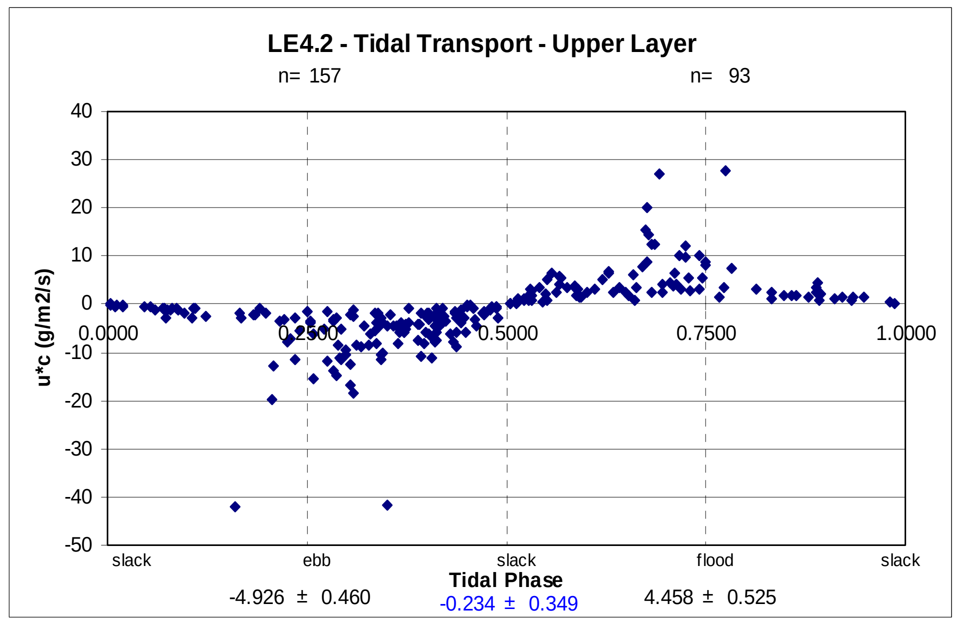

LE4.2 - River Velocity - Lower Layer
n= 131
n= 119
u (m/s)
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
0.0000
0.2500
0.5000
0.7500
1.0000
slack
ebb
slack
flood
slack
Tidal Phase
-0.004 ± 0.001
-0.004± 0.000
-0.005 ± 0.001

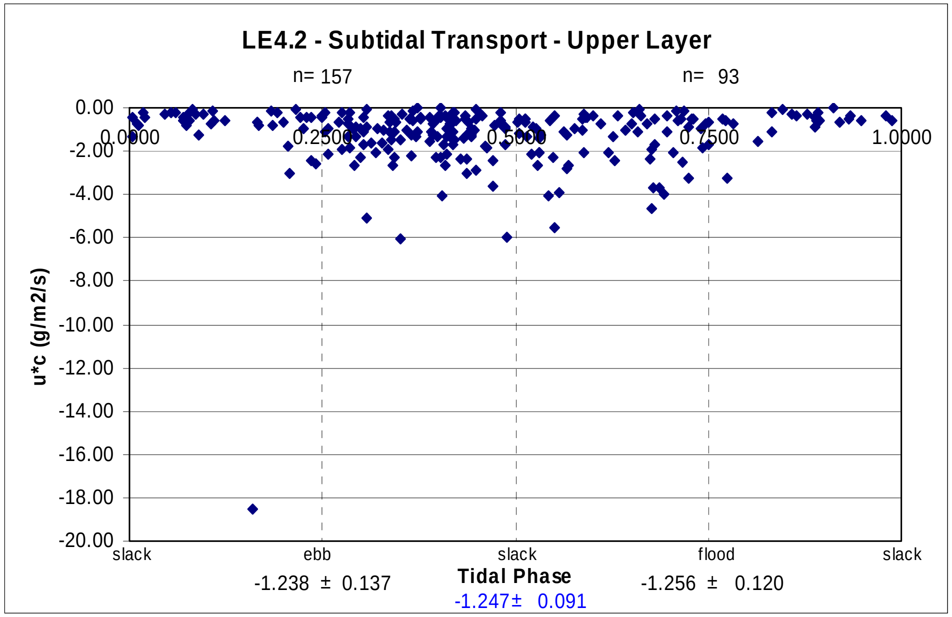

LE4.2 - River Transport - Lower Layer
n= 131
n= 119
u*c (g/m2/s)
0
-2
-4
-6
-8
-10
-12
-14
-16
0.0000
0.2500
0.5000
0.7500
1.0000
slack
ebb
slack
flood
slack
Tidal Phase
-0.133 ± 0.031
-0.246± 0.064
-0.359± 0.125

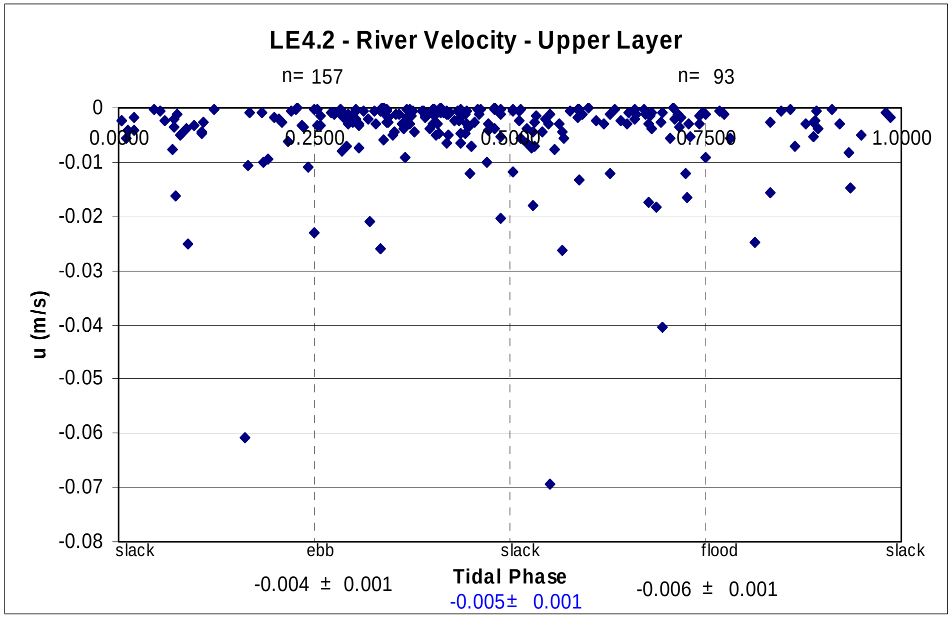

LE4.2 - Tidal Velocity - Upper Layer
n= 157
n= 93
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.249 ± 0.010
0.000 ± 0.009
0.249 ± 0.015

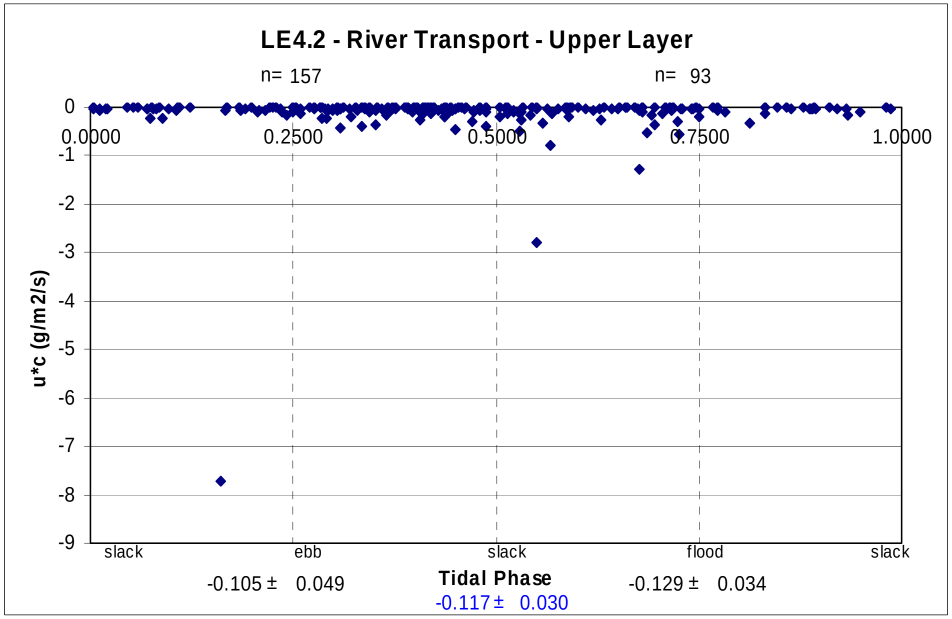

LE4.2 - TSS Concentrations - Upper Layer
n= 157
n= 93
c (mg/l)
slack
ebb
slack
flood
slack
Tidal Phase
18.369 ± 1.261
17.788± 0.889
17.207 ± 1.254

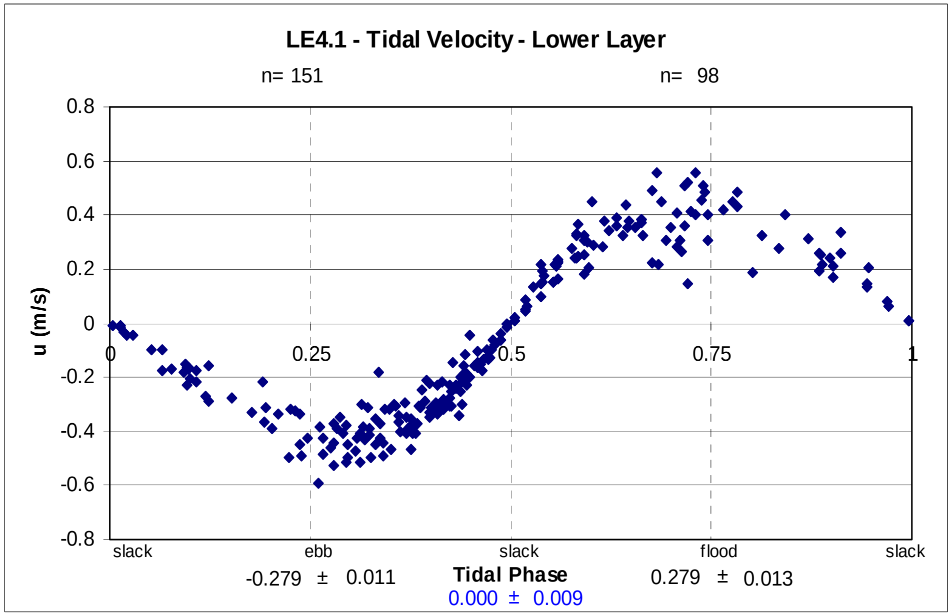

LE4.2 - Subtidal Velocity - Upper Layer
n= 157
n= 93
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.063 ± 0.002
-0.066± 0.002
-0.069 ± 0.004


LE4.2 - Tidal Transport - Upper Layer
n= 157
n= 93
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
-4.926 ± 0.460
-0.234 ± 0.349
4.458 ± 0.525

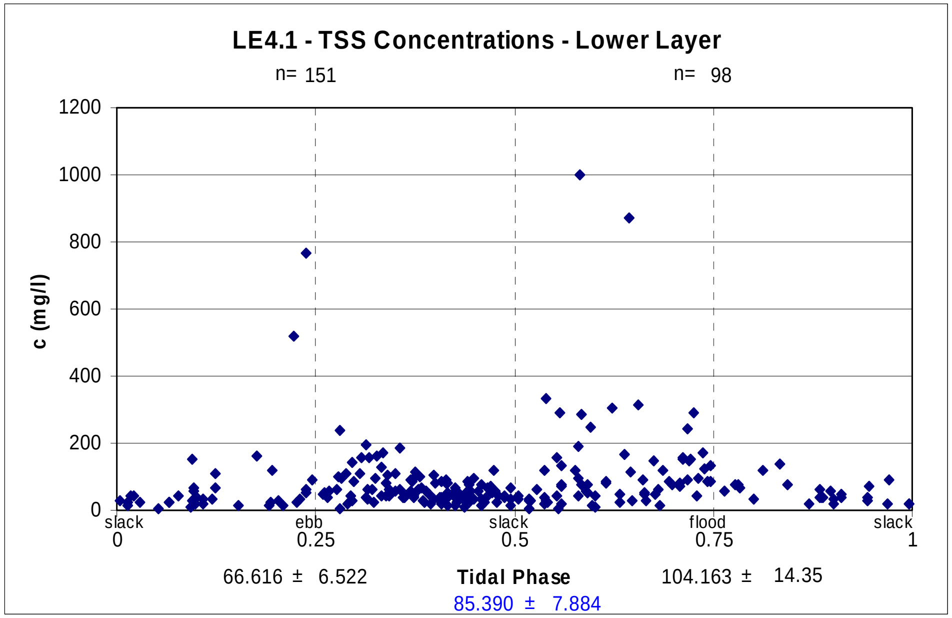

LE4.2 - Subtidal Transport - Upper Layer
n= 157
n= 93
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
0.0000
0.2500
0.5000
0.7500
1.0000
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
-1.238 ± 0.137
-1.247± 0.091
-1.256 ± 0.120


LE4.2 - River Velocity - Upper Layer
n= 157
n= 93
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
0.0000
0.2500
0.5000
0.7500
1.0000
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.004 ± 0.001
-0.005± 0.001
-0.006 ± 0.001

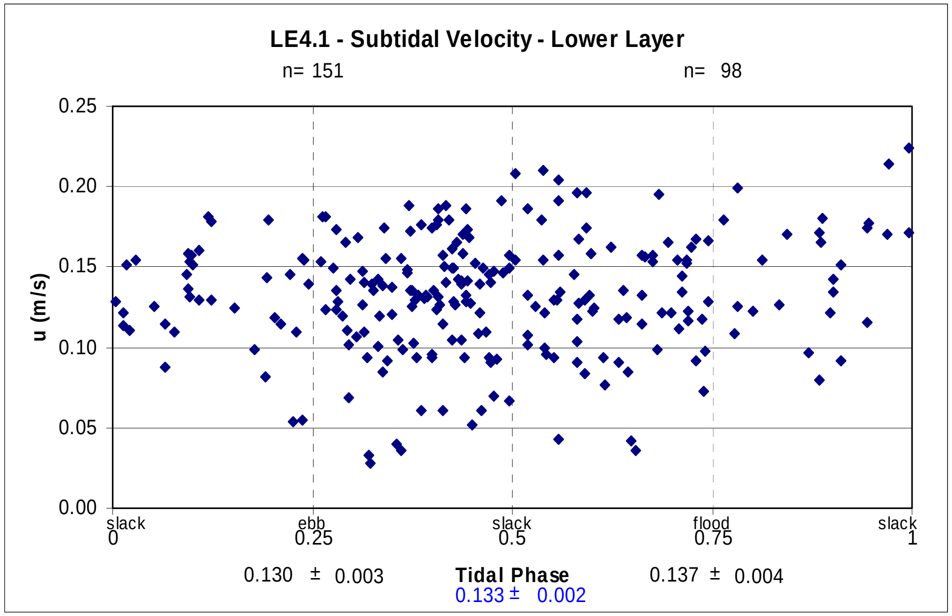

LE4.2 - River Transport - Upper Layer
n= 157
n= 93
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0.0000
0.2500
0.5000
0.7500
1.0000
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.105 ± 0.049
-0.117± 0.030
-0.129 ± 0.034



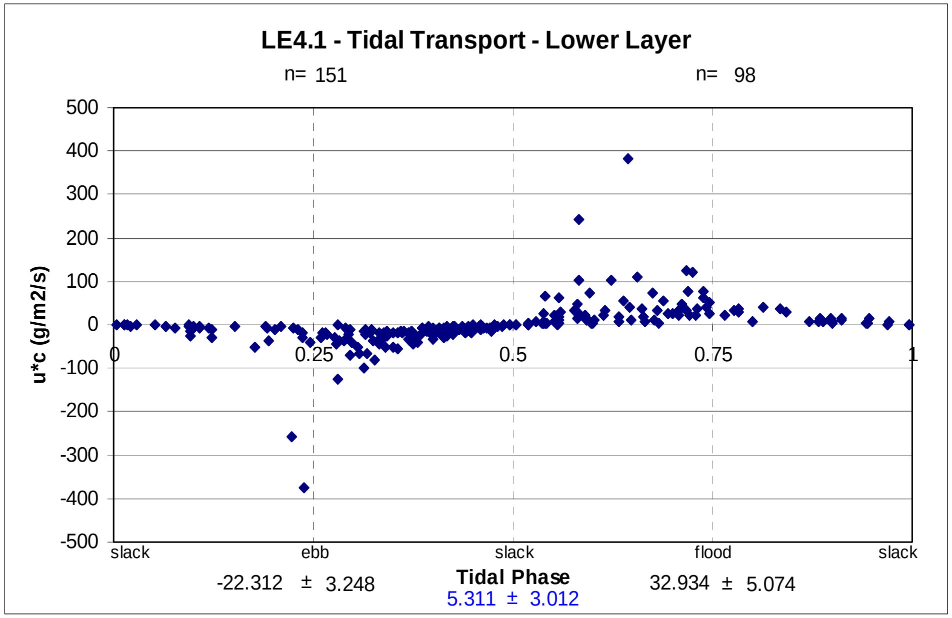
LE4.1 - Tidal Velocity - Lower Layer
n= 151
n= 98
u (m/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.279 ± 0.011
Tidal Phase
0.279 ± 0.013
0.000 ± 0.009



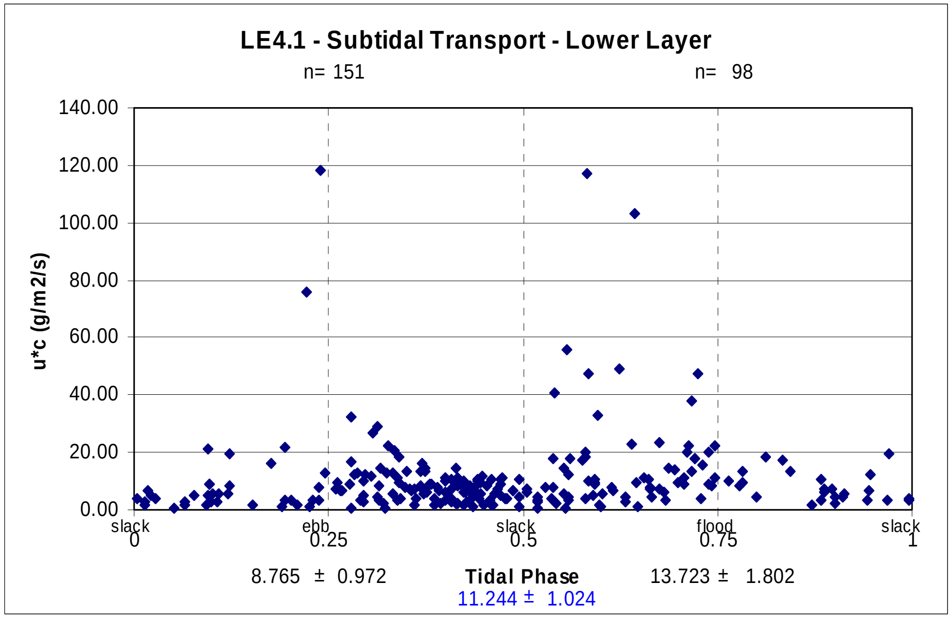
LE4.1 - TSS Concentrations - Lower Layer
n= 151
n= 98
c (mg/l)
1200
1000
800
600
400
200
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
66.616 ± 6.522
Tidal Phase
104.163 ± 14.35
85.390 ± 7.884



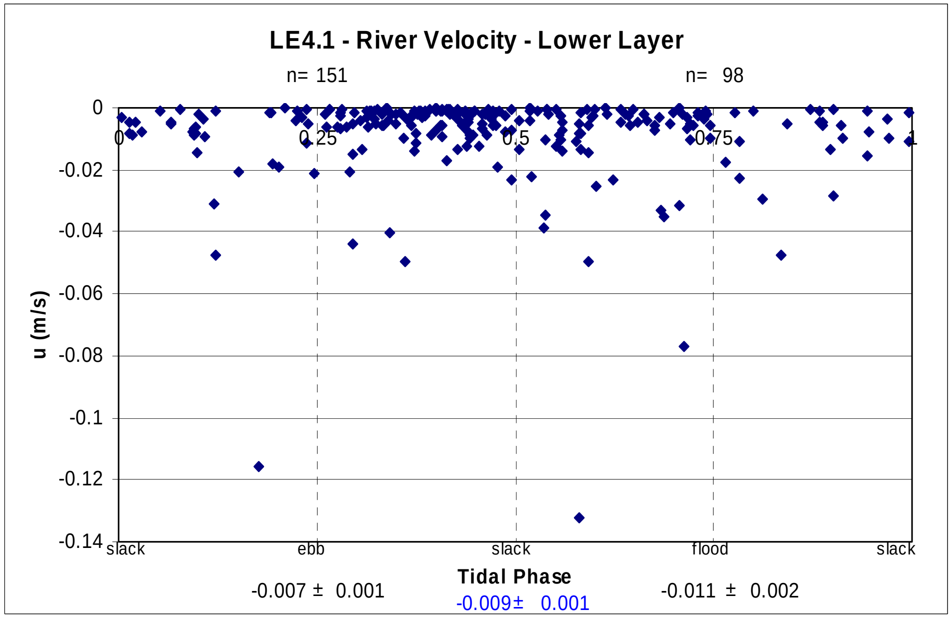
LE4.1 - Subtidal Velocity - Lower Layer
n= 151
n= 98
u (m/s)
0.25
0.20
0.15
0.10
0.05
0.00
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
0.130 ± 0.003
Tidal Phase
0.137 ± 0.004
0.133 ± 0.002



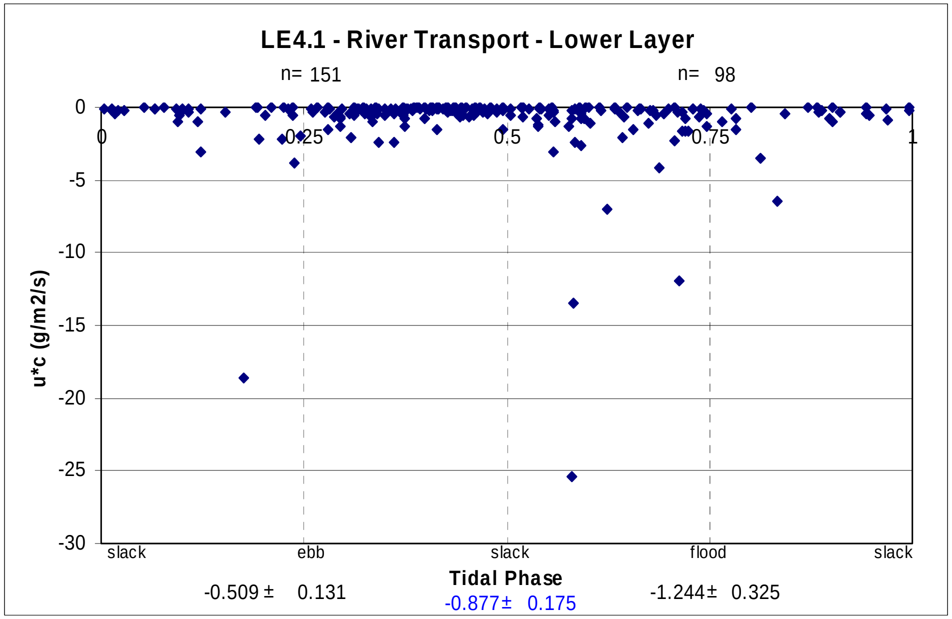
LE4.1 - Tidal Transport - Lower Layer
n= 151
n= 98
u*c (g/m2/s)
500
400
300
200
100
0
-100
-200
-300
-400
-500
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-22.312 ± 3.248
Tidal Phase
32.934 ± 5.074
5.311 ± 3.012



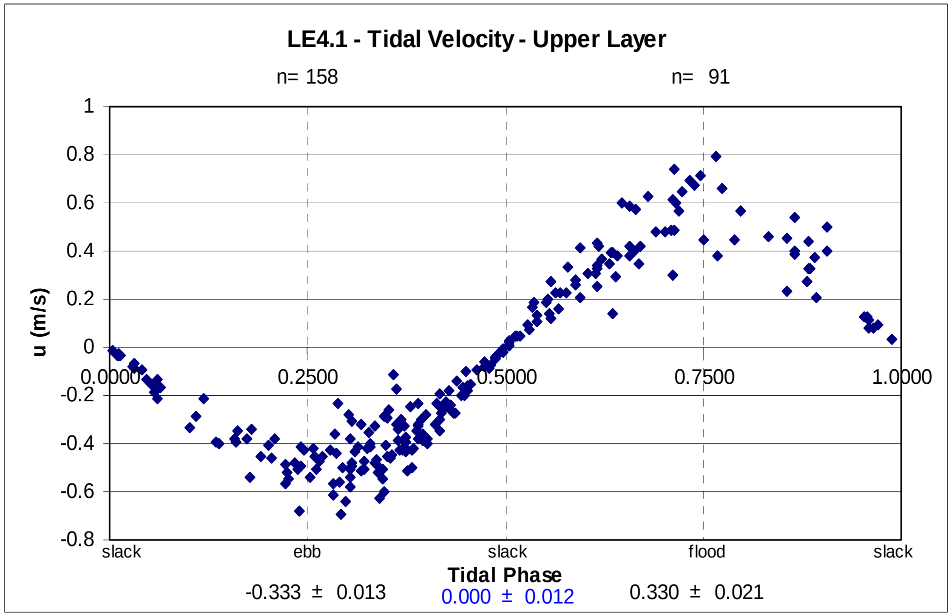
LE4.1 - Subtidal Transport - Lower Layer
n= 151
n= 98
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
u*c (g/m2/s)
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
8.765 ± 0.972
Tidal Phase
13.723 ± 1.802
11.244 ± 1.024

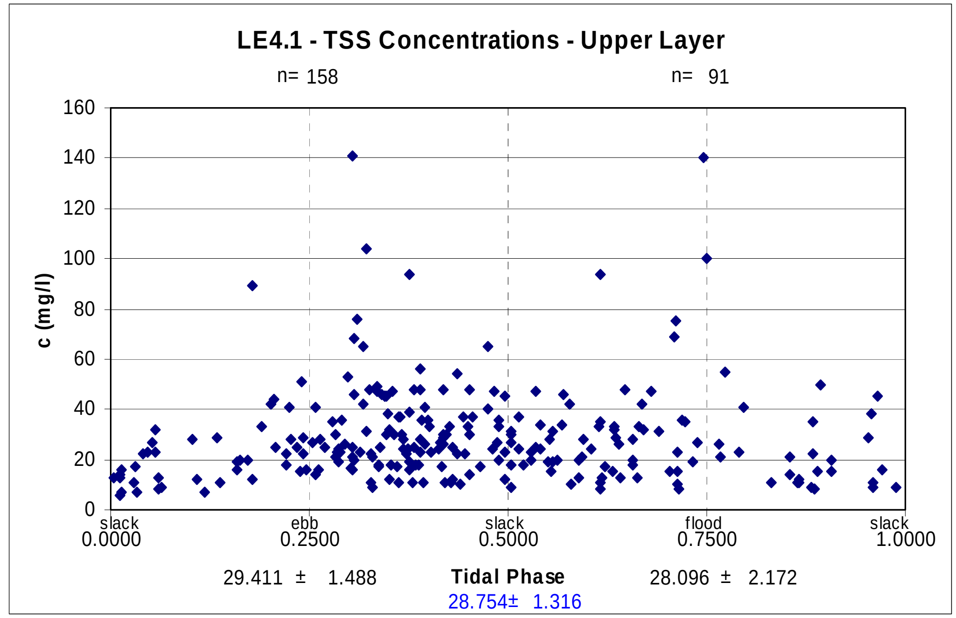


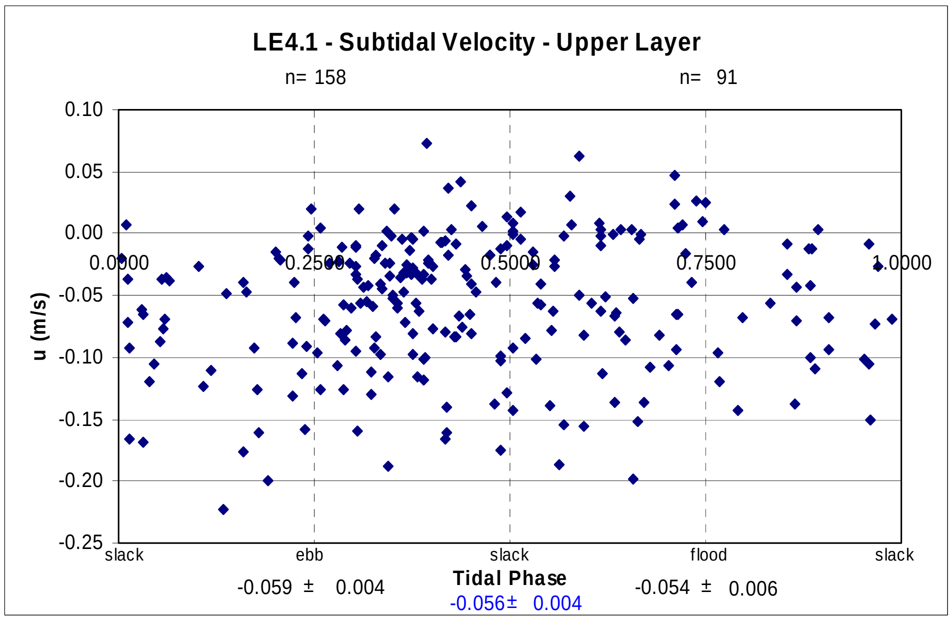
LE4.1 - River Velocity - Lower Layer
n= 151
n= 98
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.007 ± 0.001
Tidal Phase
-0.011 ± 0.002
-0.009± 0.001

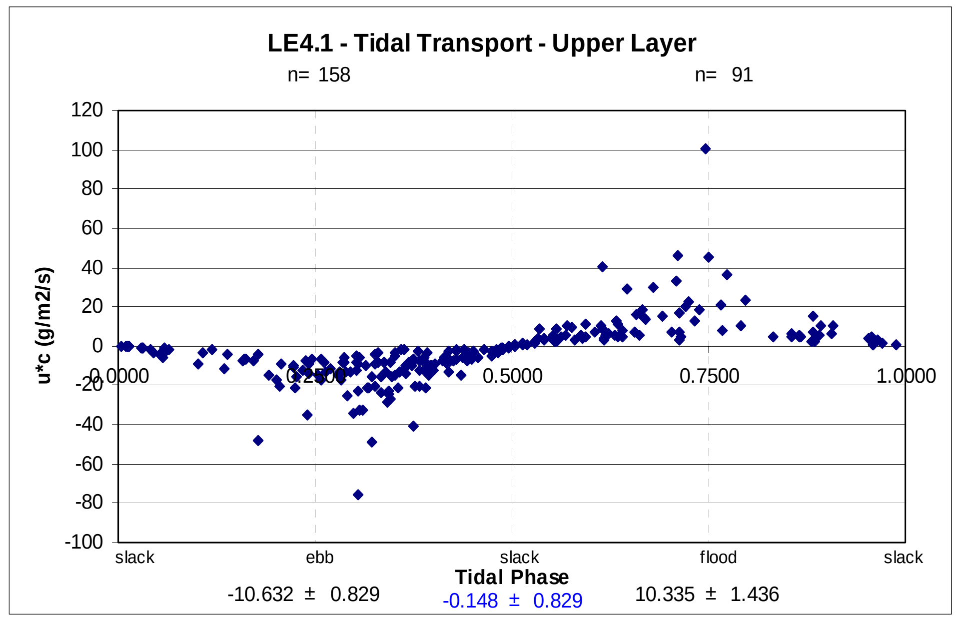


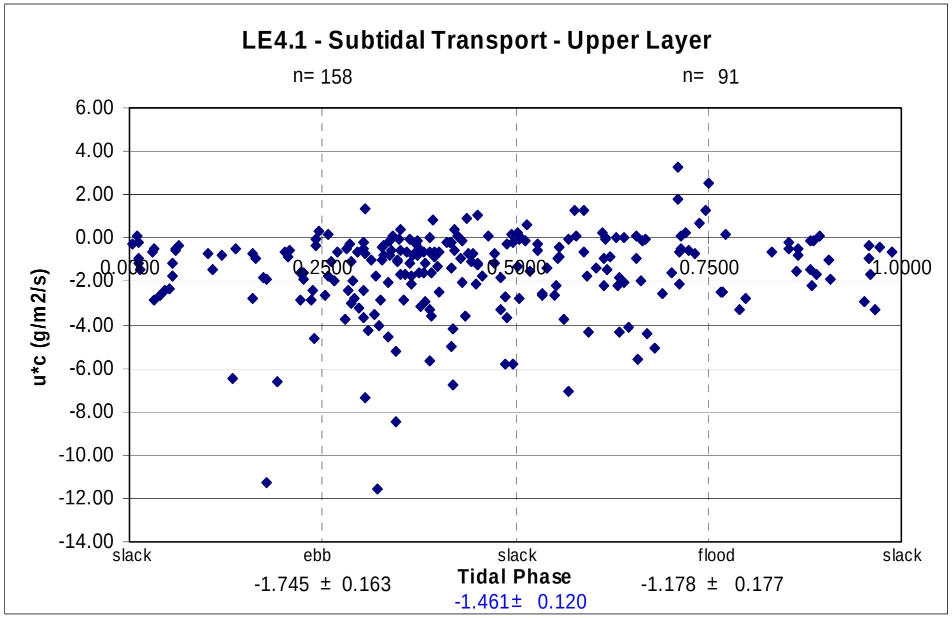
LE4.1 - River Transport - Lower Layer
n= 151
n= 98
0
-5
-10
-15
-20
-25
-30
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.509 ± 0.131
Tidal Phase
-1.244± 0.325
-0.877± 0.175

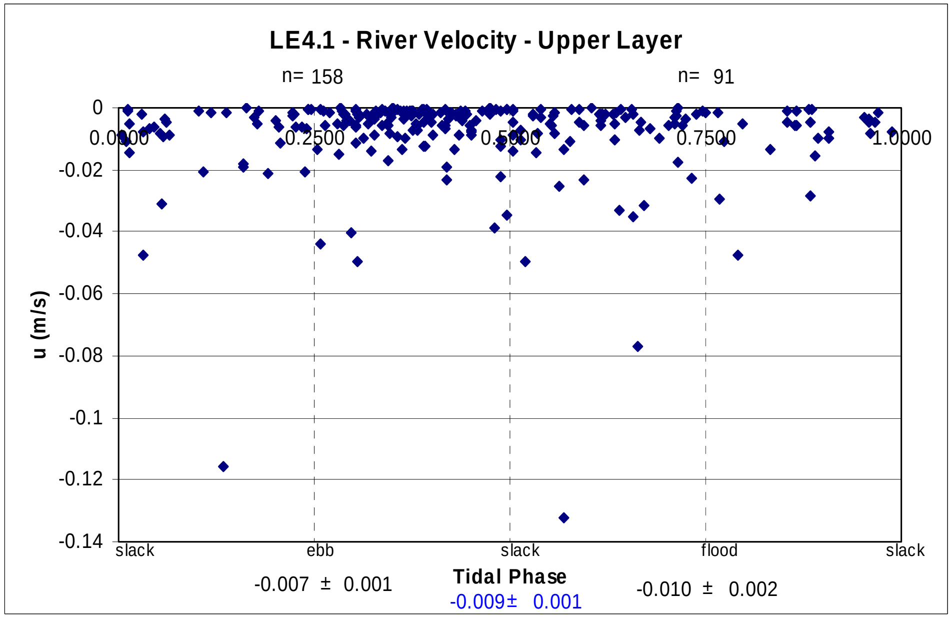

LE4.1 - Tidal Velocity - Upper Layer
n= 158
n= 91
u (m/s)
Tidal Phase
slack
ebb
slack
flood
slack
-0.333 ± 0.013
0.000 ± 0.012
0.330 ± 0.021

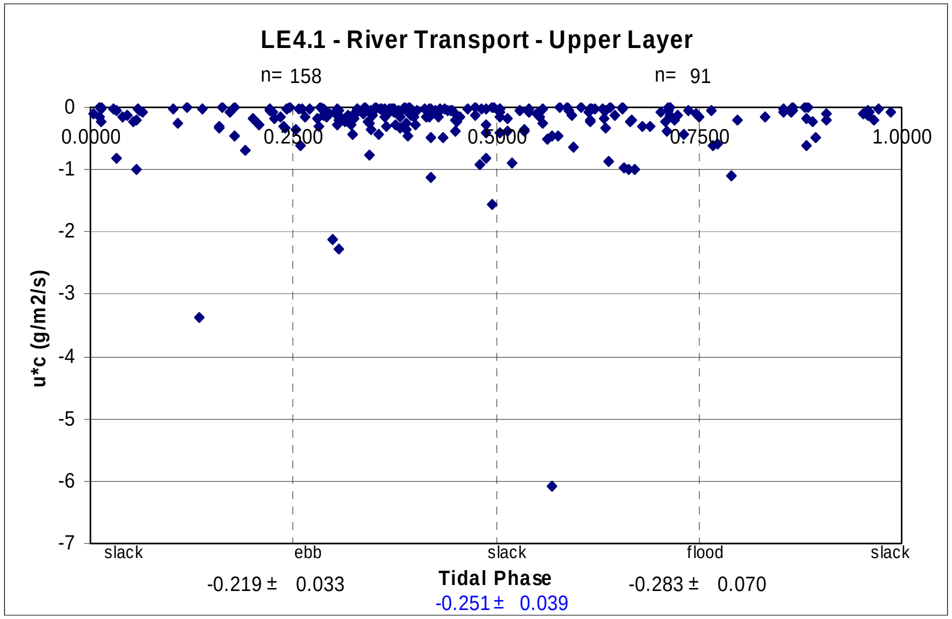

LE4.1 - TSS Concentrations - Upper Layer
n= 158
n= 91
c (mg/l)
Tidal Phase
29.411 ± 1.488
28.754± 1.316
28.096 ± 2.172

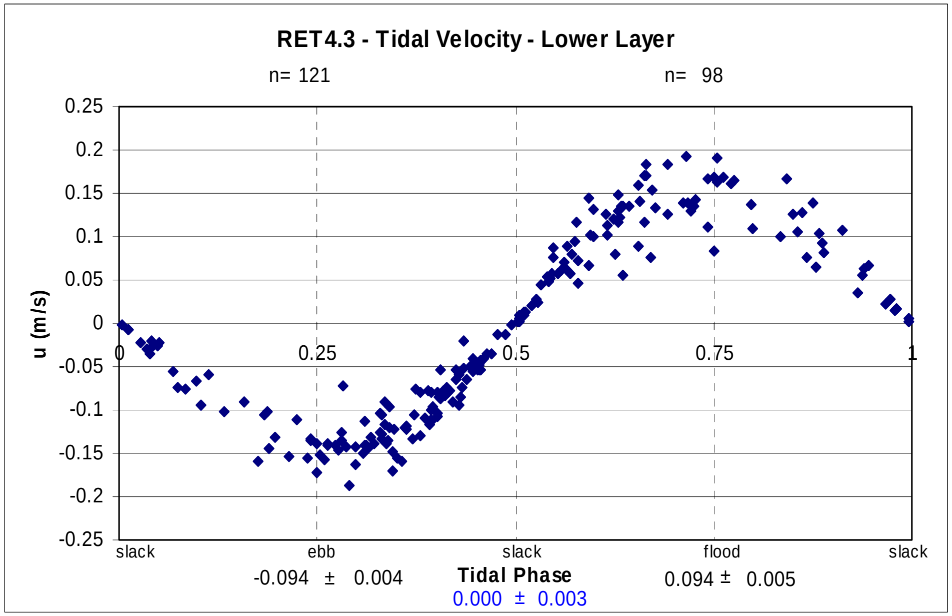

LE4.1 - Subtidal Velocity - Upper Layer
n= 158
n= 91
u (m/s)
Tidal Phase
-0.059 ± 0.004
-0.056± 0.004
-0.054 ± 0.006

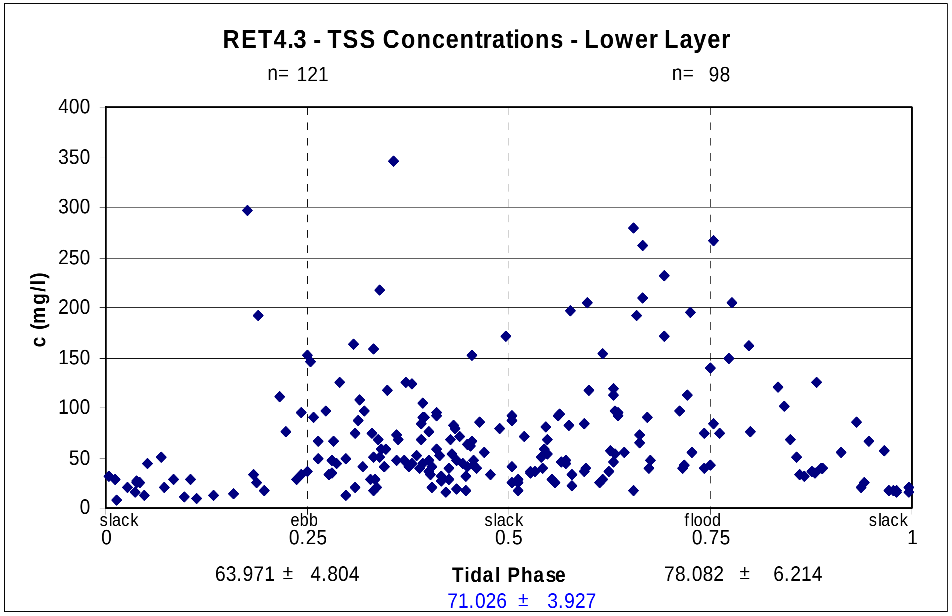

LE4.1 - Tidal Transport - Upper Layer
n= 158
n= 91
u*c (g/m2/s)
Tidal Phase
-10.632 ± 0.829
-0.148 ± 0.829
10.335 ± 1.436

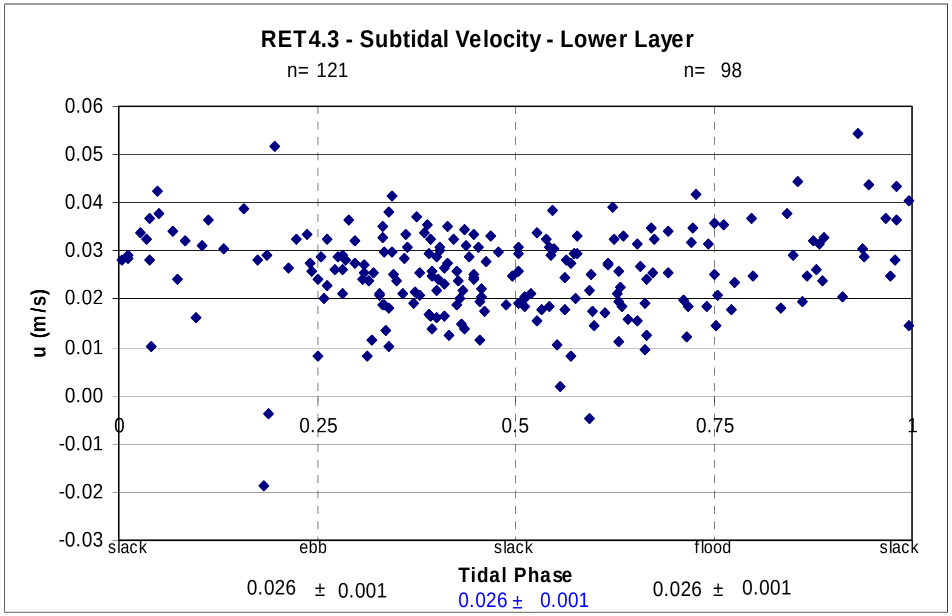

LE4.1 - Subtidal Transport - Upper Layer
n= 158
n= 91
u*c (g/m2/s)
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
0.0000
0.2500
0.5000
0.7500
1.0000
slack
ebb
slack
flood
slack
Tidal Phase
-1.745 ± 0.163
-1.461± 0.120
-1.178 ± 0.177

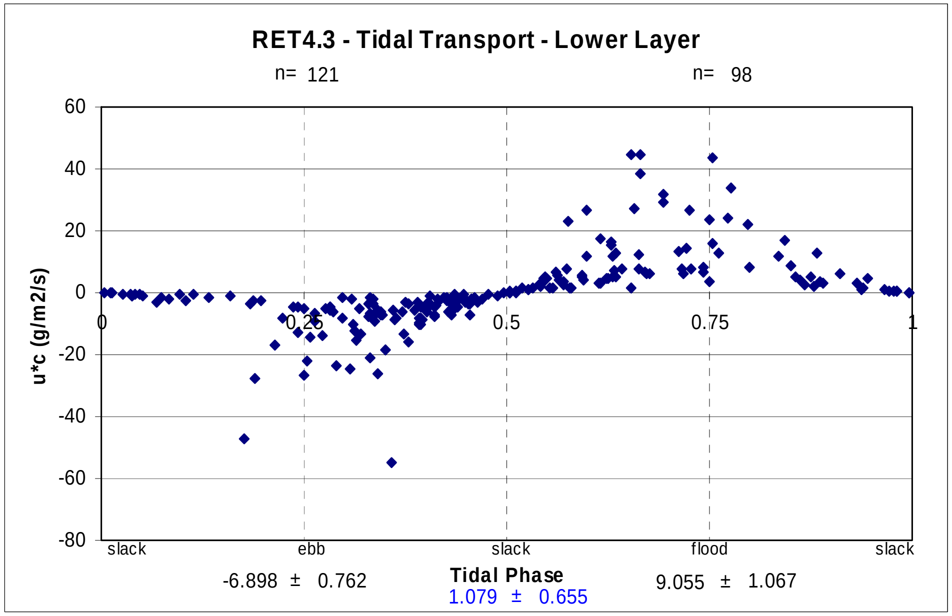

LE4.1 - River Velocity - Upper Layer
n= 158
n= 91
u (m/s)
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
0.0000
0.2500
0.5000
0.7500
1.0000
slack
ebb
slack
flood
slack
Tidal Phase
-0.007 ± 0.001
-0.009± 0.001
-0.010 ± 0.002

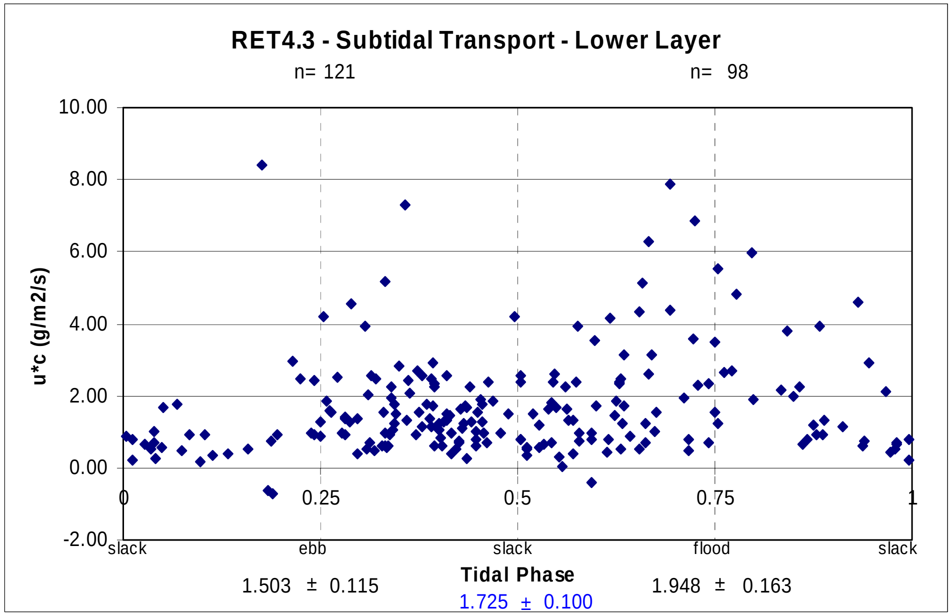

LE4.1 - River Transport - Upper Layer
n= 158
n= 91
u*c (g/m2/s)
0
-1
-2
-3
-4
-5
-6
-7
0.0000
0.2500
0.5000
0.7500
1.0000
slack
ebb
slack
flood
slack
Tidal Phase
-0.219 ± 0.033
-0.251 ± 0.039
-0.283 ± 0.070

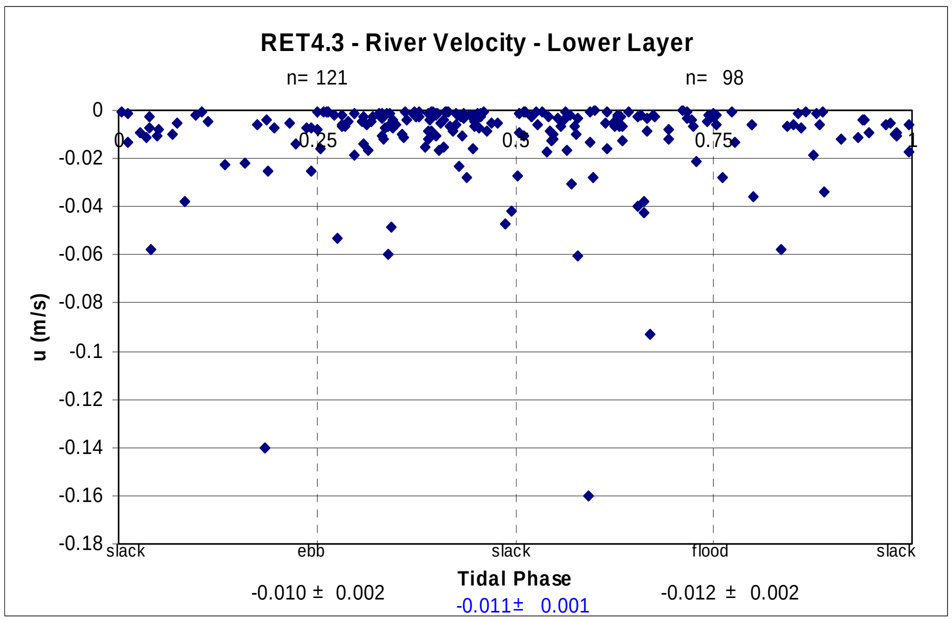

RET4.3 - Tidal Velocity - Lower Layer
n= 121
n= 98
u (m/s)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.094 ± 0.004
Tidal Phase
0.094 ± 0.005
0.000 ± 0.003

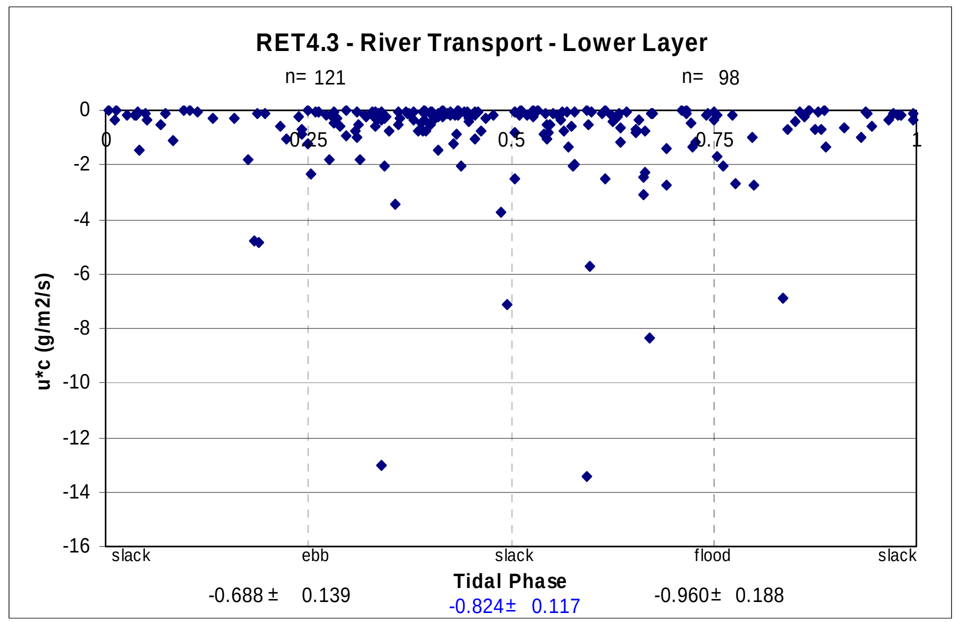

RET4.3 - TSS Concentrations - Lower Layer
n= 121
n= 98
c (mg/l)
400
350
300
250
200
150
100
50
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
63.971 ± 4.804
Tidal Phase
78.082 ± 6.214
71.026 ± 3.927

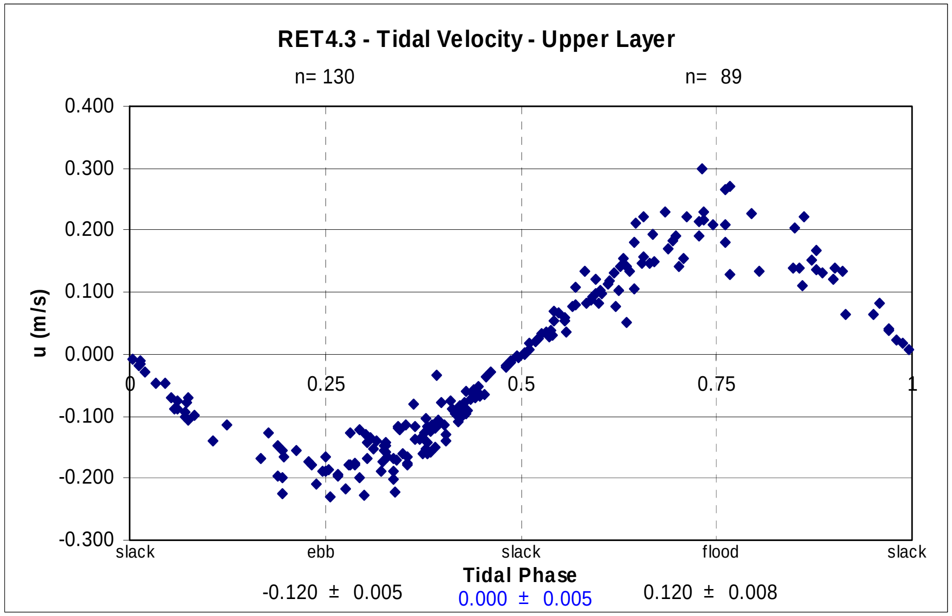

RET4.3 - Subtidal Velocity - Lower Layer
n= 121
n= 98
u (m/s)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.026 ± 0.001
Tidal Phase
0.026 ± 0.001
0.026 ± 0.001

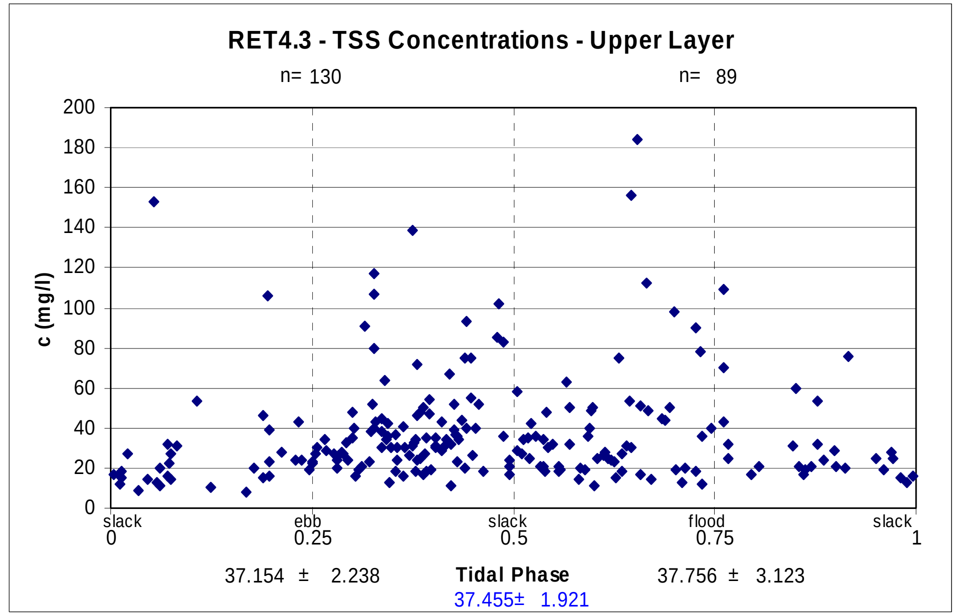

RET4.3 - Tidal Transport - Lower Layer
n= 121
n= 98
u*c (g/m2/s)
60
40
20
0
-20
-40
-60
-80
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-6.898 ± 0.762
Tidal Phase
9.055 ± 1.067
1.079 ± 0.655

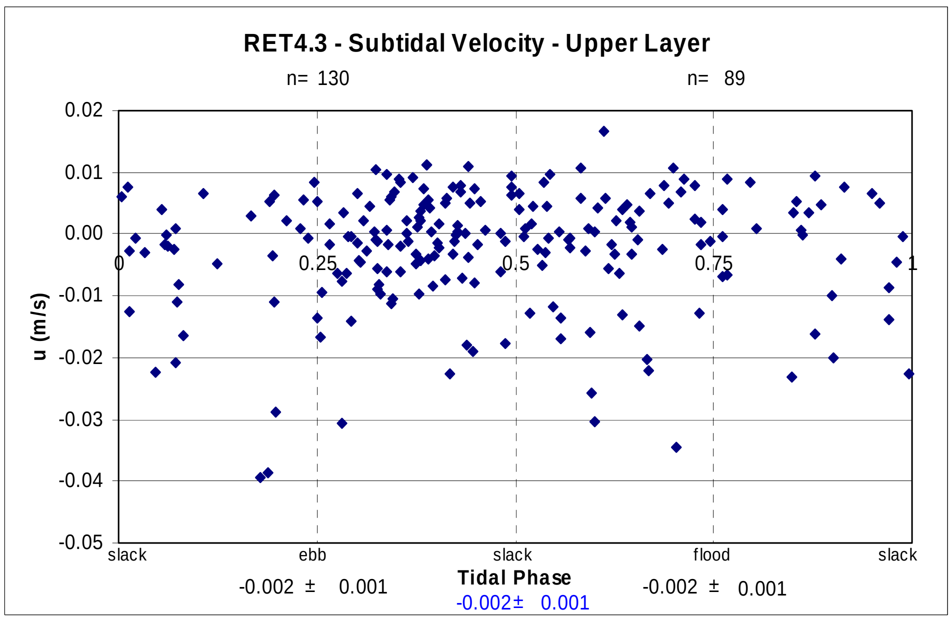

RET4.3 - Subtidal Transport - Lower Layer
n= 121
n= 98
u*c (g/m2/s)
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
1.503 ± 0.115
1.725 ± 0.100
1.948 ± 0.163

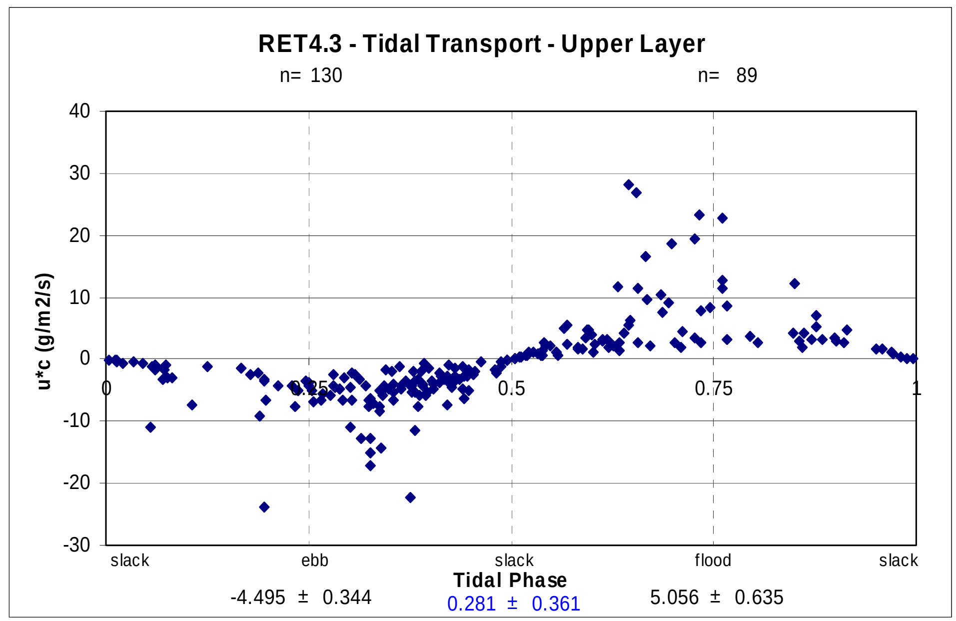

RET4.3 - River Velocity - Lower Layer
n= 121
n= 98
u (m/s)
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.010 ± 0.002
-0.011± 0.001
-0.012 ± 0.002

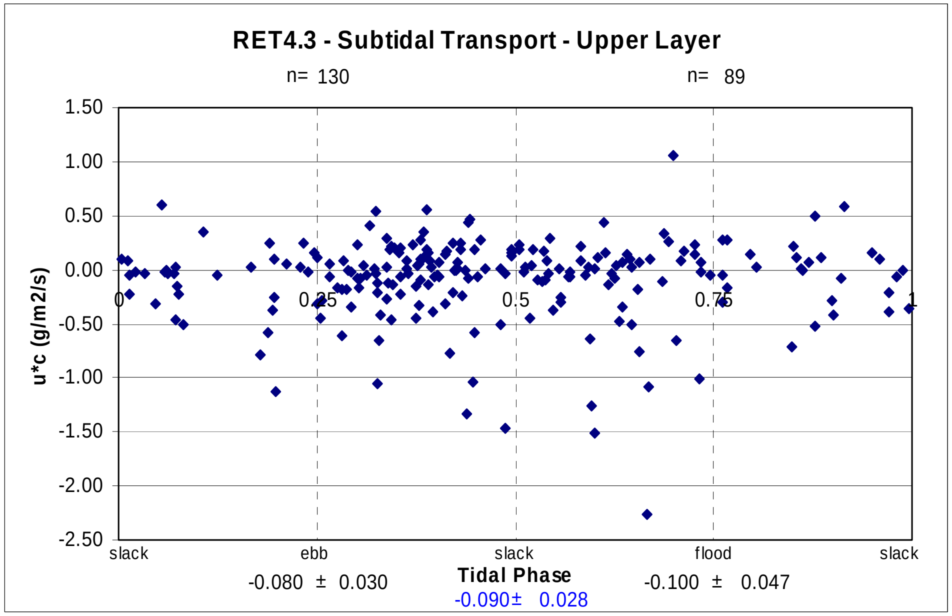

RET4.3 - River Transport - Lower Layer
n= 121
n= 98
u*c (g/m2/s)
0
-2
-4
-6
-8
-10
-12
-14
-16
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.688 ± 0.139
-0.824± 0.117
-0.960± 0.188

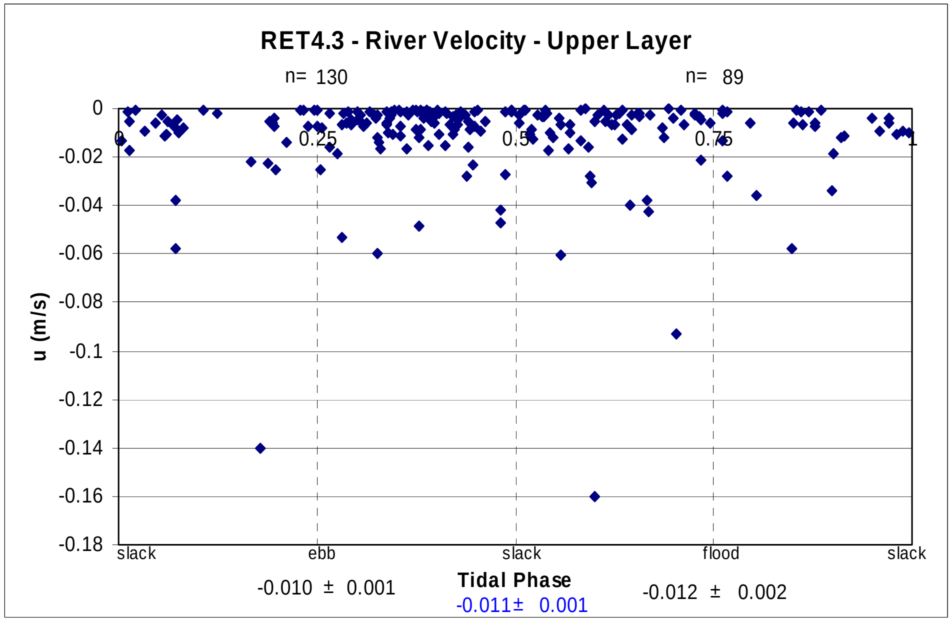

RET4.3 - Tidal Velocity - Upper Layer
n= 130
n= 89
u (m/s)
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.120 ± 0.005
0.000 ± 0.005
0.120 ± 0.008

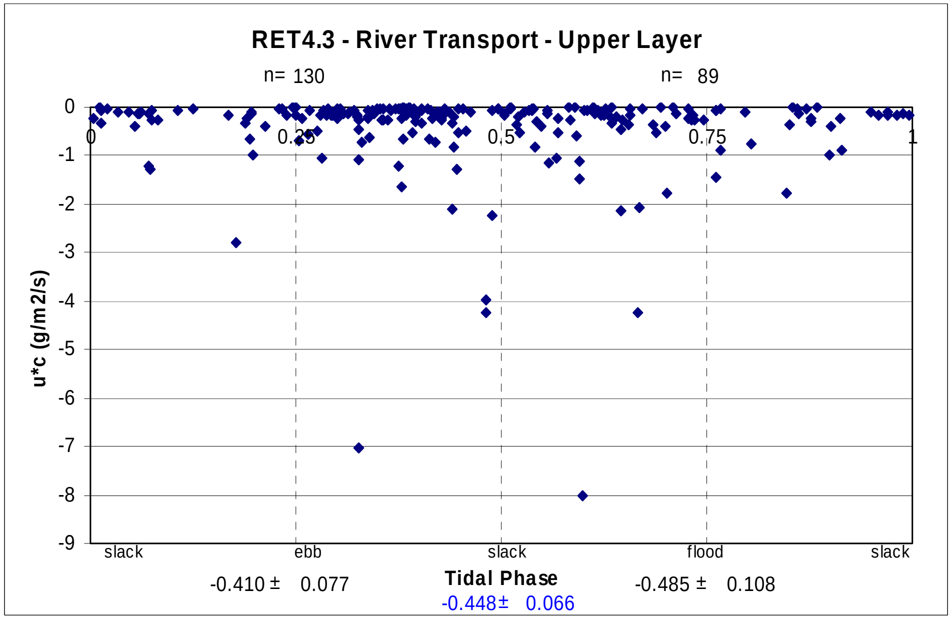

RET4.3 - TSS Concentrations - Upper Layer
n= 130
n= 89
c (mg/l)
200
180
160
140
120
100
80
60
40
20
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
Tidal Phase
37.154 ± 2.238
37.455± 1.921
37.756 ± 3.123

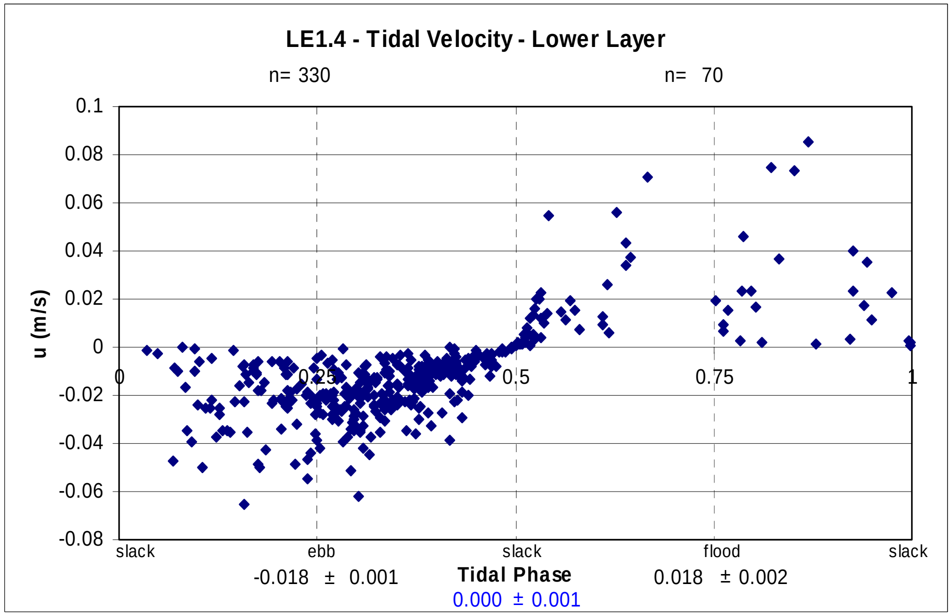

RET4.3 - Subtidal Velocity - Upper Layer
n= 130
n= 89
u (m/s)
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.002 ± 0.001
-0.002± 0.001
-0.002 ± 0.001

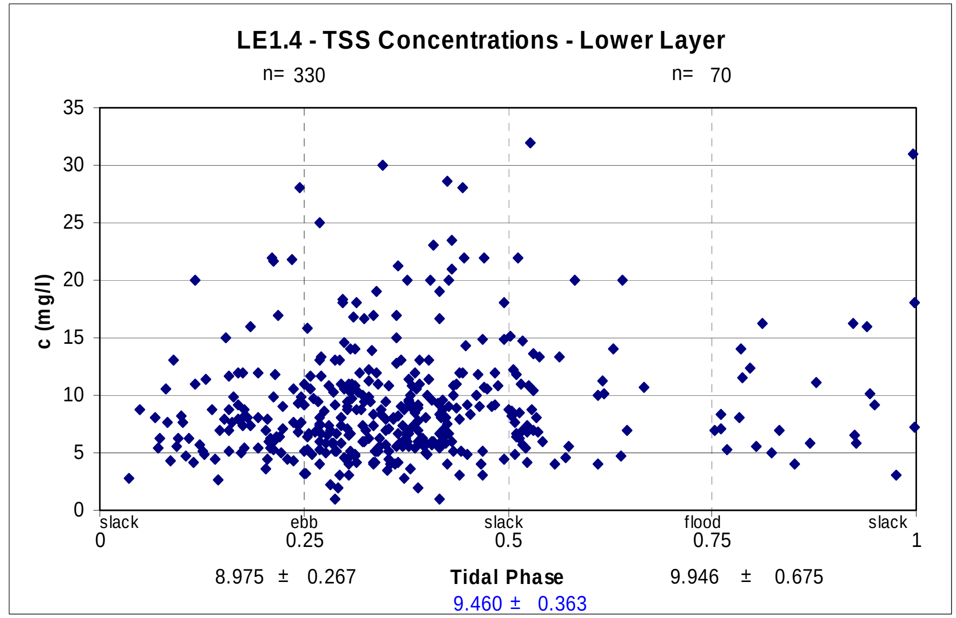

RET4.3 - Tidal Transport - Upper Layer
n= 130
n= 89
u*c (g/m2/s)
40
30
20
10
0
-10
-20
-30
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-4.495 ± 0.344
0.281 ± 0.361
5.056 ± 0.635

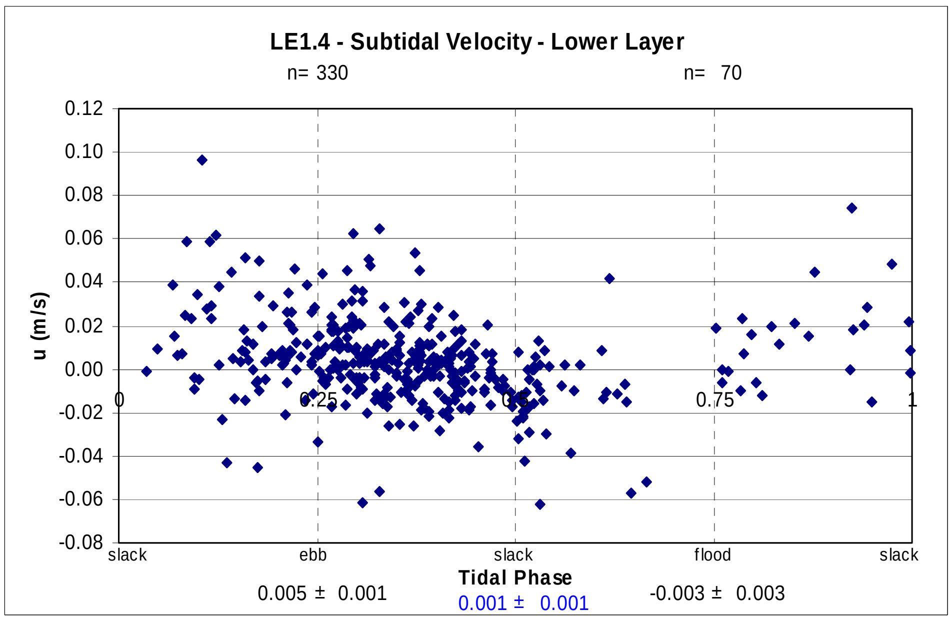

RET4.3 - Subtidal Transport - Upper Layer
n= 130
n= 89
u*c (g/m2/s)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.080 ± 0.030
-0.090± 0.028
-0.100 ± 0.047

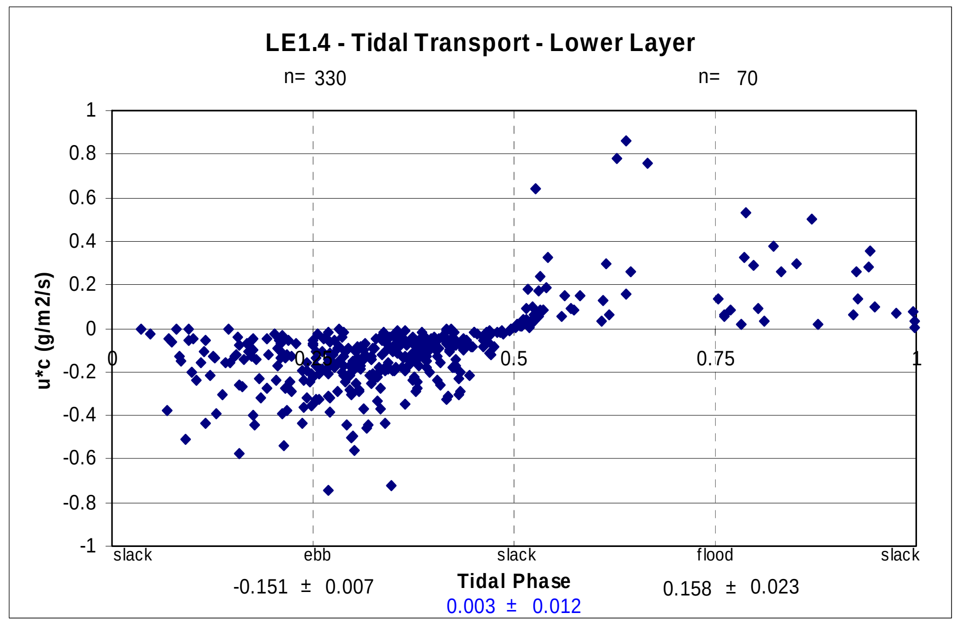

RET4.3 - River Velocity - Upper Layer
n= 130
n= 89
u (m/s)
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.010 ± 0.001
-0.011± 0.001
-0.012 ± 0.002

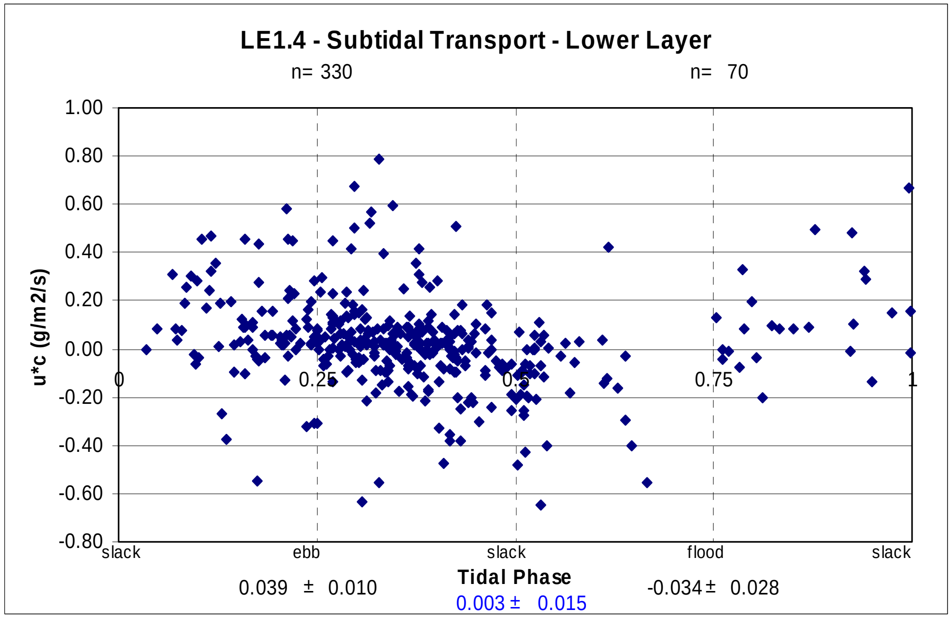

RET4.3 - River Transport - Upper Layer
n= 130
n= 89
u*c (g/m2/s)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.410 ± 0.077
-0.448± 0.066
-0.485 ± 0.108

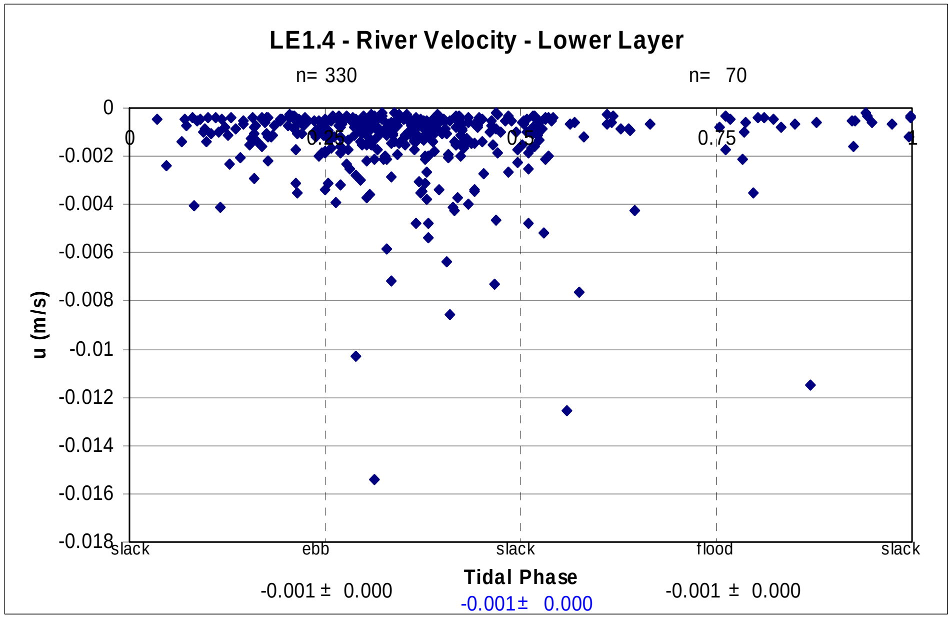

LE1.4 - Tidal Velocity - Lower Layer
n= 330
n= 70
u (m/s)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.018 ± 0.001
Tidal Phase
0.018 ± 0.002
0.000 ± 0.001

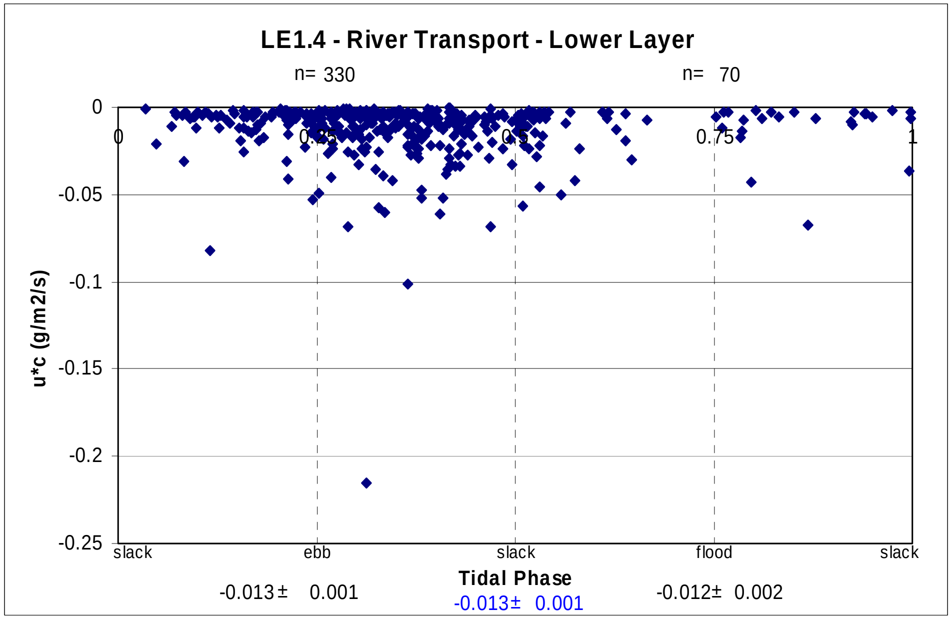

LE1.4 - TSS Concentrations - Lower Layer
n= 330
n= 70
c (mg/l)
35
30
25
20
15
10
5
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
8.975 ± 0.267
Tidal Phase
9.946 ± 0.675
9.460 ± 0.363

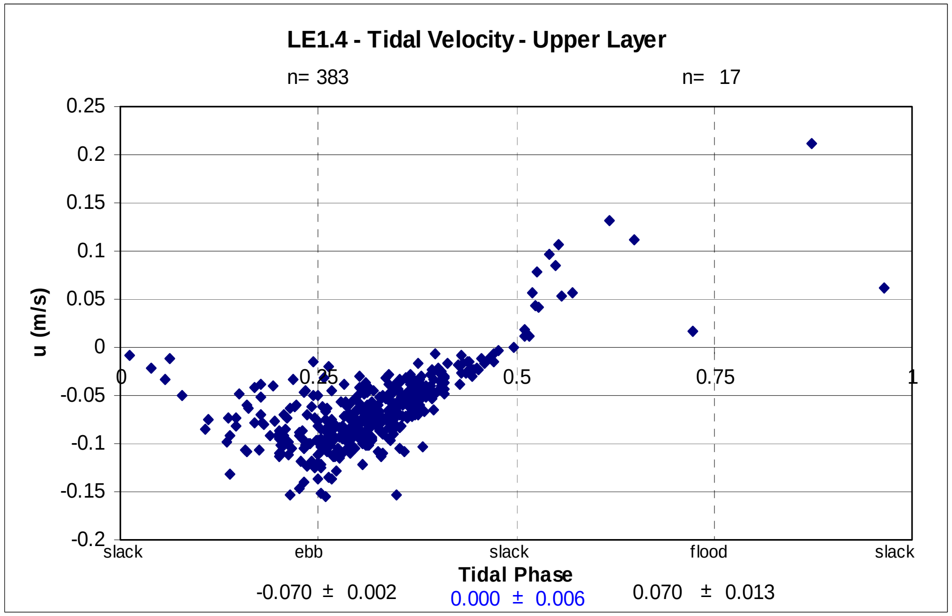

LE1.4 - Subtidal Velocity - Lower Layer
n= 330
n= 70
u (m/s)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.005 ± 0.001
Tidal Phase
-0.003 ± 0.003
0.001 ± 0.001

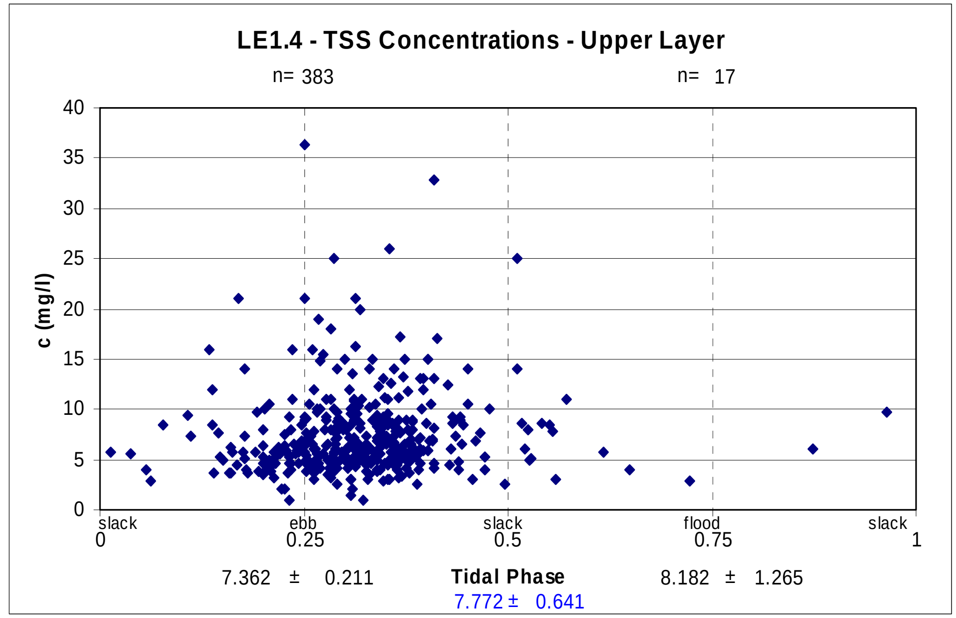

LE1.4 - Tidal Transport - Lower Layer
n= 330
n= 70
u*c (g/m2/s)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.151 ± 0.007
Tidal Phase
0.158 ± 0.023
0.003 ± 0.012

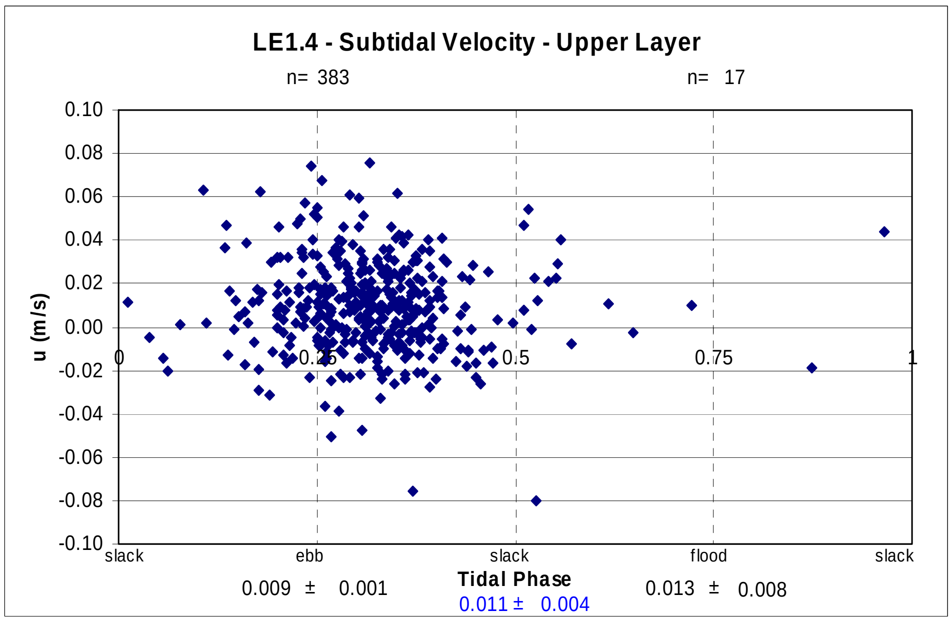

LE1.4 - Subtidal Transport - Lower Layer
n= 330
n= 70
u*c (g/m2/s)
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.039 ± 0.010
0.003 ± 0.015
-0.034 ± 0.028

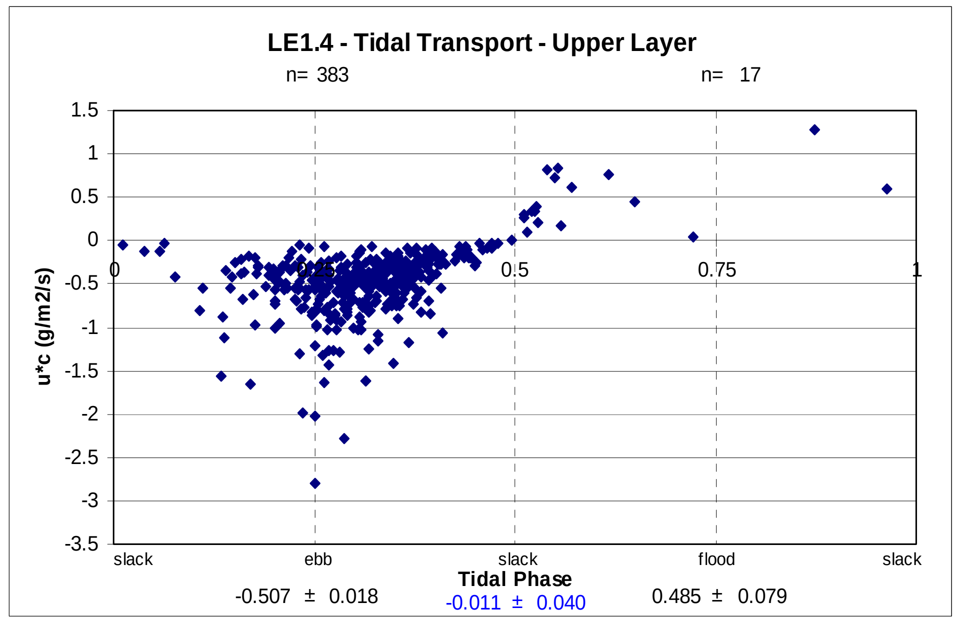

LE1.4 - River Velocity - Lower Layer
n= 330
n= 70
u (m/s)
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.001 ± 0.000
-0.001 ± 0.000
-0.001 ± 0.000

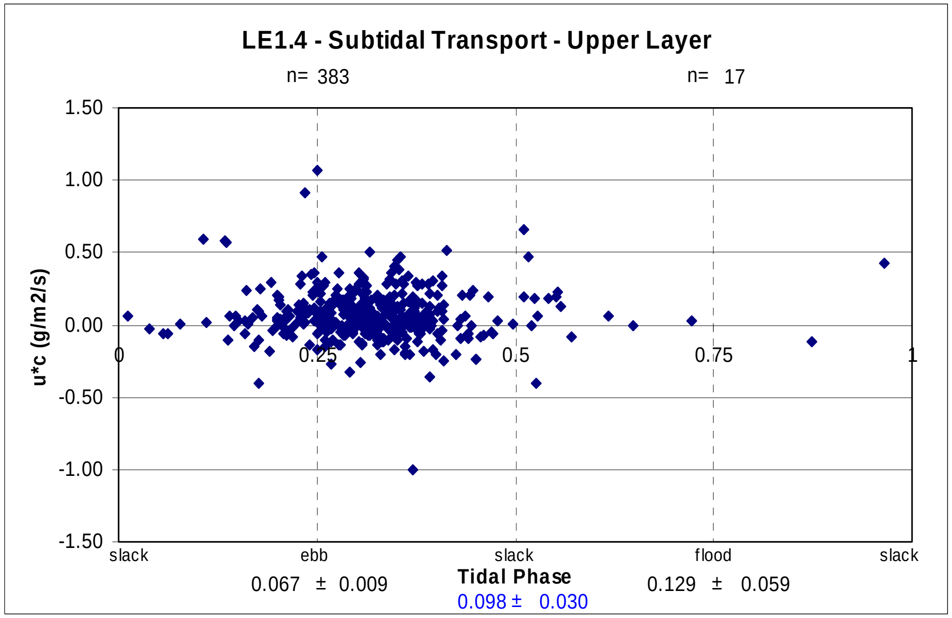

LE1.4 - River Transport - Lower Layer
n= 330
n= 70
u*c (g/m2/s)
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.013 ± 0.001
-0.013 ± 0.001
-0.012 ± 0.002


LE1.4 - Tidal Velocity - Upper Layer
n= 383
n= 17
u (m/s)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.070 ± 0.002
0.000 ± 0.006
0.070 ± 0.013

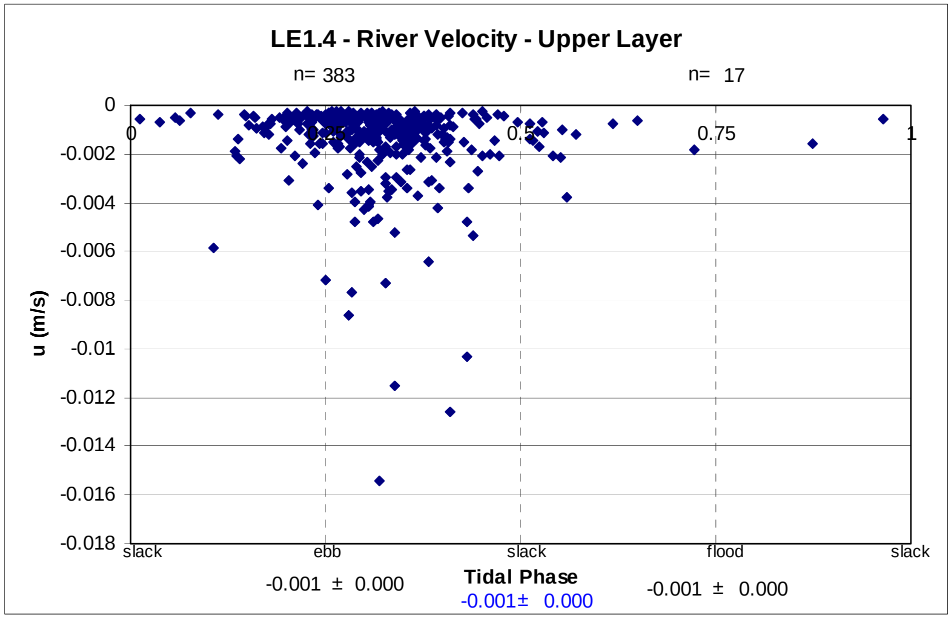

LE1.4 - TSS Concentrations - Upper Layer
n= 383
n= 17
c (mg/l)
40
35
30
25
20
15
10
5
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
Tidal Phase
7.362 ± 0.211
7.772 ± 0.641
8.182 ± 1.265


LE1.4 - Subtidal Velocity - Upper Layer
n= 383
n= 17
u (m/s)
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.009 ± 0.001
0.011 ± 0.004
0.013 ± 0.008

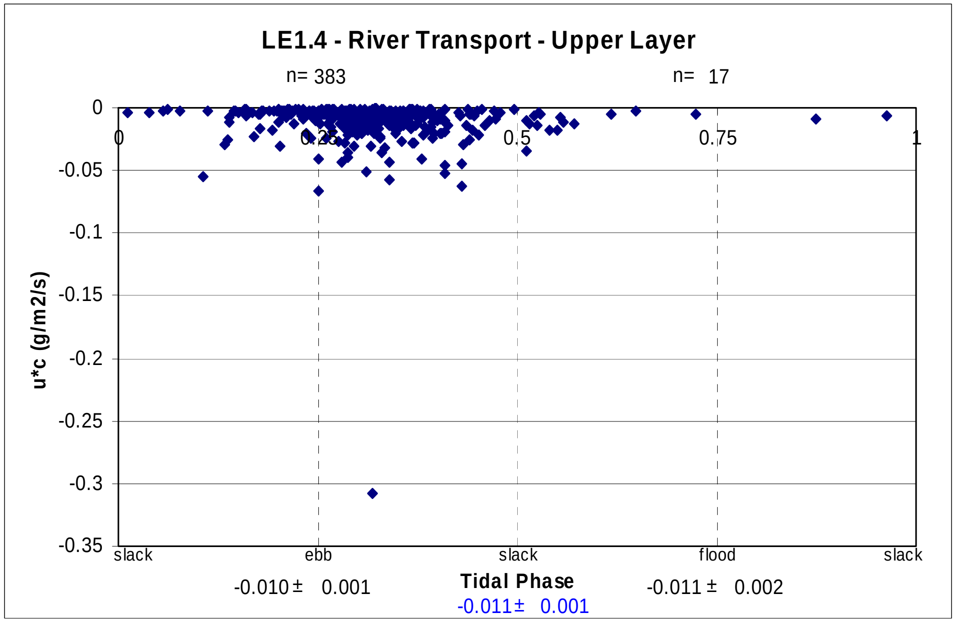

LE1.4 - Tidal Transport - Upper Layer
n= 383
n= 17
u*c (g/m2/s)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.507 ± 0.018
-0.011 ± 0.040
0.485 ± 0.079



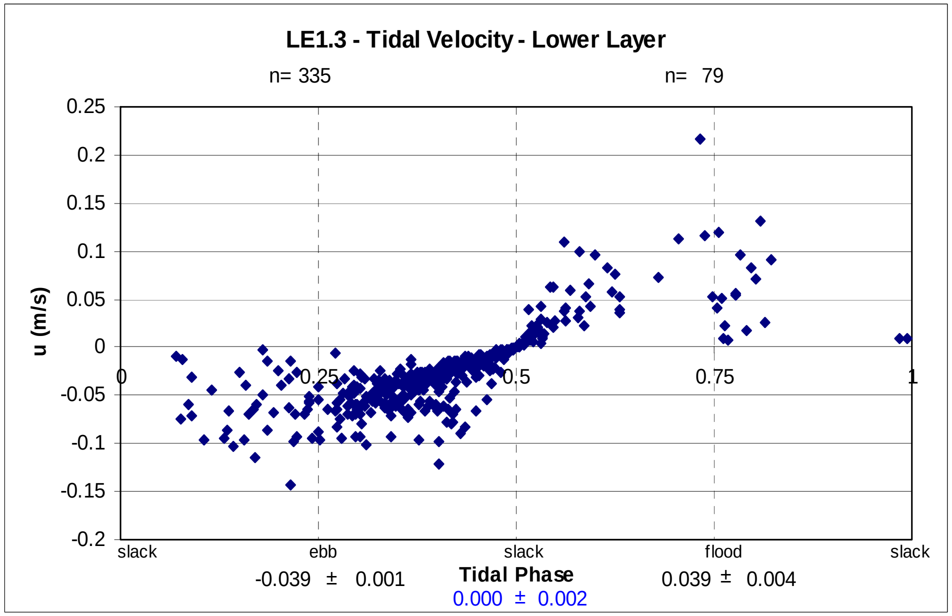
LE1.4 - Subtidal Transport - Upper Layer
n= 383
n= 17
u*c (g/m2/s)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.067 ± 0.009
0.098 ± 0.030
0.129 ± 0.059

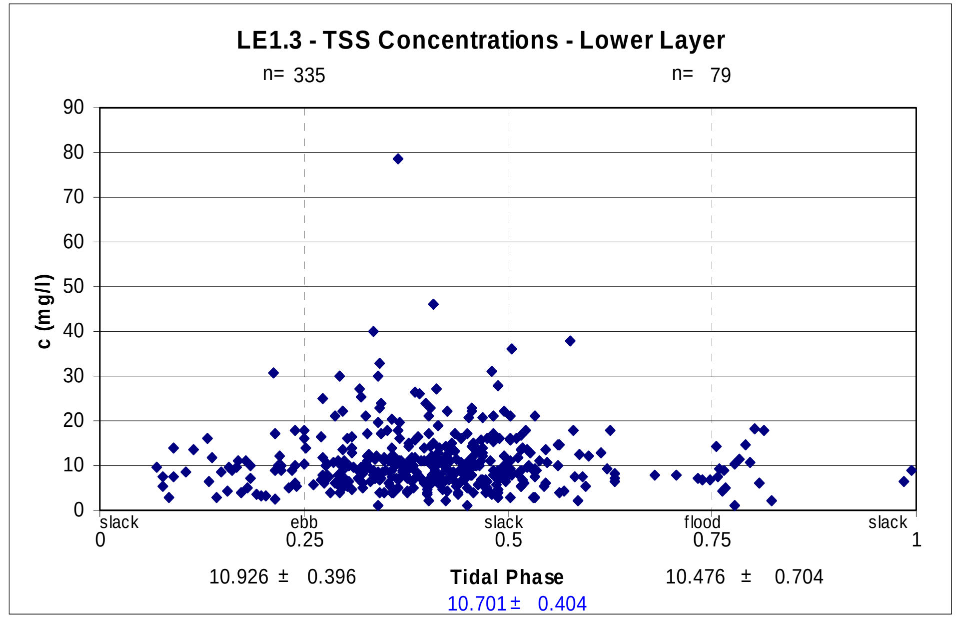


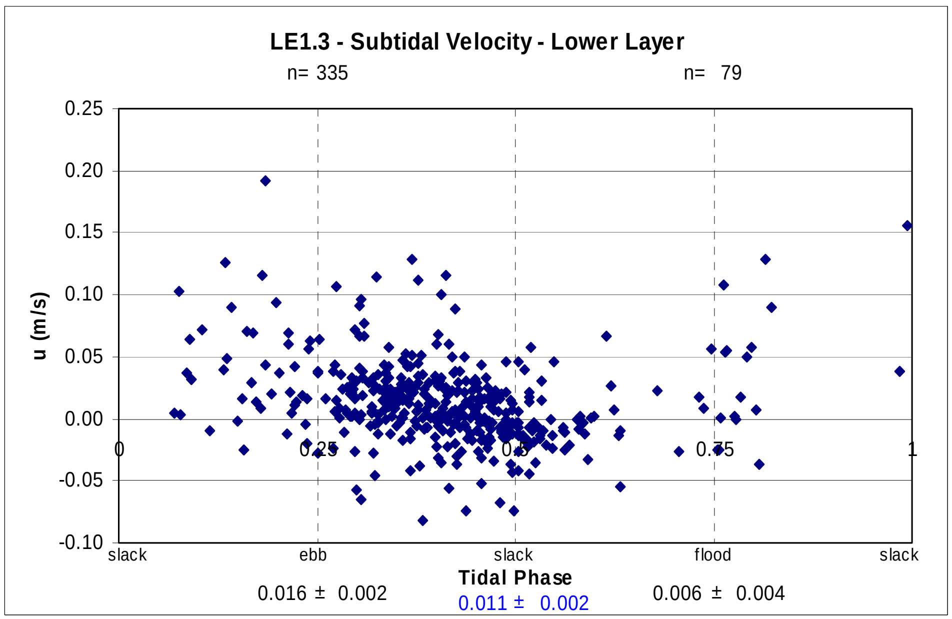
LE1.4 - River Velocity - Upper Layer
n= 383
n= 17
u (m/s)
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.001 ± 0.000
-0.001± 0.000
-0.001 ± 0.000

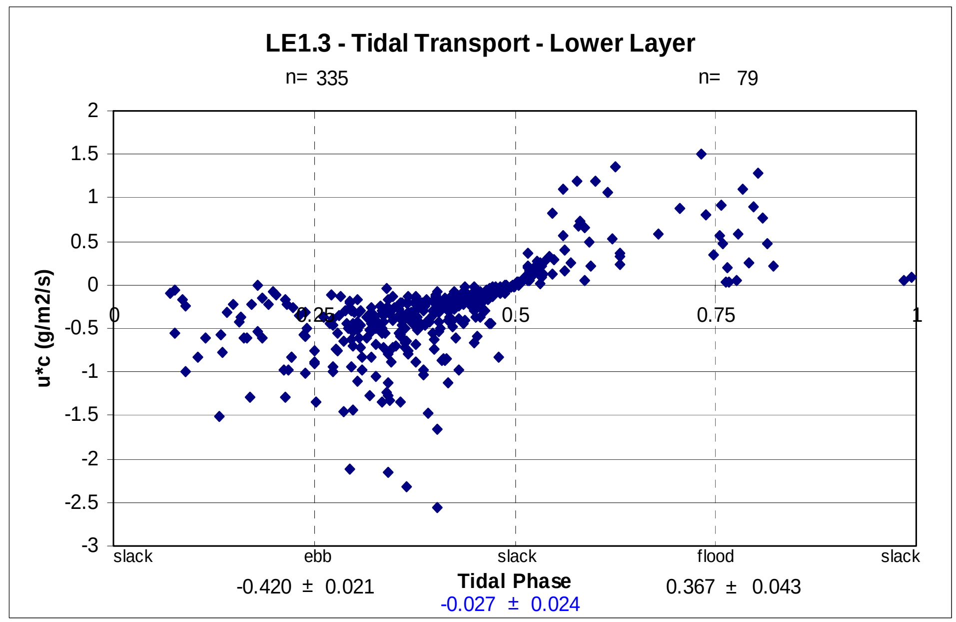


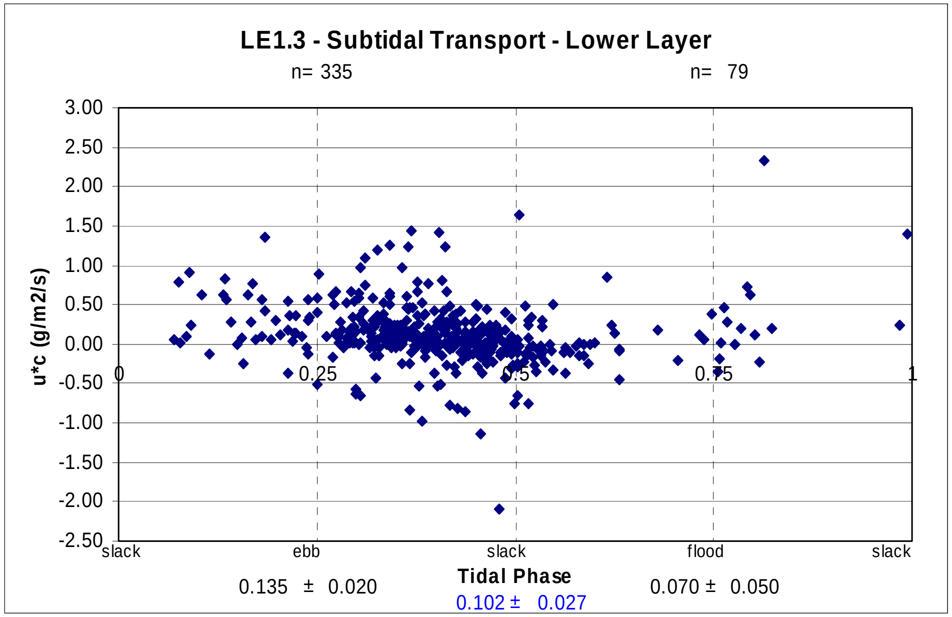
LE1.4 - River Transport - Upper Layer
n= 383
n= 17
u*c (g/m2/s)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.010 ± 0.001
-0.011 ± 0.001
-0.011 ± 0.002

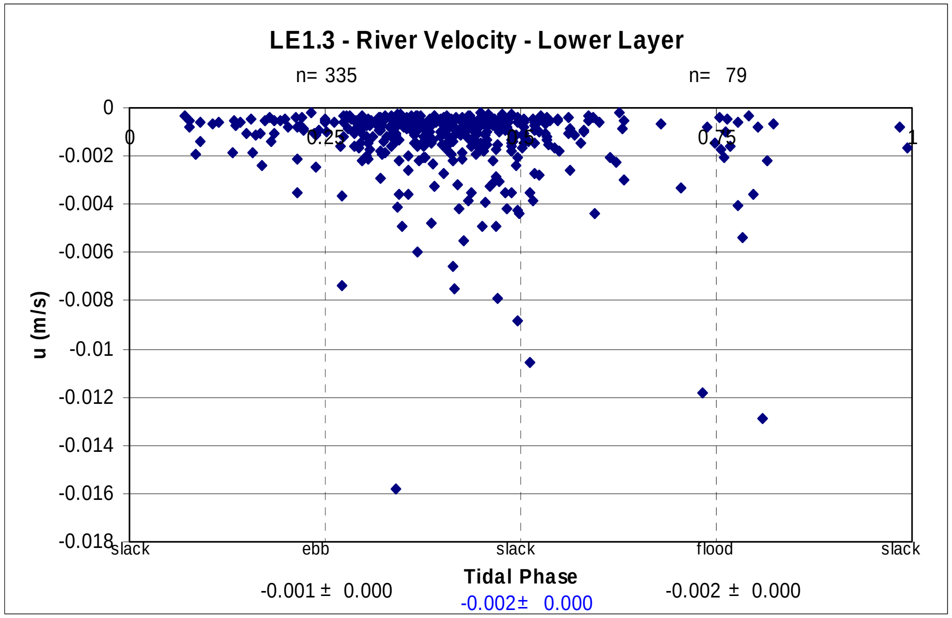

LE1.3 - Tidal Velocity - Lower Layer
n= 335
n= 79
u (m/s)
Tidal Phase
slack
ebb
slack
flood
slack
-0.039 ± 0.001
0.000 ± 0.002
0.039 ± 0.004

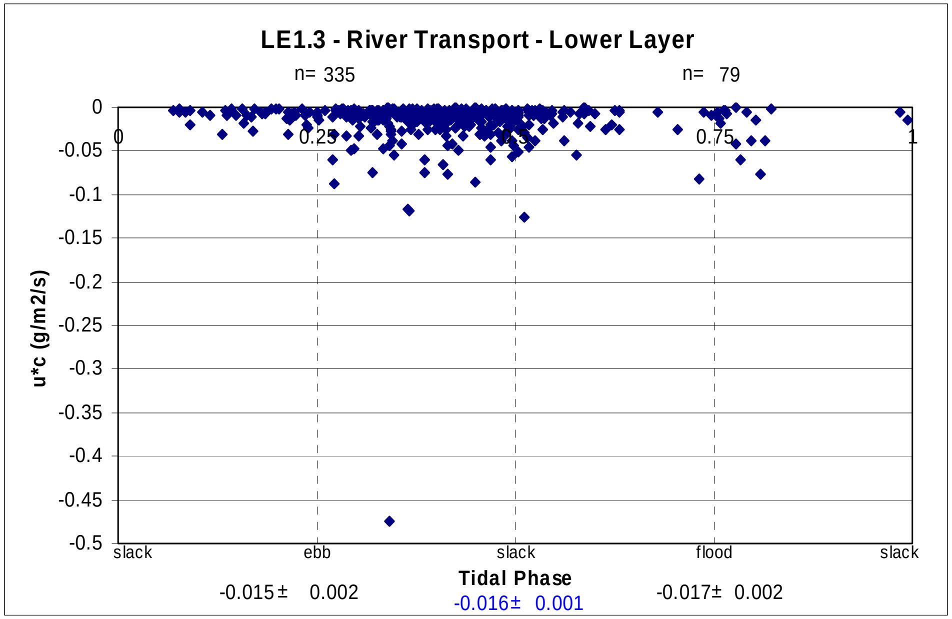

LE1.3 - TSS Concentrations - Lower Layer
n= 335
n= 79
c (mg/l)
Tidal Phase
slack
ebb
slack
flood
slack
10.926 ± 0.396
10.701 ± 0.404
10.476 ± 0.704

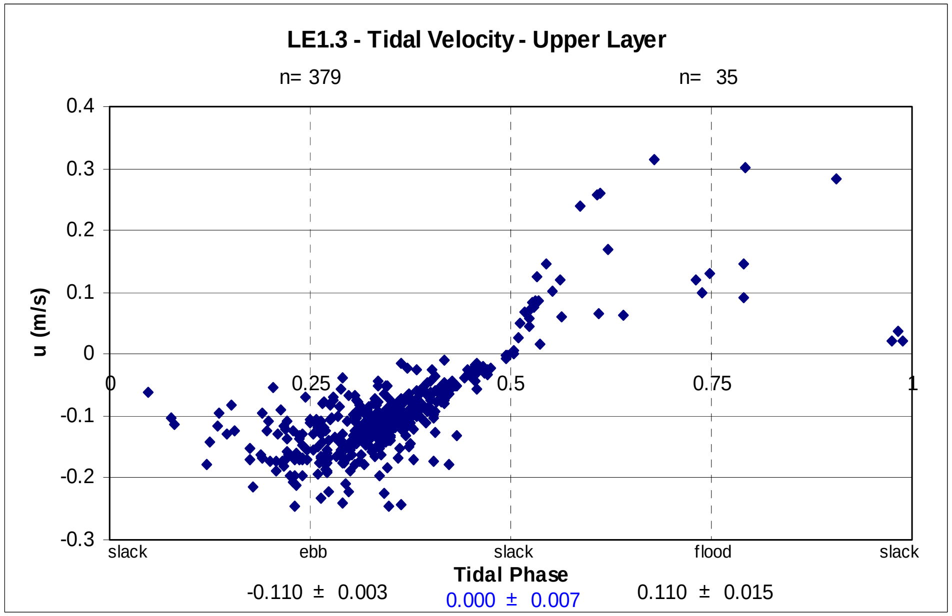

LE1.3 - Subtidal Velocity - Lower Layer
n= 335
n= 79
u (m/s)
Tidal Phase
slack
ebb
slack
flood
slack
0.016 ± 0.002
0.011 ± 0.002
0.006 ± 0.004

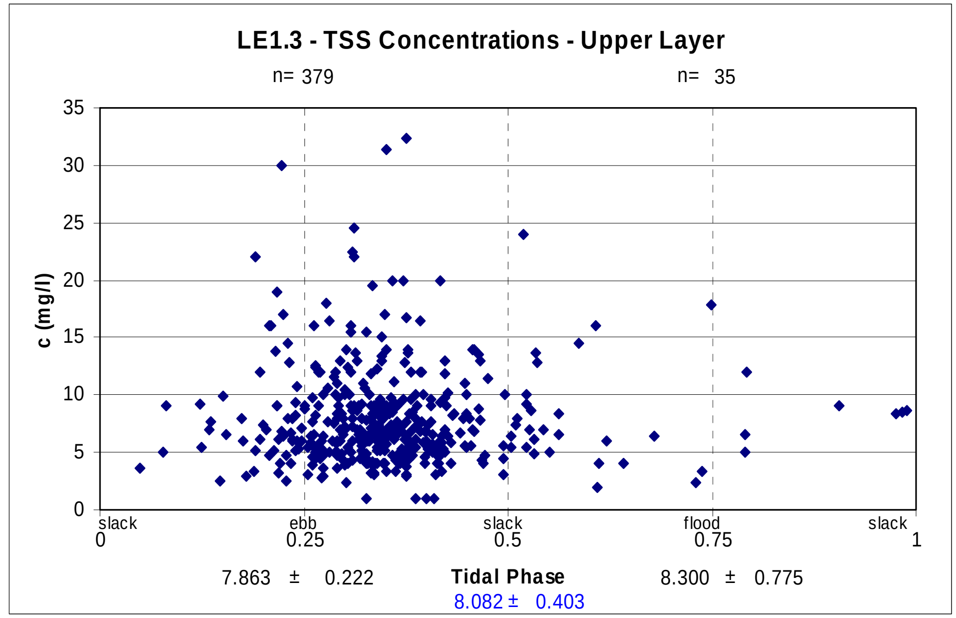

LE1.3 - Tidal Transport - Lower Layer
n= 335
n= 79
u*c (g/m2/s)
Tidal Phase
slack
ebb
slack
flood
slack
-0.420 ± 0.021
-0.027 ± 0.024
0.367 ± 0.043

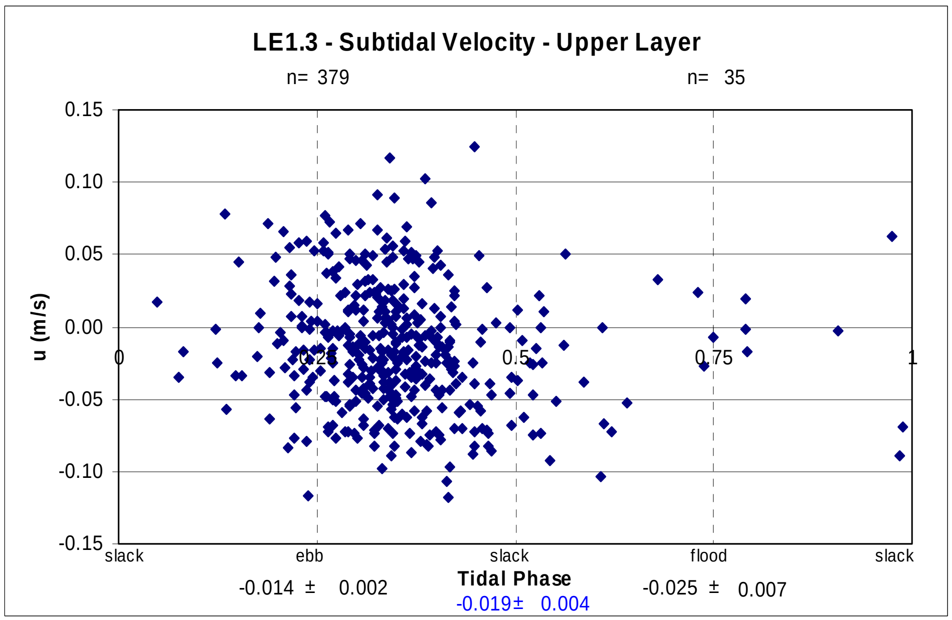

LE1.3 - Subtidal Transport - Lower Layer
n= 335
n= 79
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.135 ± 0.020
0.102 ± 0.027
0.070 ± 0.050

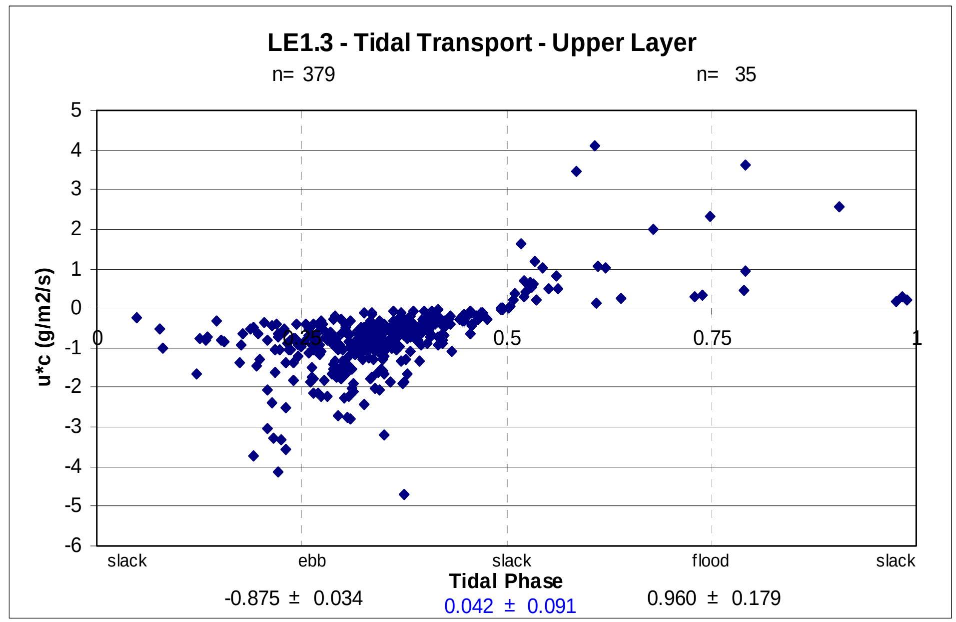

LE1.3 - River Velocity - Lower Layer
n= 335
n= 79
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.001 ± 0.000
-0.002± 0.000
-0.002 ± 0.000

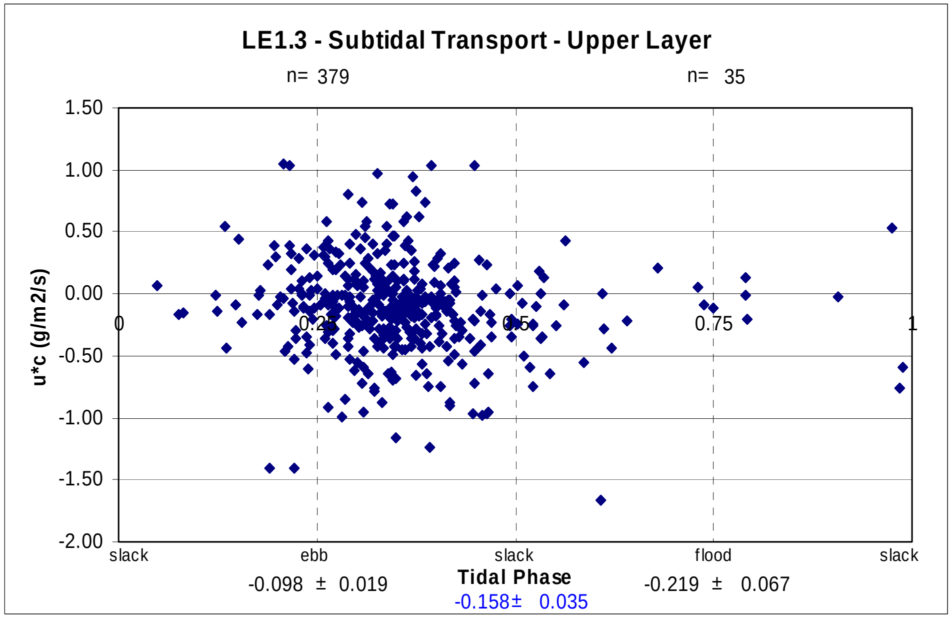

LE1.3 - River Transport - Lower Layer
n= 335
n= 79
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.015 ± 0.002
-0.016± 0.001
-0.017± 0.002

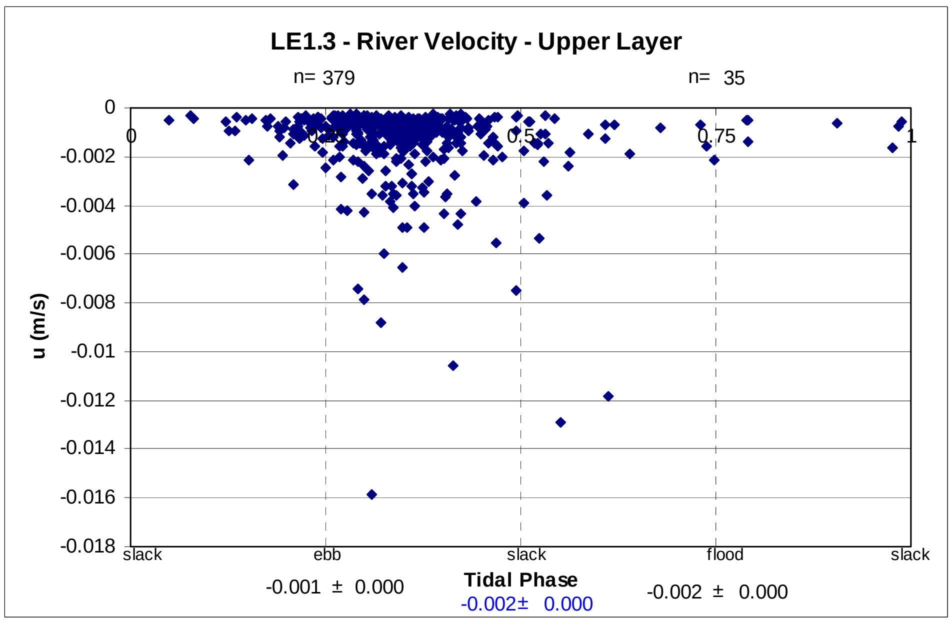

LE1.3 - Tidal Velocity - Upper Layer
n= 379
n= 35
u (m/s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.110 ± 0.003
0.000 ± 0.007
0.110 ± 0.015

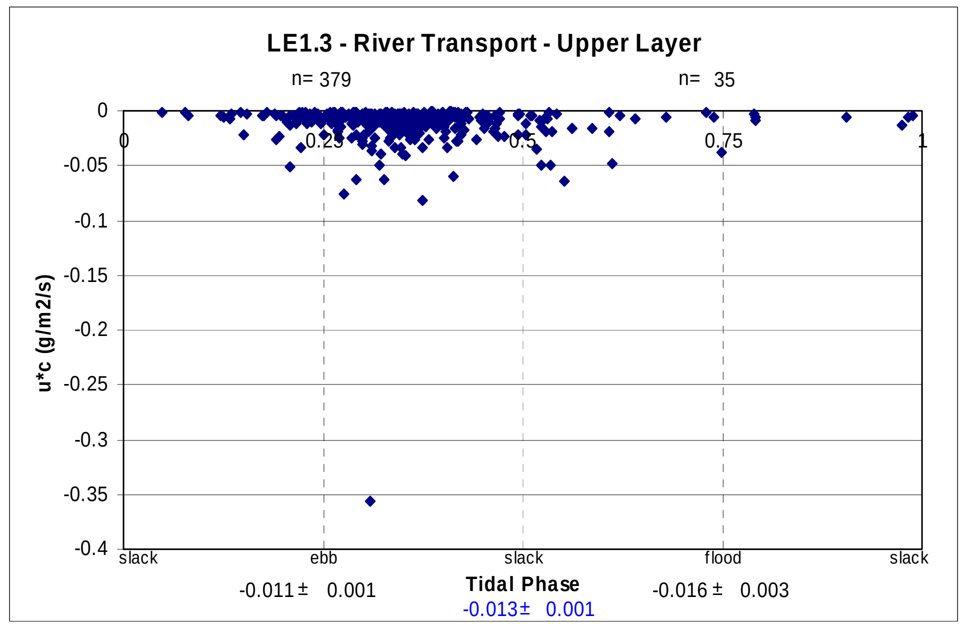

LE1.3 - TSS Concentrations - Upper Layer
n= 379
n= 35
c (mg/l)
35
30
25
20
15
10
5
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
7.863 ± 0.222
Tidal Phase
8.300 ± 0.775
8.082 ± 0.403

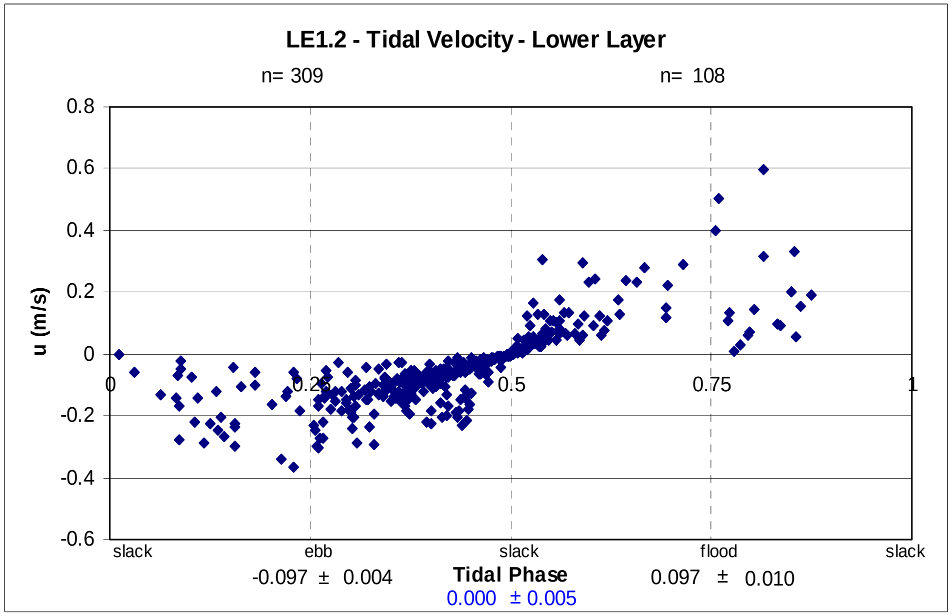

LE1.3 - Subtidal Velocity - Upper Layer
n= 379
n= 35
u (m/s)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.014 ± 0.002
-0.019± 0.004
-0.025 ± 0.007

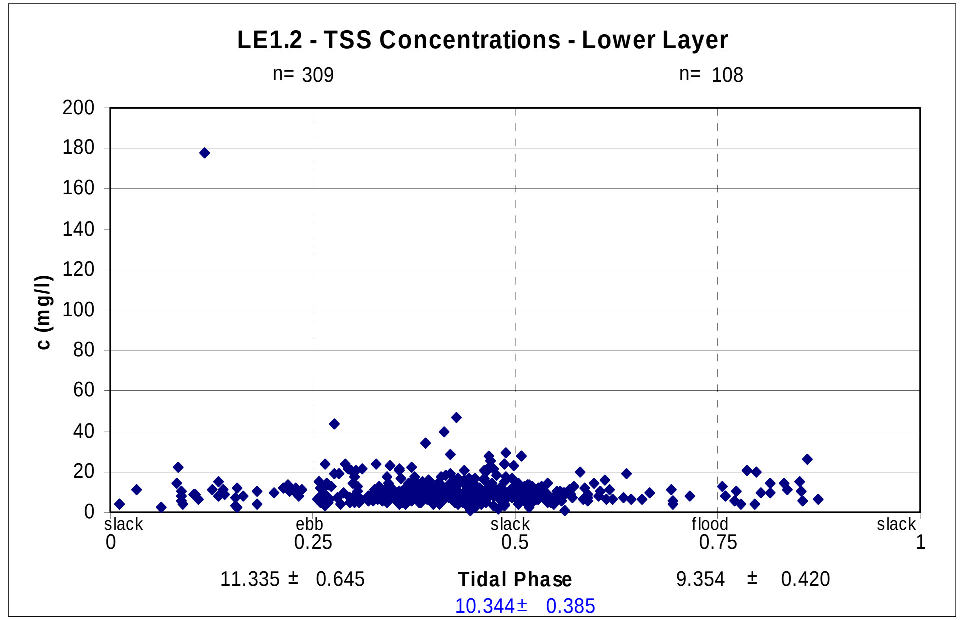

LE1.3 - Tidal Transport - Upper Layer
n= 379
n= 35
u*c (g/m2/s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.875 ± 0.034
0.042 ± 0.091
0.960 ± 0.179

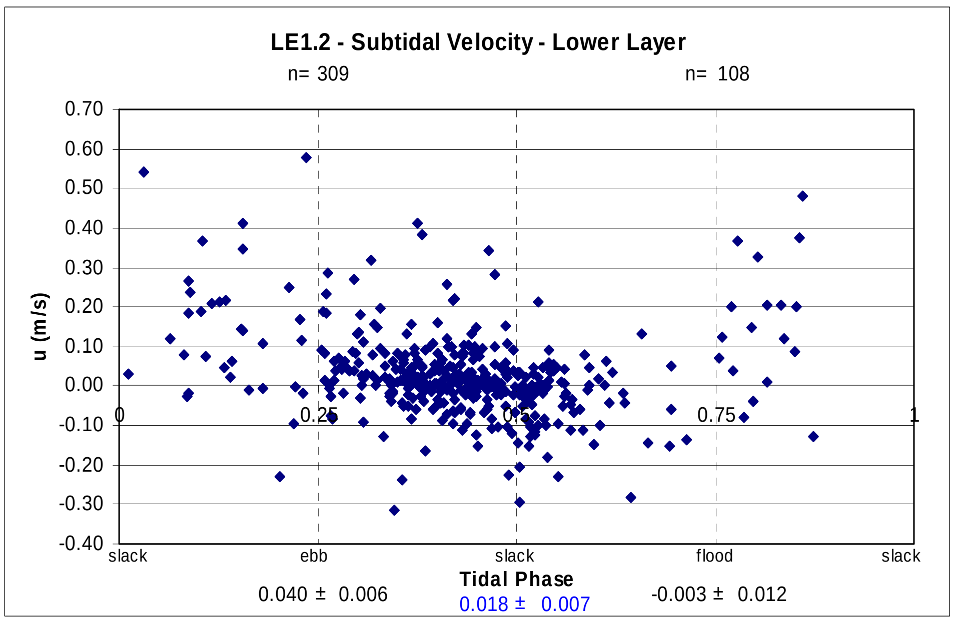

LE1.3 - Subtidal Transport - Upper Layer
n= 379
n= 35
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.098 ± 0.019
-0.158± 0.035
-0.219 ± 0.067

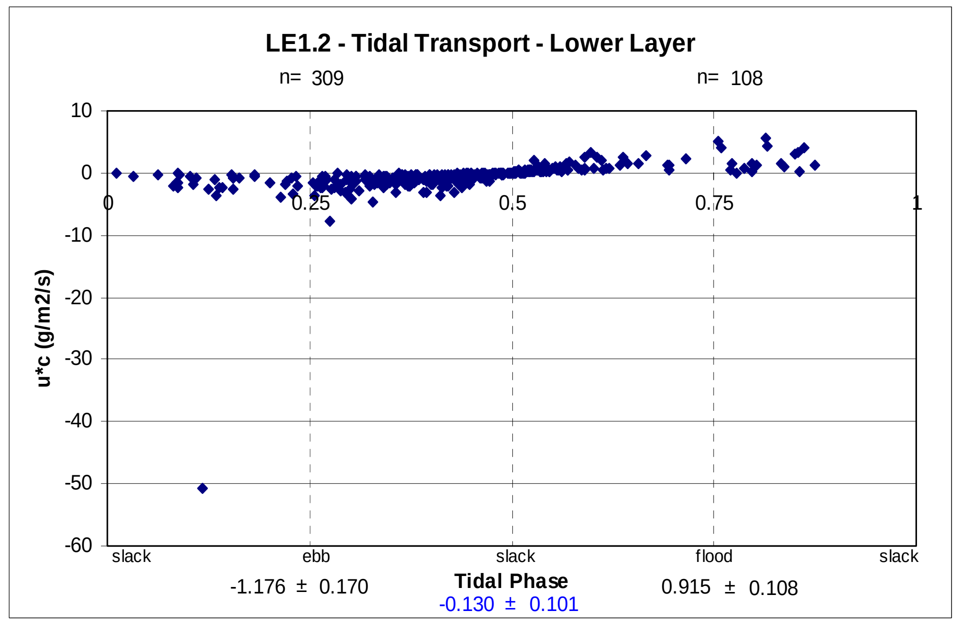

LE1.3 - River Velocity - Upper Layer
n= 379
n= 35
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.001 ± 0.000
-0.002± 0.000
-0.002 ± 0.000

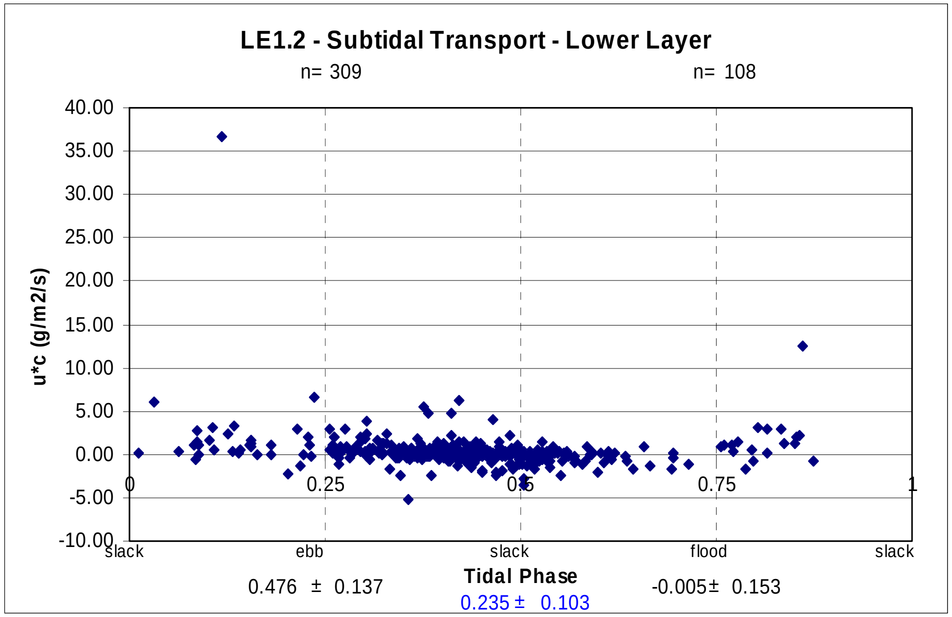

LE1.3 - River Transport - Upper Layer
n= 379
n= 35
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.011 ± 0.001
-0.013± 0.001
-0.016 ± 0.003

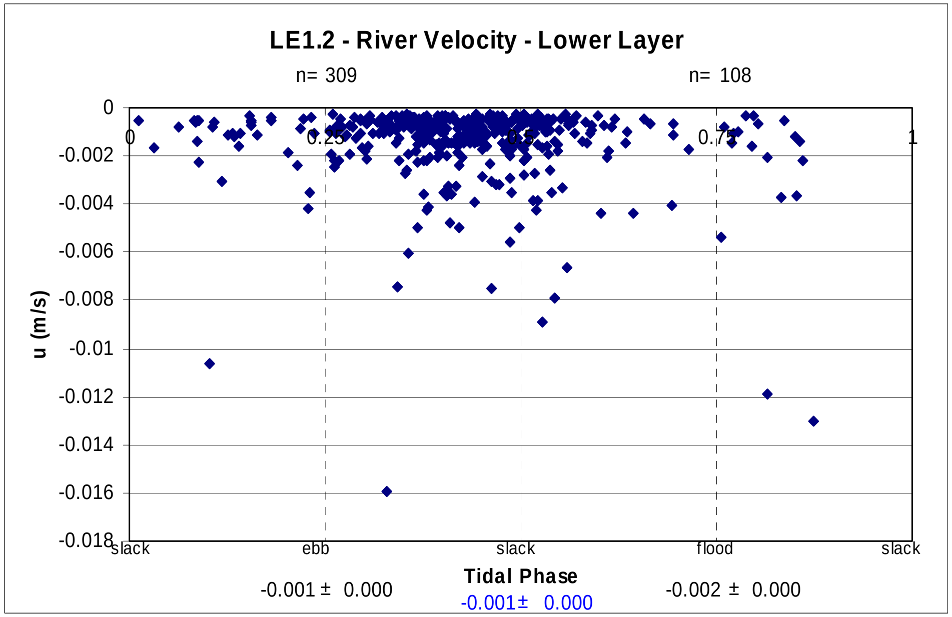

LE1.2 - Tidal Velocity - Lower Layer
n= 309
n= 108
u (m/s)
slack
ebb
slack
flood
slack
-0.097 ± 0.004
Tidal Phase
0.097 ± 0.010
0.000 ± 0.005

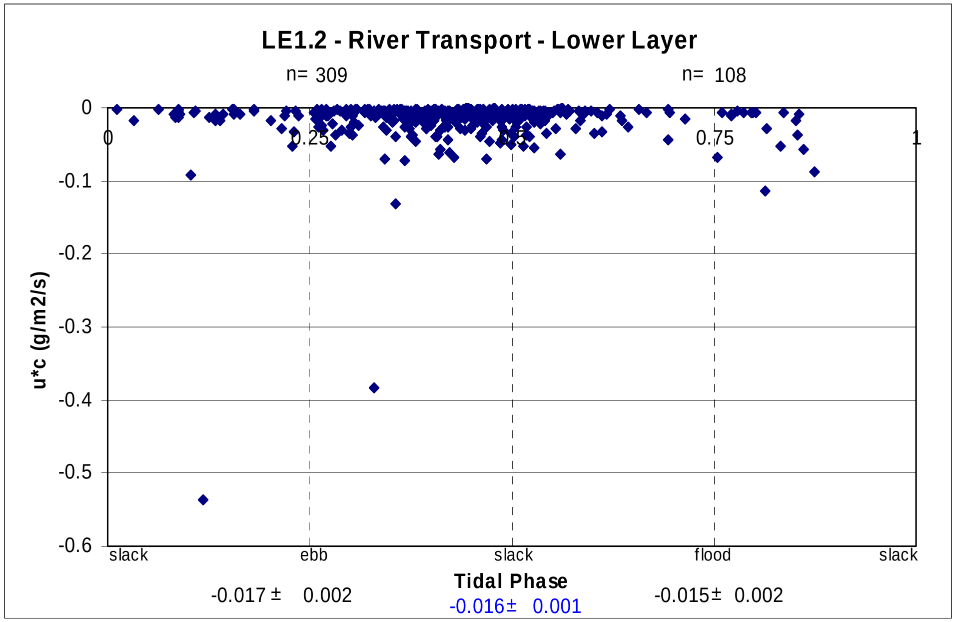

LE1.2 - TSS Concentrations - Lower Layer
n= 309
n= 108
c (mg/l)
slack
ebb
slack
flood
slack
11.335 ± 0.645
Tidal Phase
9.354 ± 0.420
10.344± 0.385

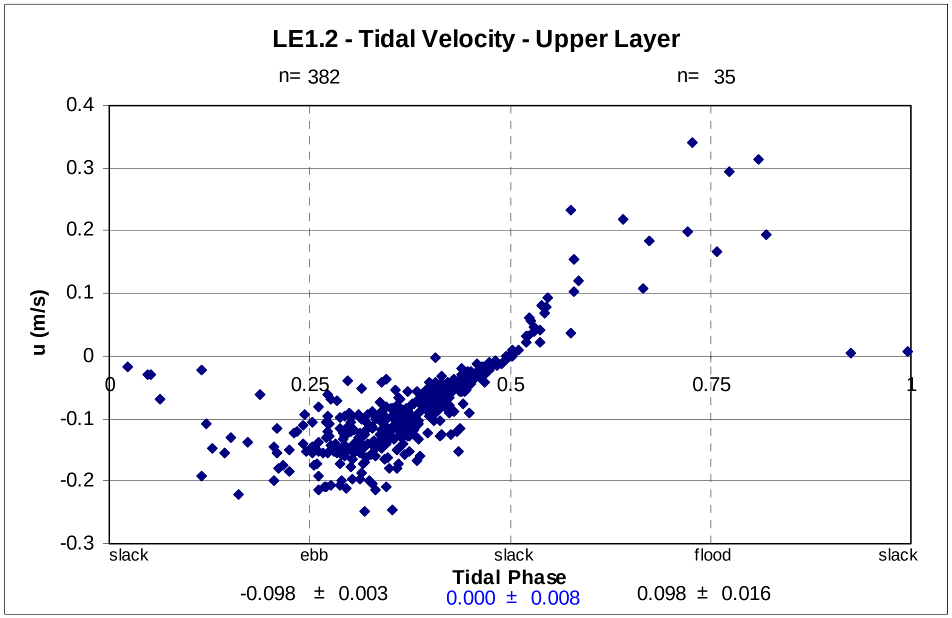

LE1.2 - Subtidal Velocity - Lower Layer
n= 309
n= 108
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
0.040 ± 0.006
-0.003 ± 0.012
0.018 ± 0.007


LE1.2 - Tidal Transport - Lower Layer
n= 309
n= 108
u*c (g/m2/s)
slack
ebb
slack
flood
slack
-1.176 ± 0.170
Tidal Phase
0.915 ± 0.108
-0.130 ± 0.101

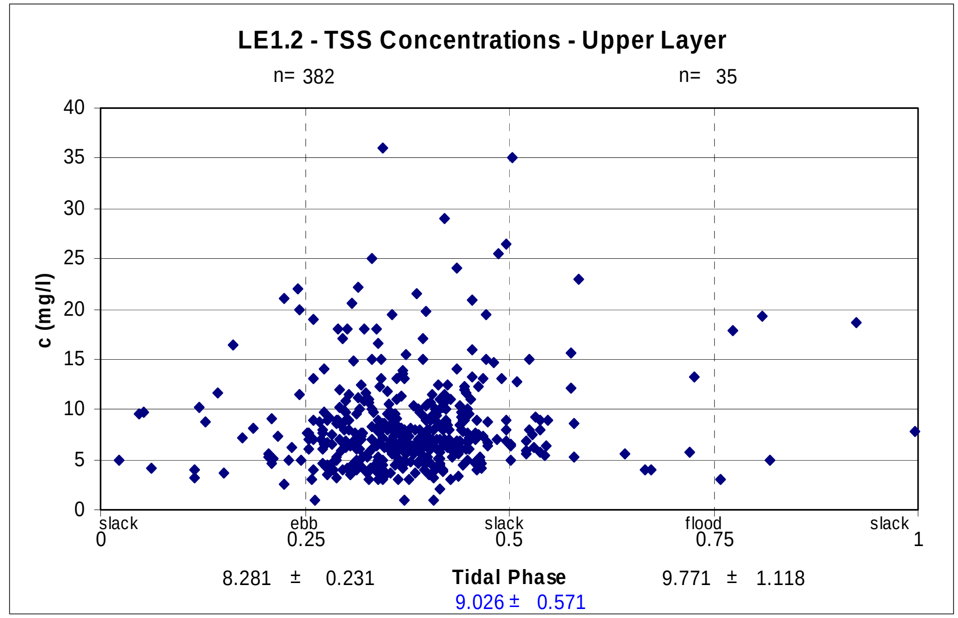

LE1.2 - Subtidal Transport - Lower Layer
n= 309
n= 108
u*c (g/m2/s)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.476 ± 0.137
0.235 ± 0.103
-0.005± 0.153


LE1.2 - River Velocity - Lower Layer
n= 309
n= 108
u (m/s)
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.001 ± 0.000
-0.001± 0.000
-0.002 ± 0.000

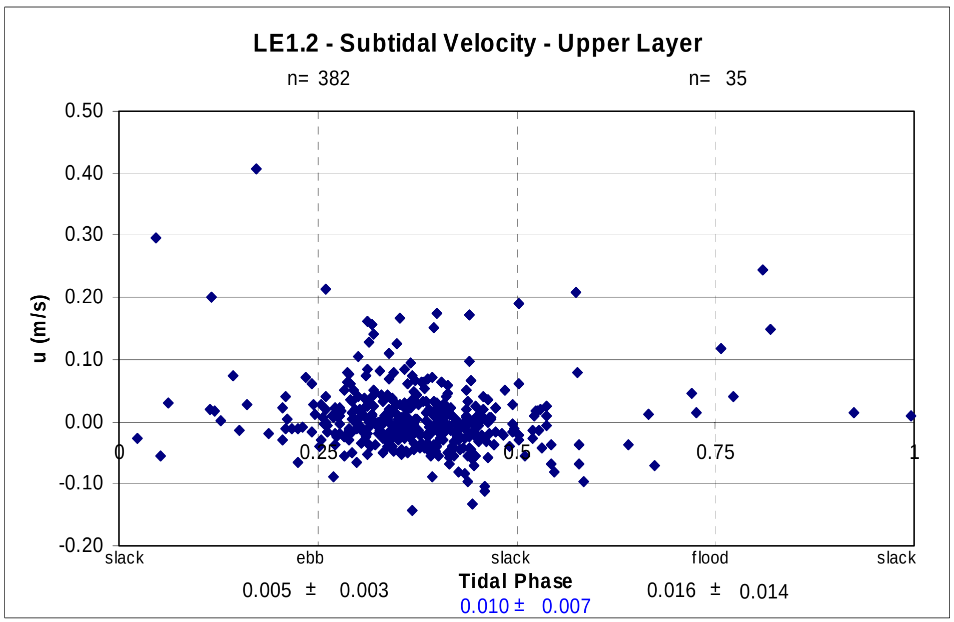

LE1.2 - River Transport - Lower Layer
n= 309
n= 108
u*c (g/m2/s)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.017 ± 0.002
-0.016± 0.001
-0.015± 0.002



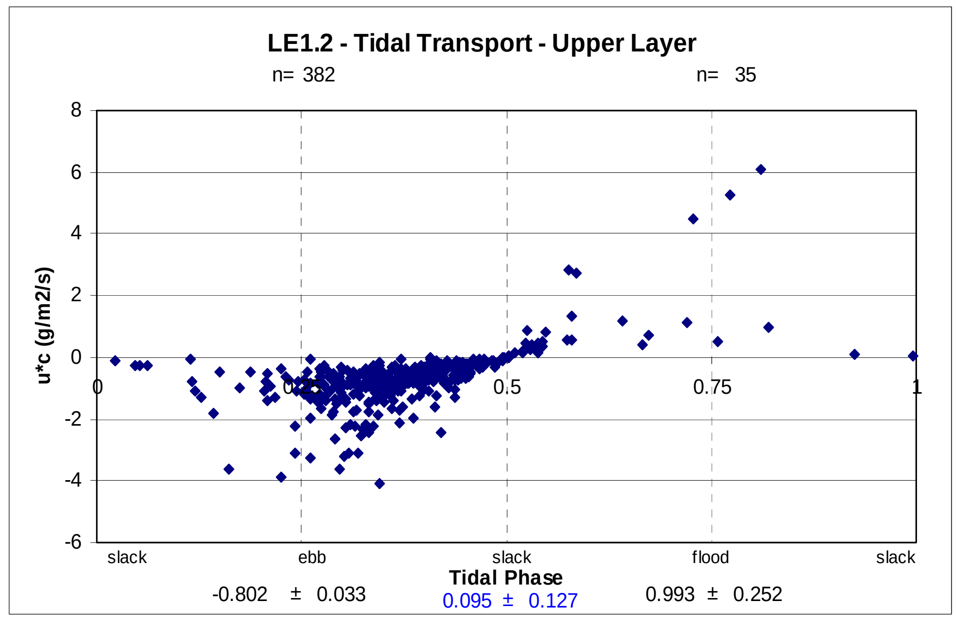
LE1.2 - Tidal Velocity - Upper Layer
n= 382
n= 35
u (m/s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.098 ± 0.003
0.000 ± 0.008
0.098 ± 0.016



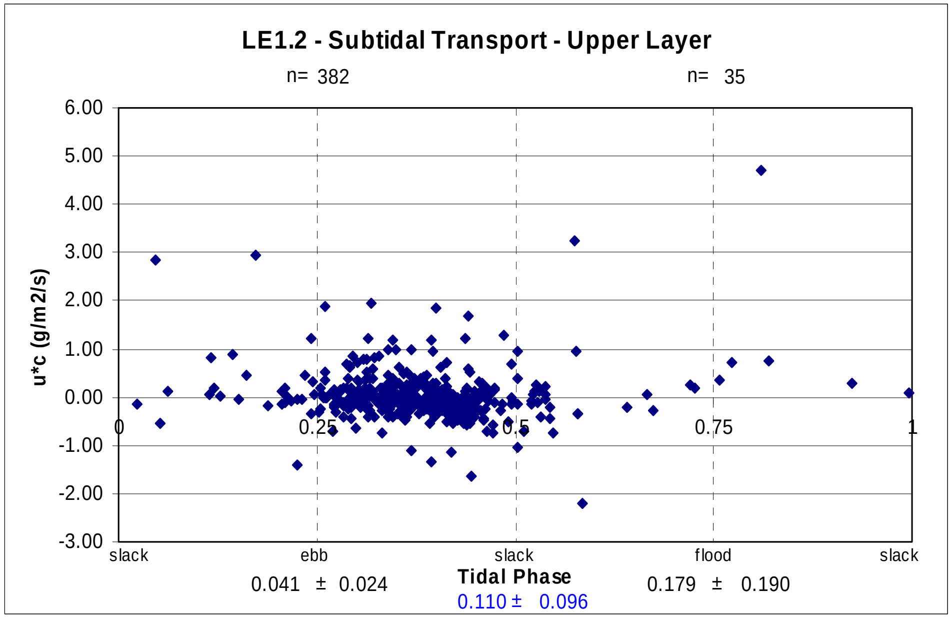
LE1.2 - TSS Concentrations - Upper Layer
n= 382
n= 35
c (mg/l)
40
35
30
25
20
15
10
5
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
8.281 ± 0.231
Tidal Phase
9.771 ± 1.118
9.026 ± 0.571

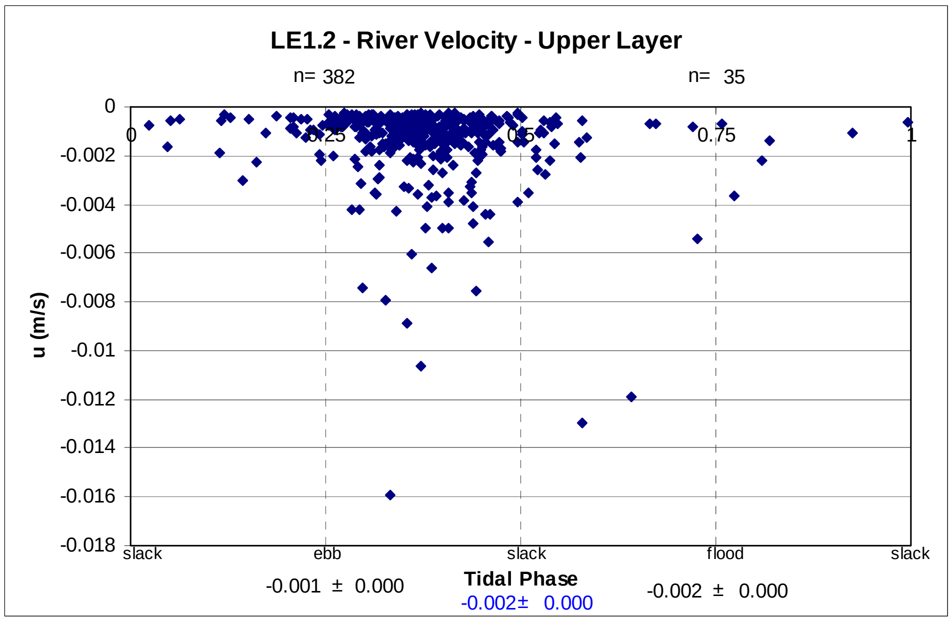


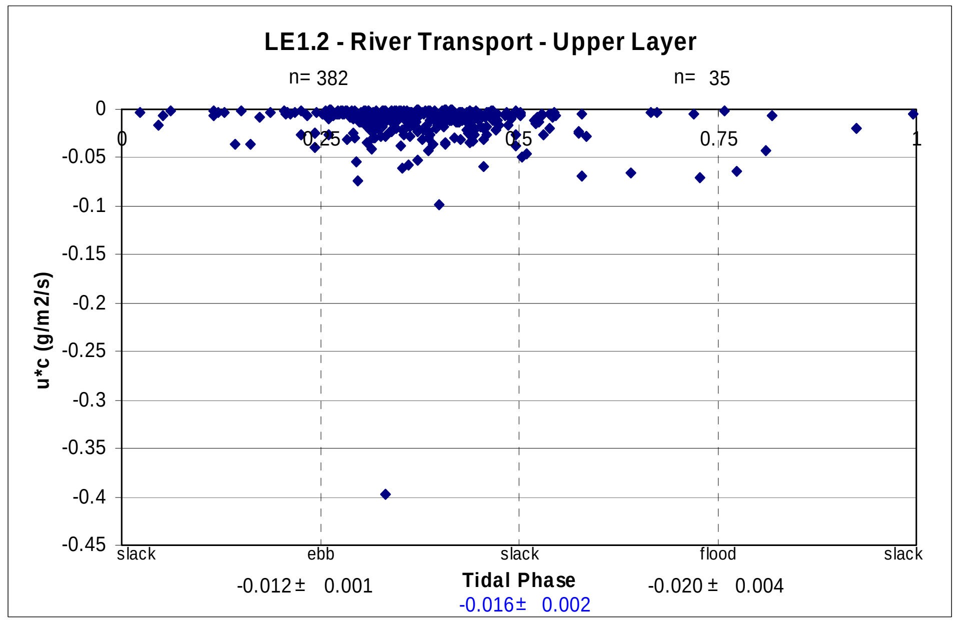
LE1.2 - Subtidal Velocity - Upper Layer
n= 382
n= 35
u (m/s)
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.005 ± 0.003
Tidal Phase
0.016 ± 0.014
0.010 ± 0.007

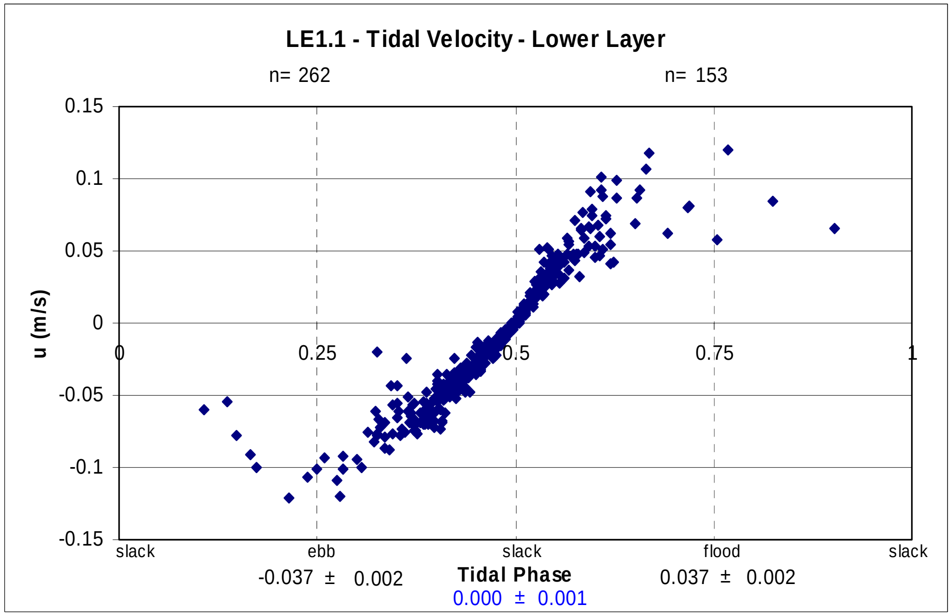


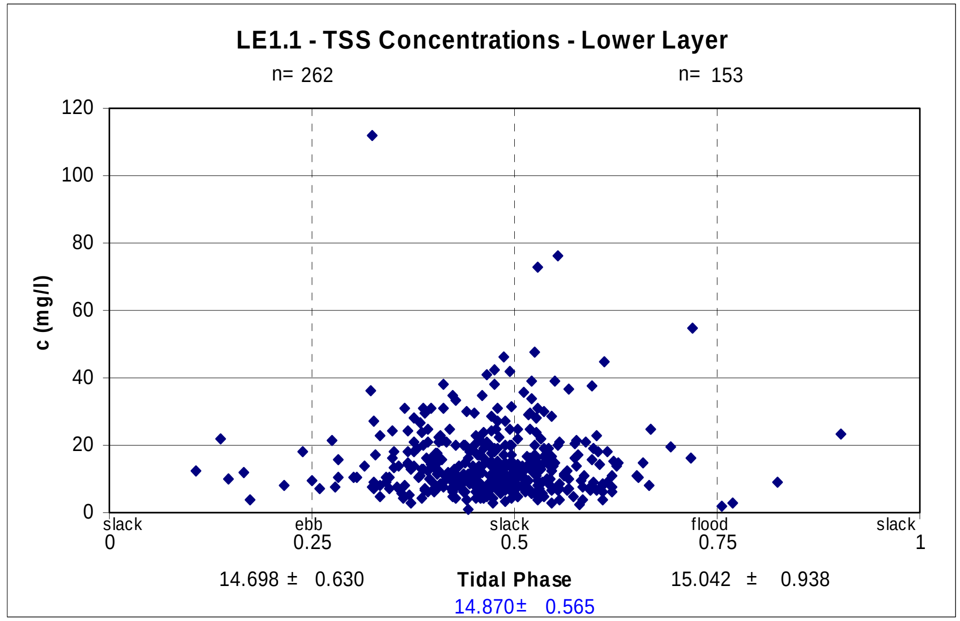
LE1.2 - Tidal Transport - Upper Layer
n= 382
n= 35
u*c (g/m2/s)
8
6
4
2
0
-2
-4
-6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.802 ± 0.033
0.095 ± 0.127
0.993 ± 0.252

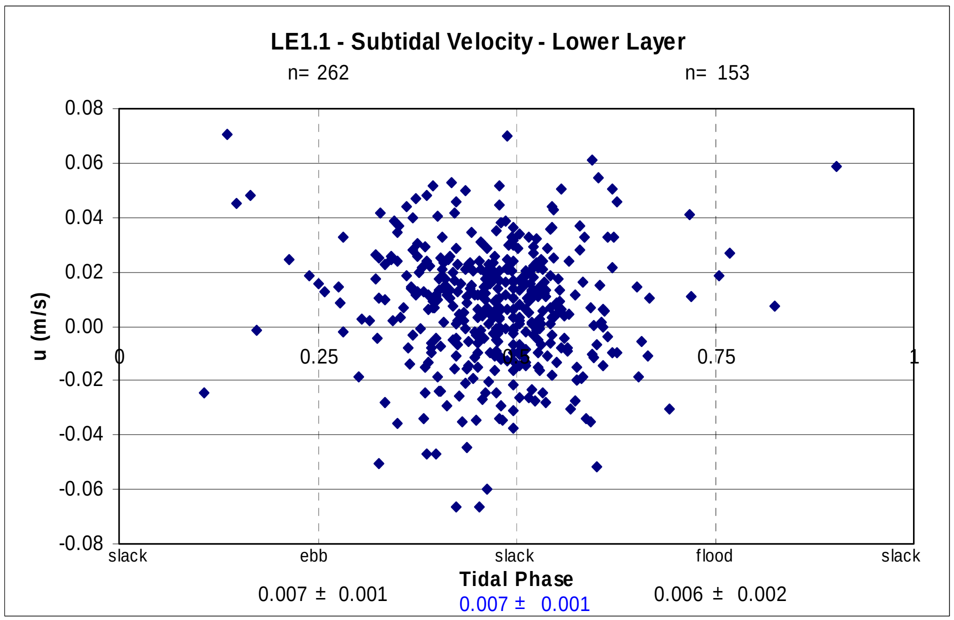

LE1.2 - Subtidal Transport - Upper Layer
n= 382
n= 35
u*c (g/m2/s)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.041 ± 0.024
0.110 ± 0.096
0.179 ± 0.190

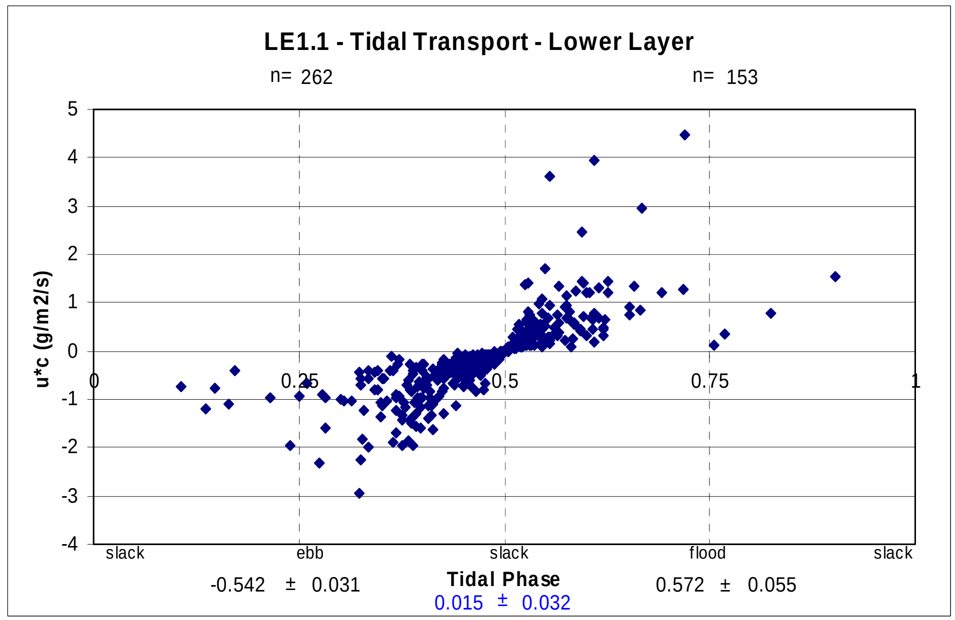

LE1.2 - River Velocity - Upper Layer
n= 382
n= 35
u (m/s)
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.001 ± 0.000
-0.002± 0.000
-0.002 ± 0.000

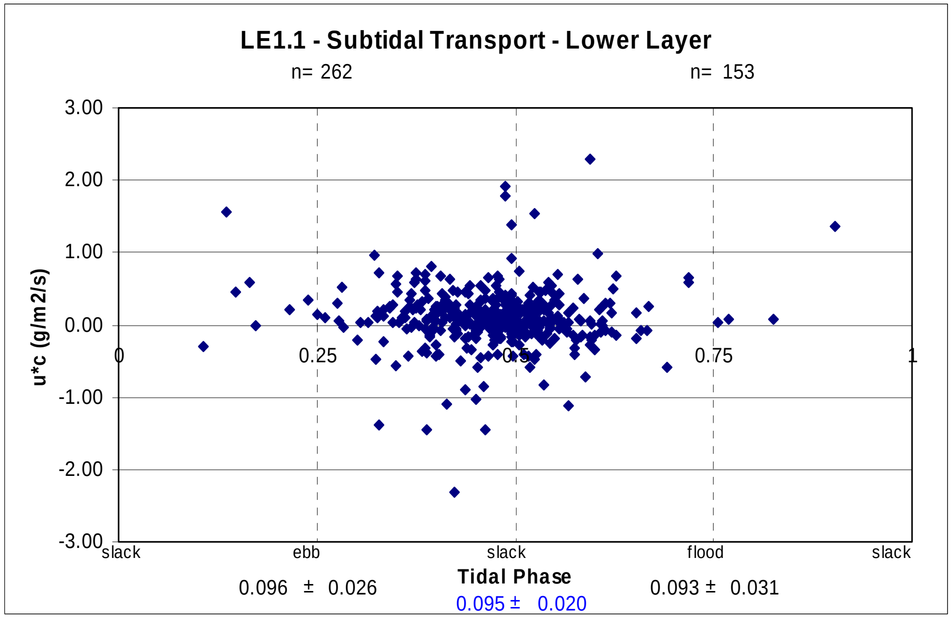

LE1.2 - River Transport - Upper Layer
n= 382
n= 35
u*c (g/m2/s)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.012 ± 0.001
-0.016± 0.002
-0.020 ± 0.004

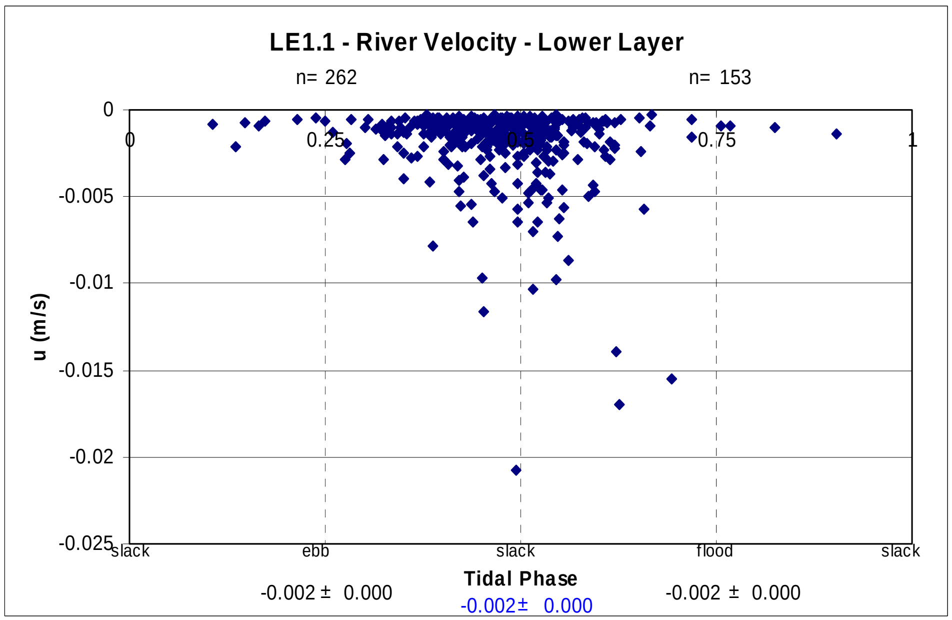

LE1.1 - Tidal Velocity - Lower Layer
n= 262
n= 153
u (m/s)
slack
ebb
slack
flood
slack
-0.037 ± 0.002
Tidal Phase
0.037 ± 0.002
0.000 ± 0.001

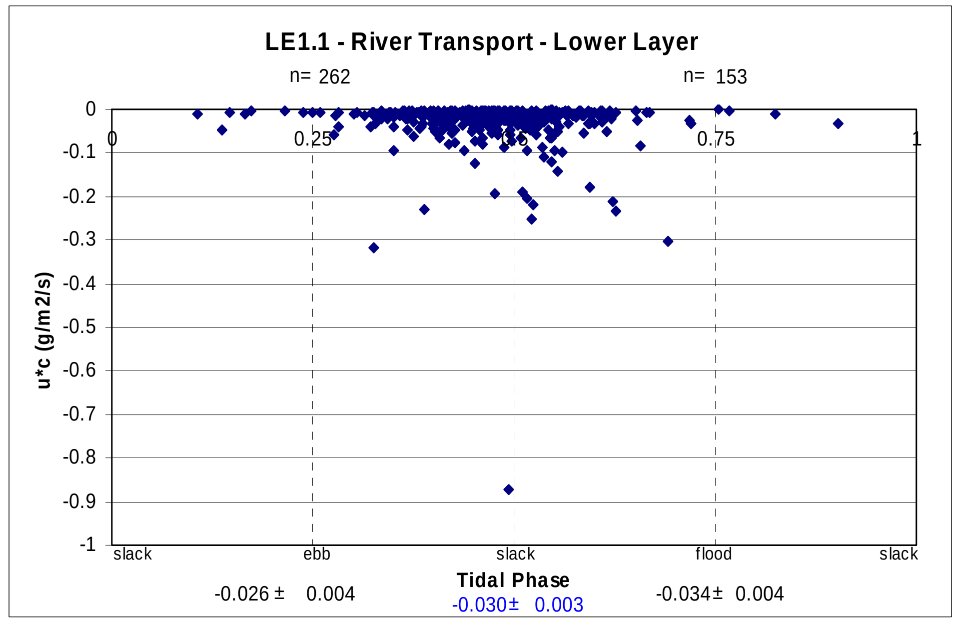

LE1.1 - TSS Concentrations - Lower Layer
n= 262
n= 153
c (mg/l)
slack
ebb
slack
flood
slack
14.698 ± 0.630
Tidal Phase
15.042 ± 0.938
14.870± 0.565

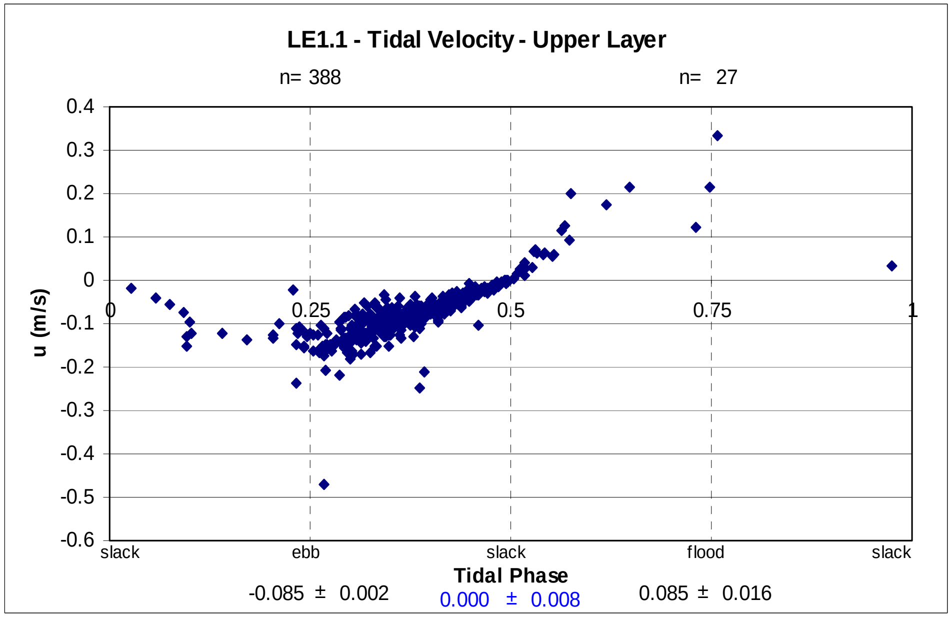

LE1.1 - Subtidal Velocity - Lower Layer
n= 262
n= 153
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
0.007 ± 0.001
0.006 ± 0.002
0.007 ± 0.001

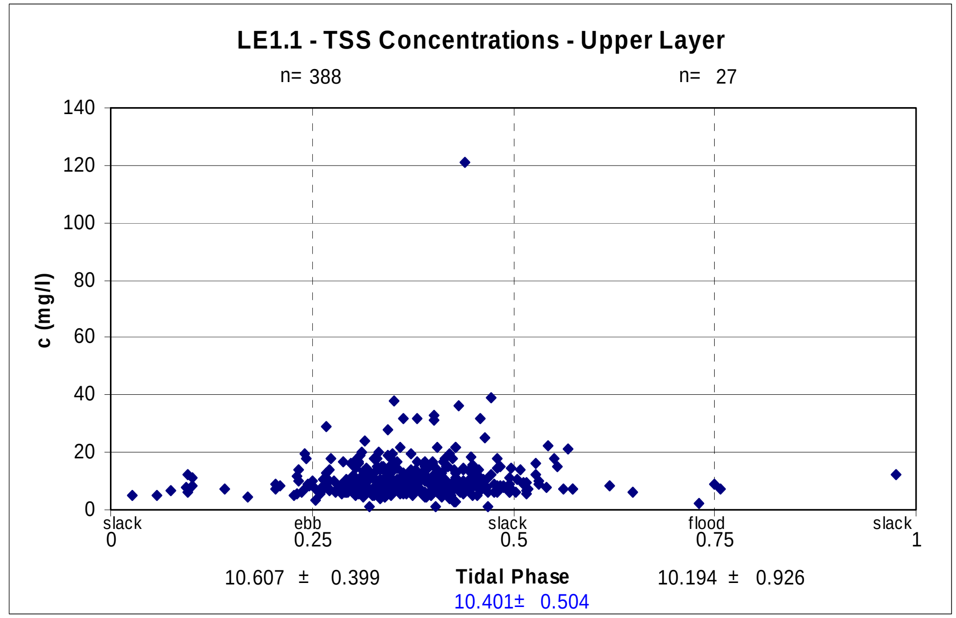

LE1.1 - Tidal Transport - Lower Layer
n= 262
n= 153
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.542 ± 0.031
0.572 ± 0.055
0.015 ± 0.032

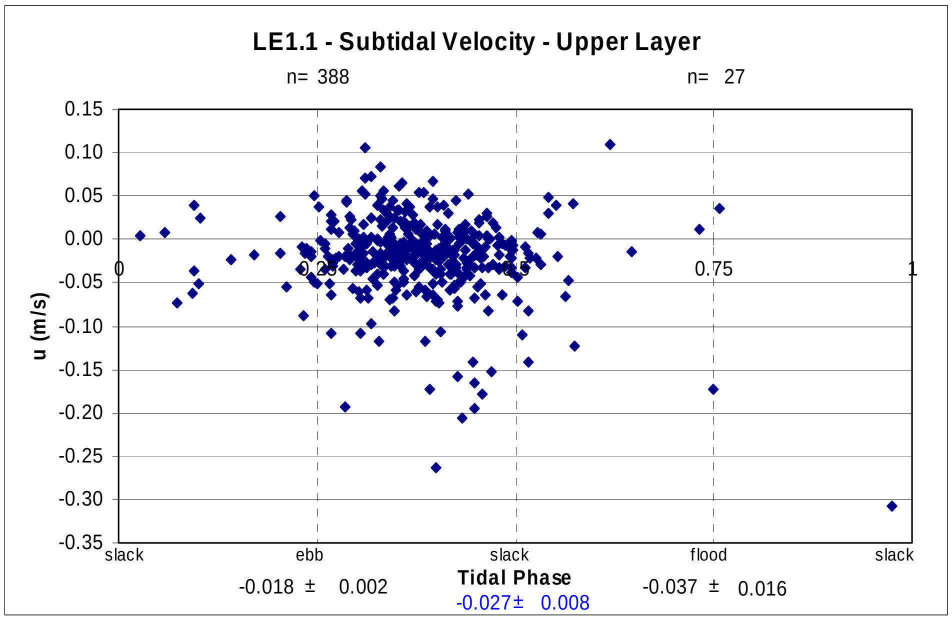

LE1.1 - Subtidal Transport - Lower Layer
n= 262
n= 153
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0
0.25
0.5
0.75
1
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
0.096 ± 0.026
0.095 ± 0.020
0.093 ± 0.031

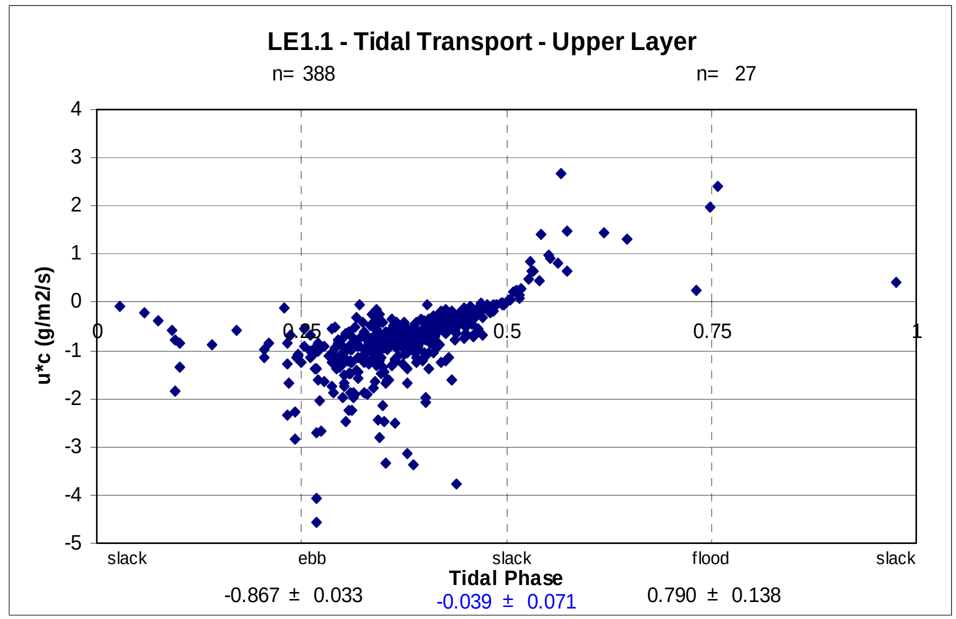

LE1.1 - River Velocity - Lower Layer
n= 262
n= 153
0
-0.005
-0.01
-0.015
-0.02
-0.025
0
0.25
0.5
0.75
1
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.002 ± 0.000
-0.002± 0.000
-0.002 ± 0.000

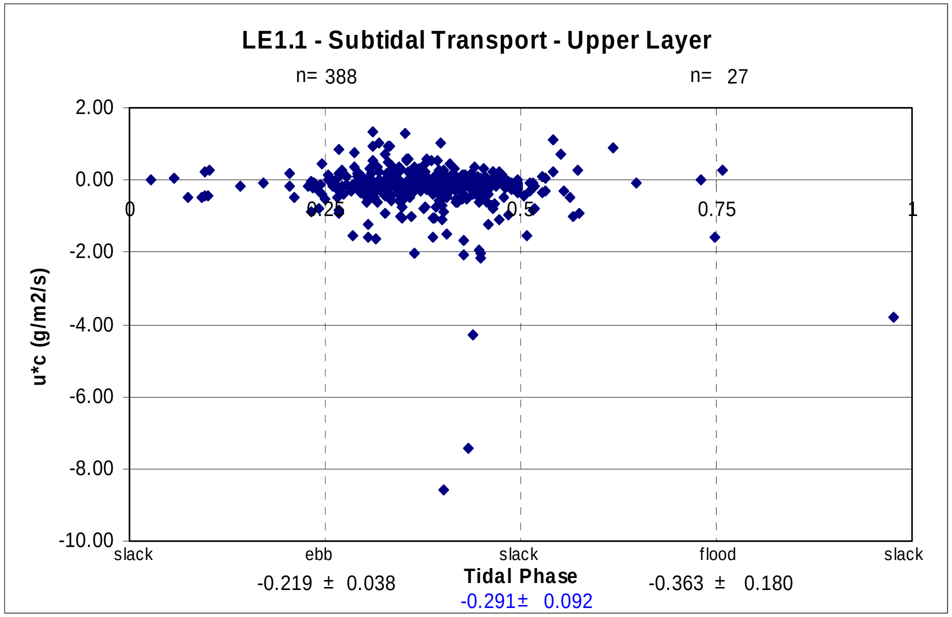

LE1.1 - River Transport - Lower Layer
n= 262
n= 153
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
0
0.25
0.5
0.75
1
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.026 ± 0.004
-0.030± 0.003
-0.034± 0.004

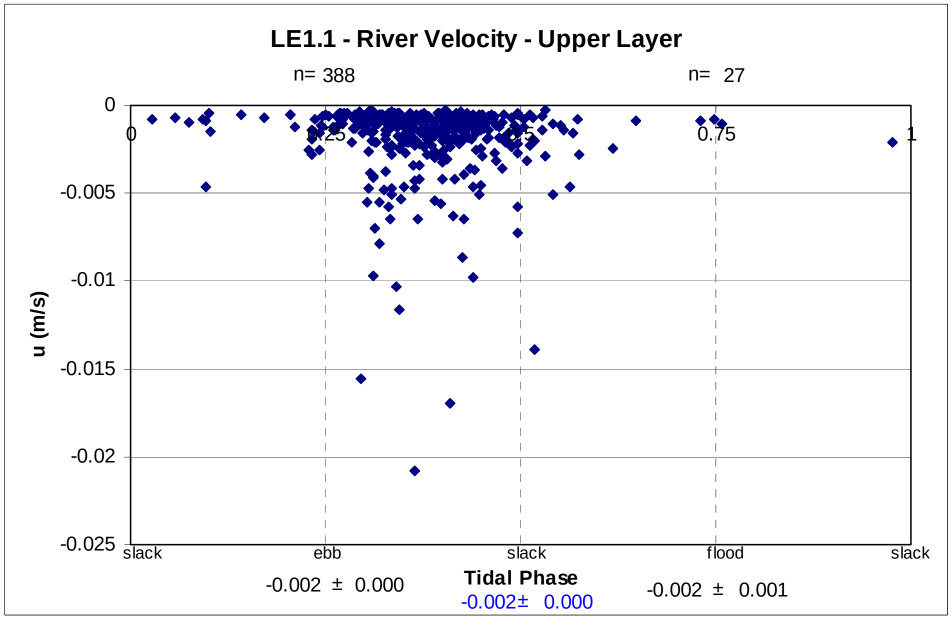

LE1.1 - Tidal Velocity - Upper Layer
n= 388
n= 27
u (m/s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.085 ± 0.002
0.000 ± 0.008
0.085 ± 0.016

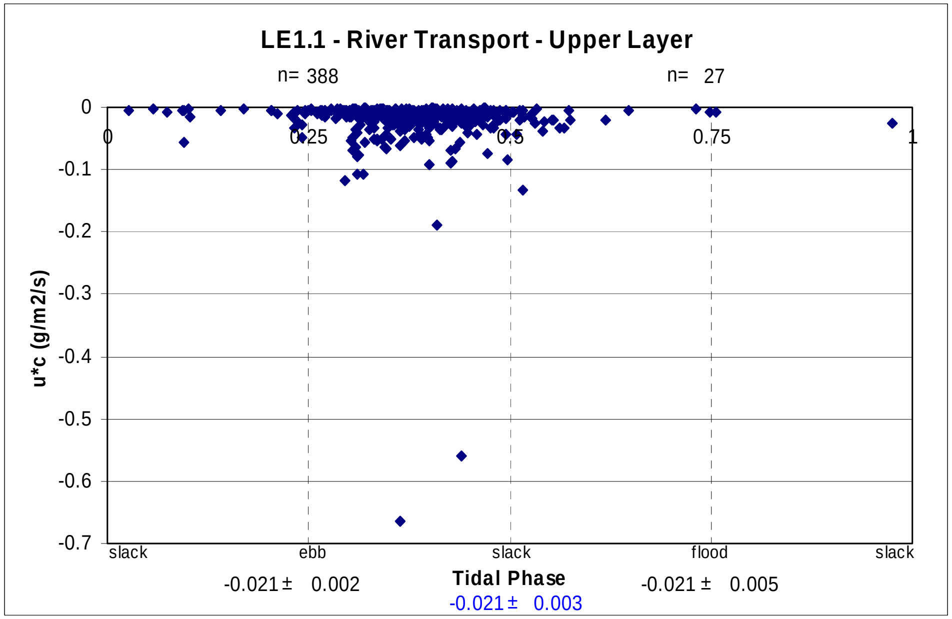

LE1.1 - TSS Concentrations - Upper Layer
n= 388
n= 27
c (mg/l)
140
120
100
80
60
40
20
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
Tidal Phase
10.607 ± 0.399
10.401± 0.504
10.194 ± 0.926

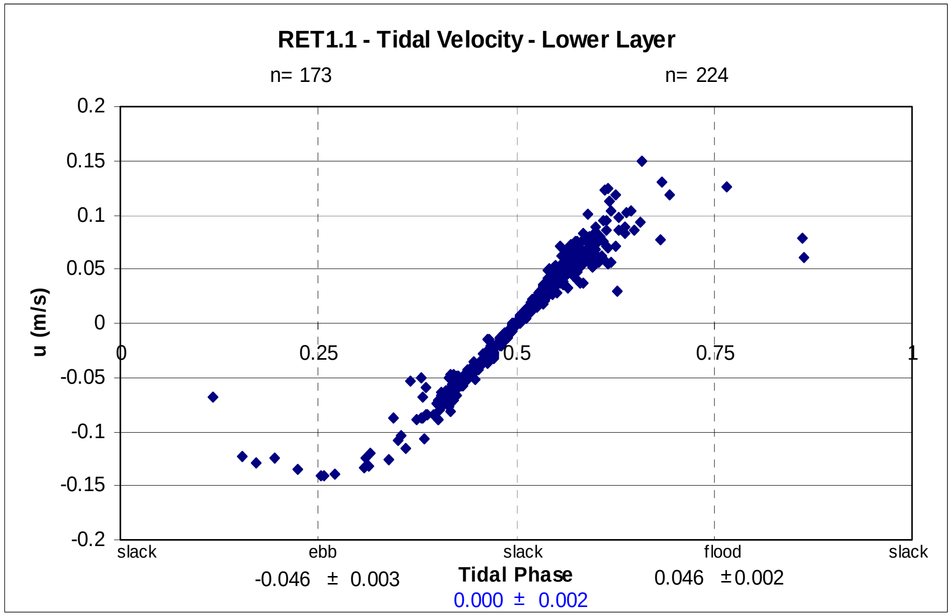

LE1.1 - Subtidal Velocity - Upper Layer
n= 388
n= 27
u (m/s)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.018 ± 0.002
-0.027± 0.008
-0.037 ± 0.016

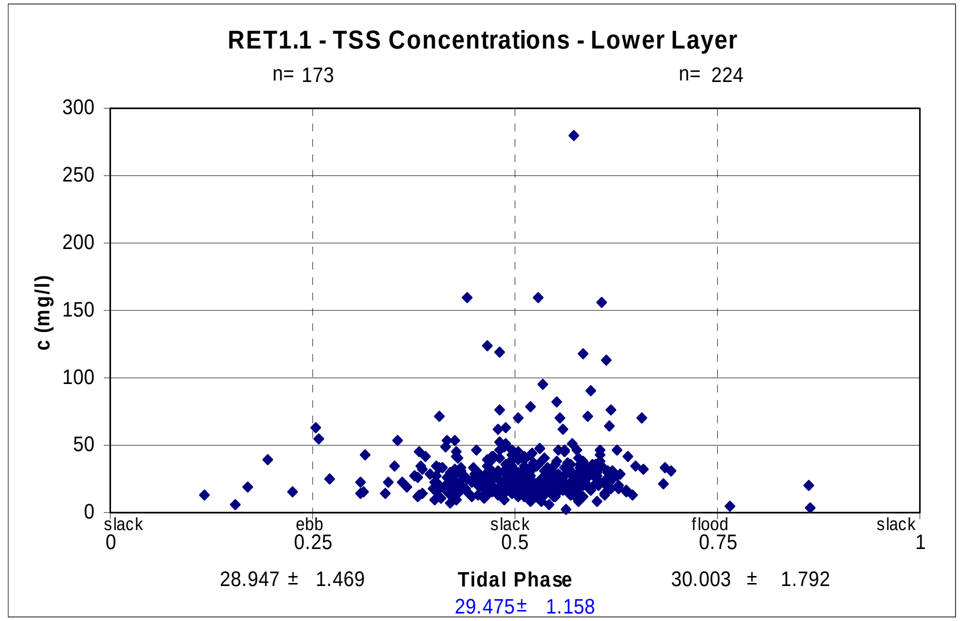

LE1.1 - Tidal Transport - Upper Layer
n= 388
n= 27
u*c (g/m2/s)
4
3
2
1
0
-1
-2
-3
-4
-5
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.867 ± 0.033
-0.039 ± 0.071
0.790 ± 0.138

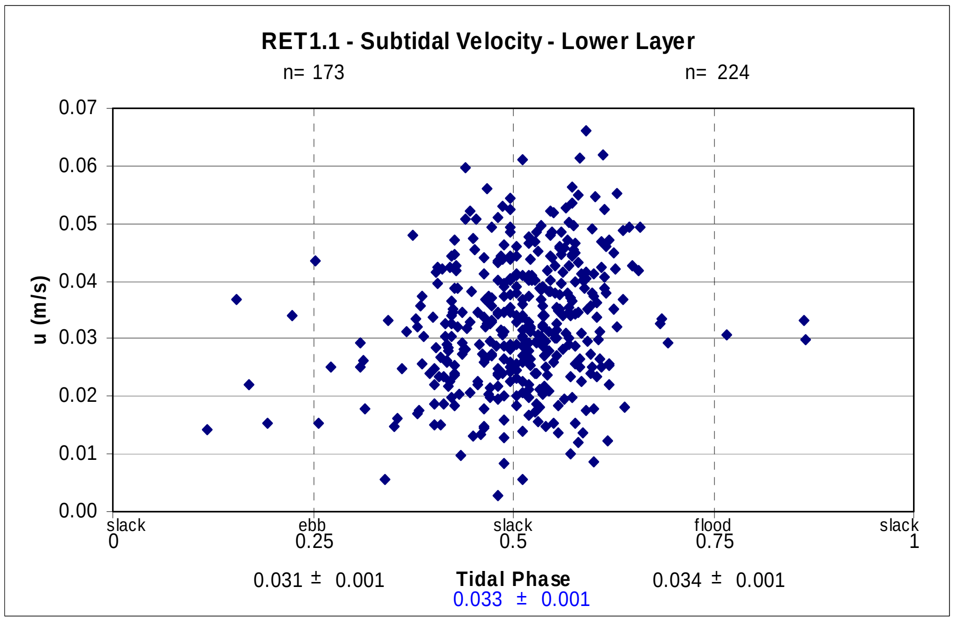

LE1.1 - Subtidal Transport - Upper Layer
n= 388
n= 27
u*c (g/m2/s)
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.219 ± 0.038
-0.291± 0.092
-0.363 ± 0.180

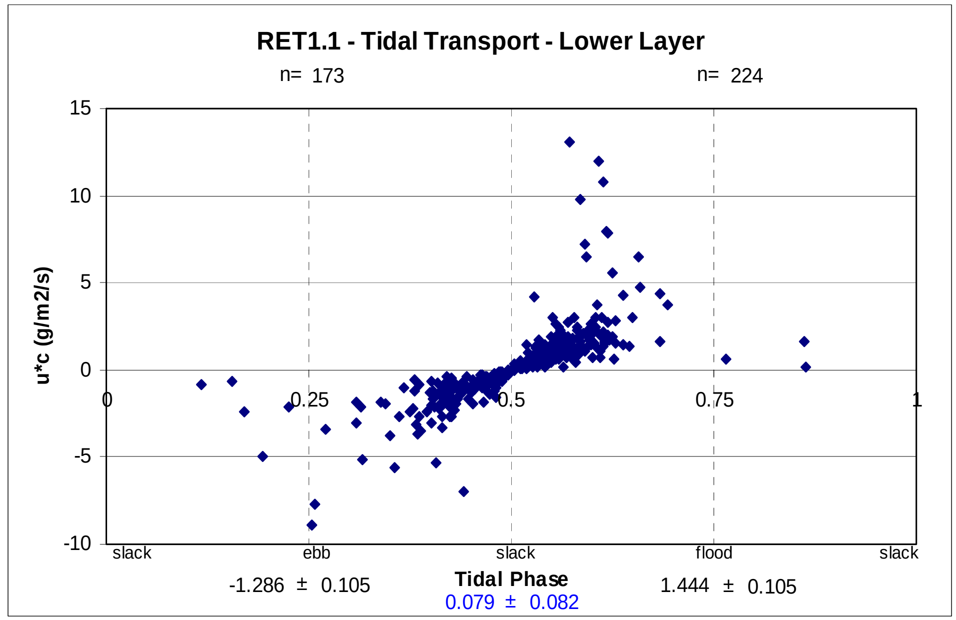

LE1.1 - River Velocity - Upper Layer
n= 388
n= 27
u (m/s)
0
-0.005
-0.01
-0.015
-0.02
-0.025
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.002 ± 0.000
-0.002± 0.000
-0.002 ± 0.001

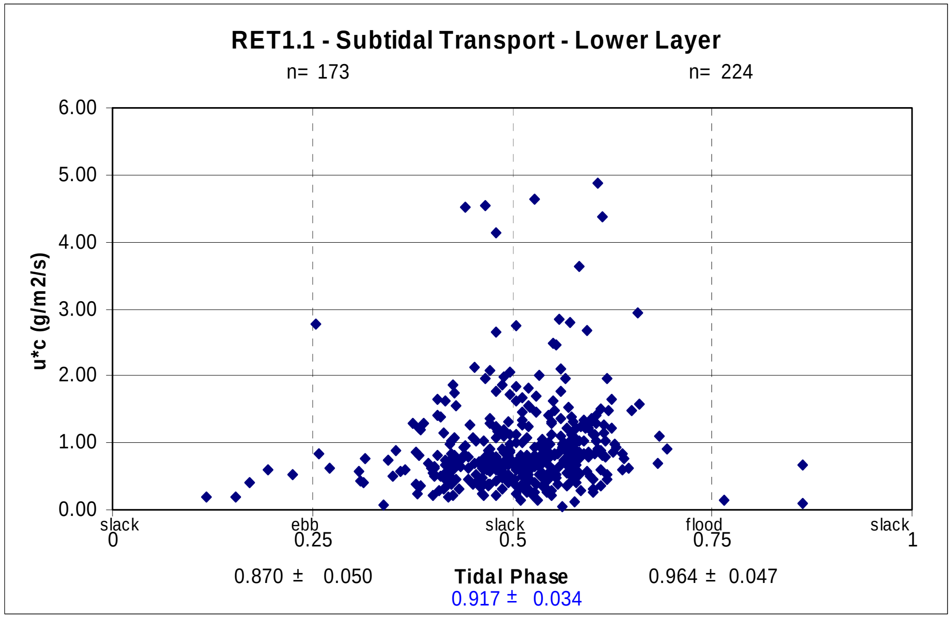

LE1.1 - River Transport - Upper Layer
n= 388
n= 27
u*c (g/m2/s)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.021 ± 0.002
-0.021 ± 0.003
-0.021 ± 0.005

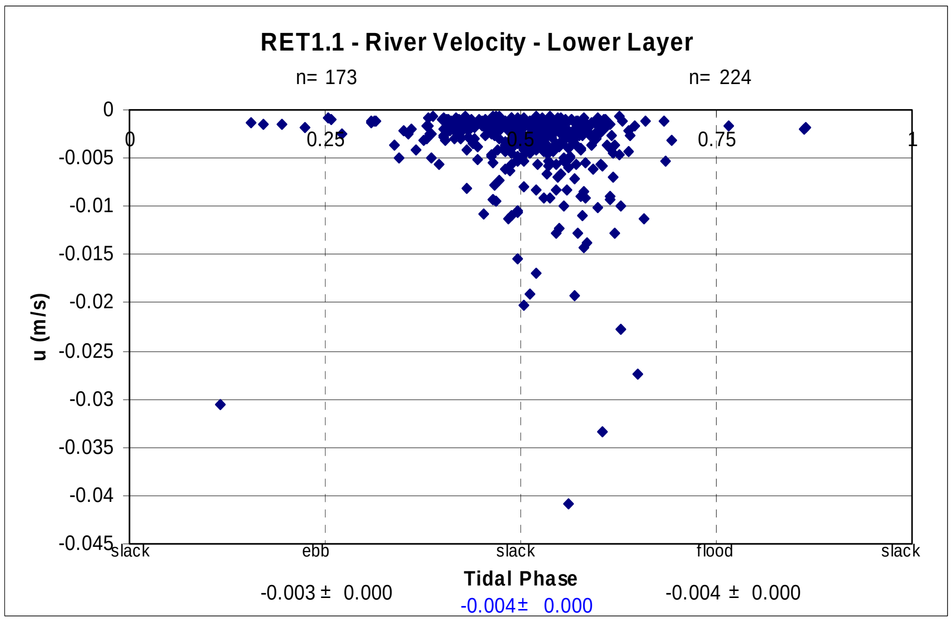

RET1.1 - Tidal Velocity - Lower Layer
n= 173
n= 224
u (m/s)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.046 ± 0.003
Tidal Phase
0.046 ±0.002
0.000 ± 0.002

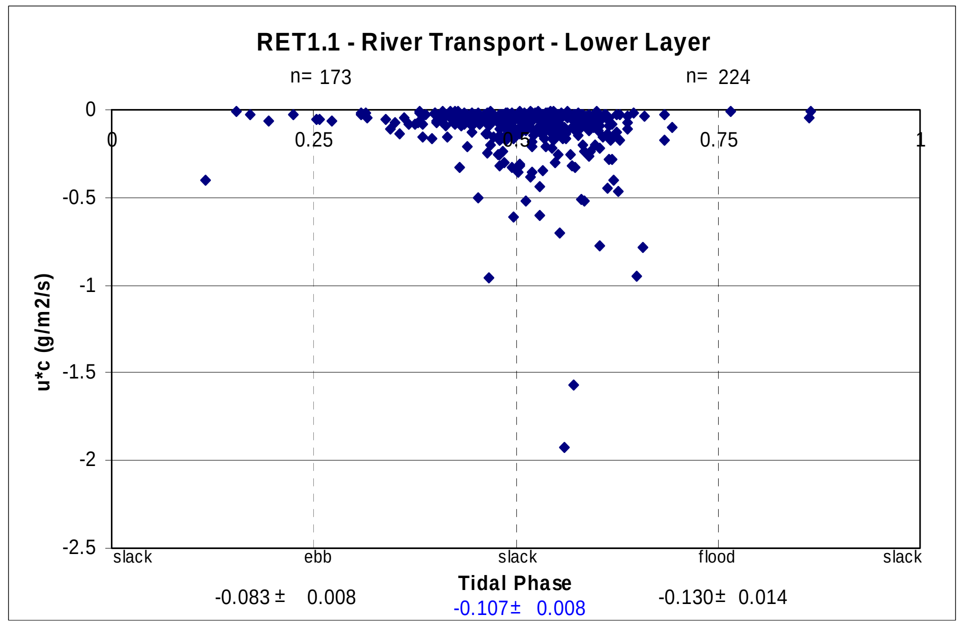

RET1.1 - TSS Concentrations - Lower Layer
n= 173
n= 224
c (mg/l)
300
250
200
150
100
50
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
28.947 ± 1.469
Tidal Phase
30.003 ± 1.792
29.475± 1.158

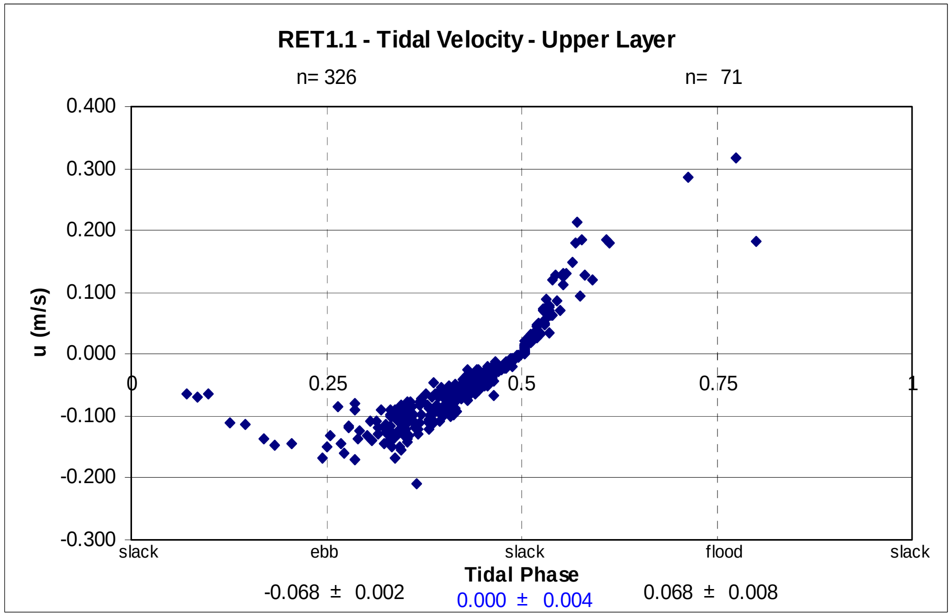

RET1.1 - Subtidal Velocity - Lower Layer
n= 173
n= 224
u (m/s)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
0.031 ± 0.001
Tidal Phase
0.034 ± 0.001
0.033 ± 0.001

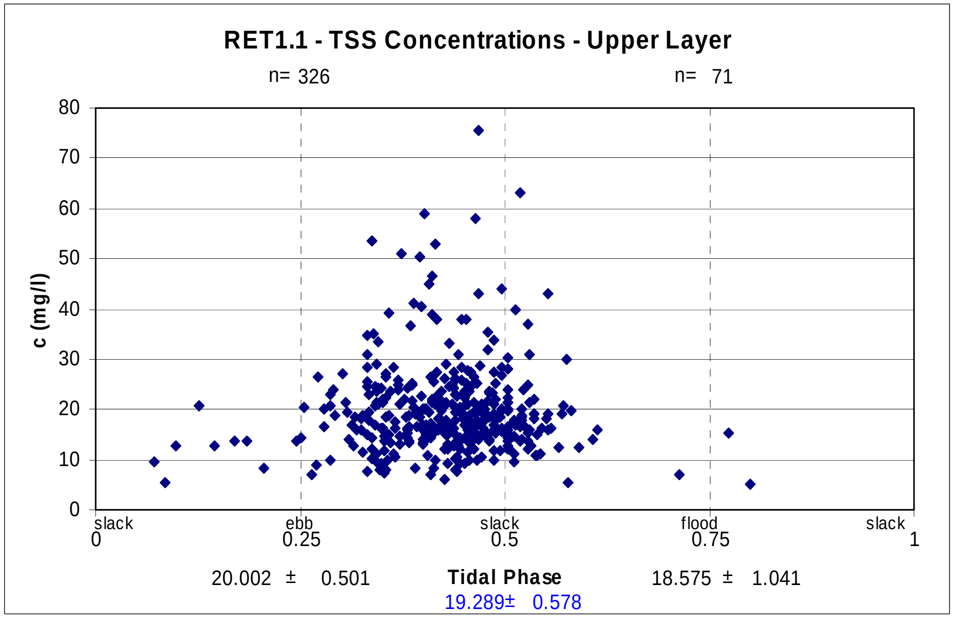

RET1.1 - Tidal Transport - Lower Layer
n= 173
n= 224
u*c (g/m2/s)
15
10
5
0
-5
-10
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-1.286 ± 0.105
Tidal Phase
1.444 ± 0.105
0.079 ± 0.082

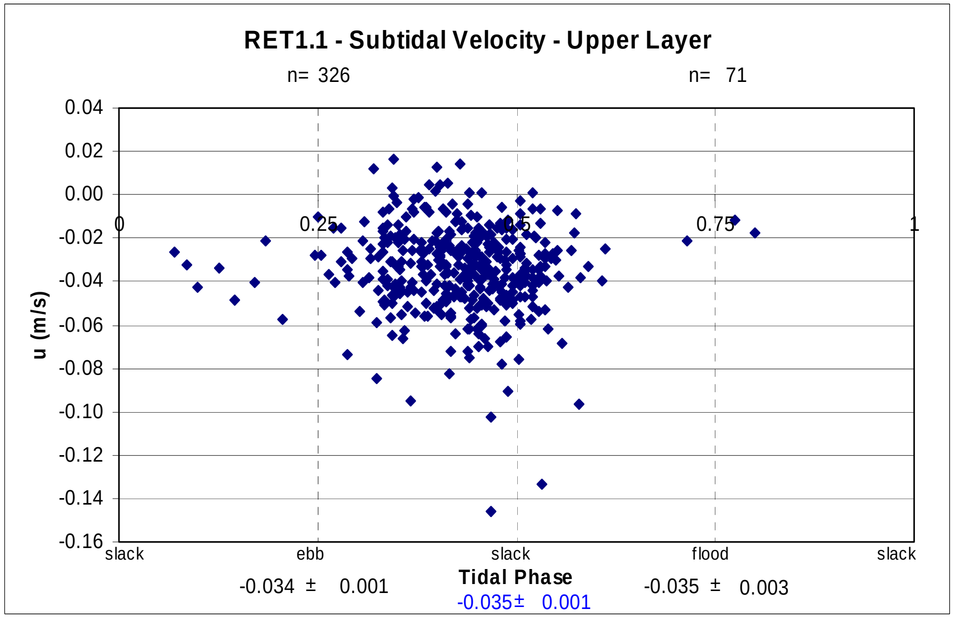

RET1.1 - Subtidal Transport - Lower Layer
n= 173
n= 224
u*c (g/m2/s)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
0.870 ± 0.050
Tidal Phase
0.964 ± 0.047
0.917 ± 0.034

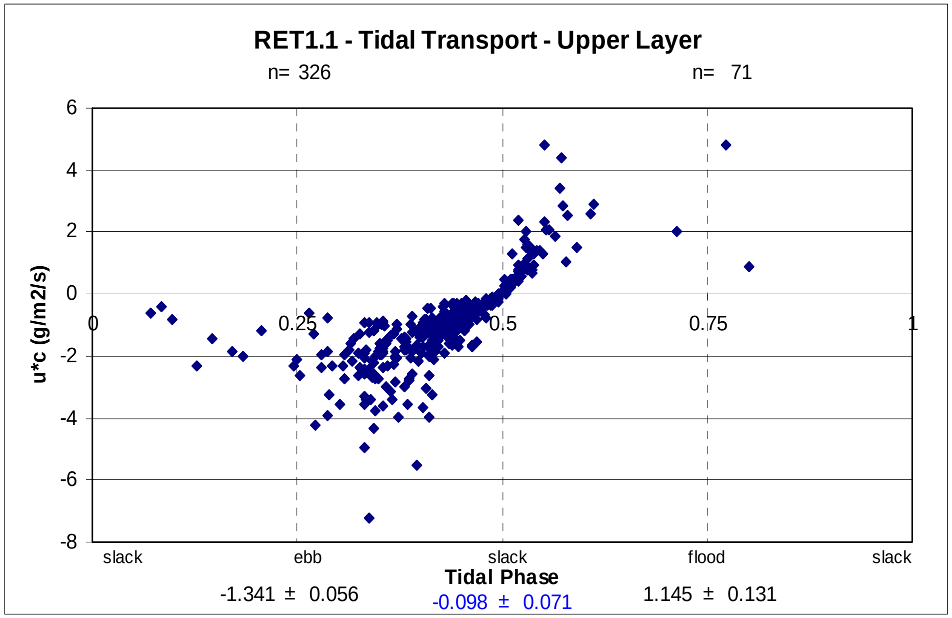

RET1.1 - River Velocity - Lower Layer
n= 173
n= 224
u (m/s)
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.003 ± 0.000
-0.004 ± 0.000
-0.004 ± 0.000

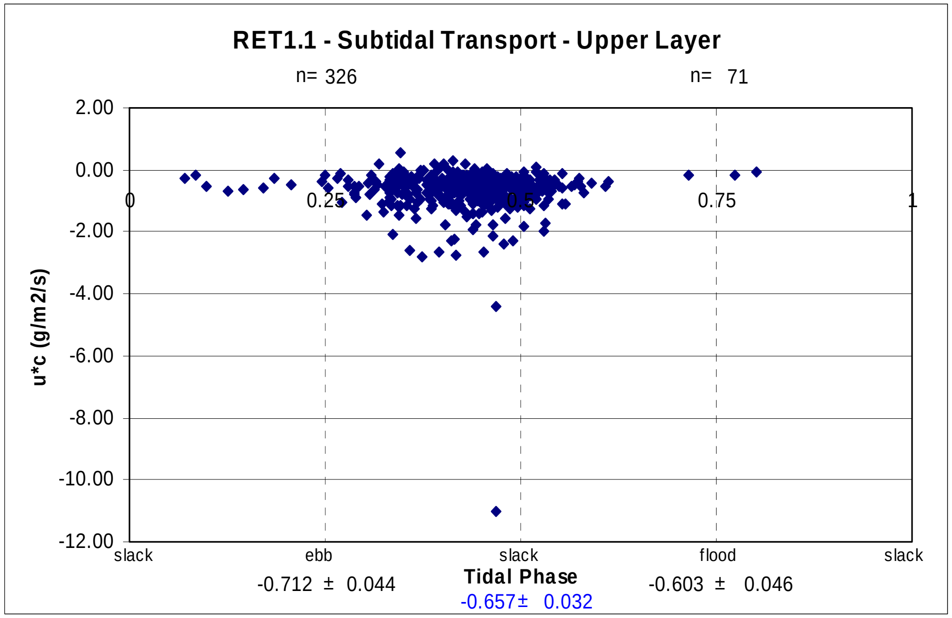

RET1.1 - River Transport - Lower Layer
n= 173
n= 224
u*c (g/m2/s)
0
-0.5
-1
-1.5
-2
-2.5
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.083 ± 0.008
-0.107 ± 0.008
-0.130 ± 0.014

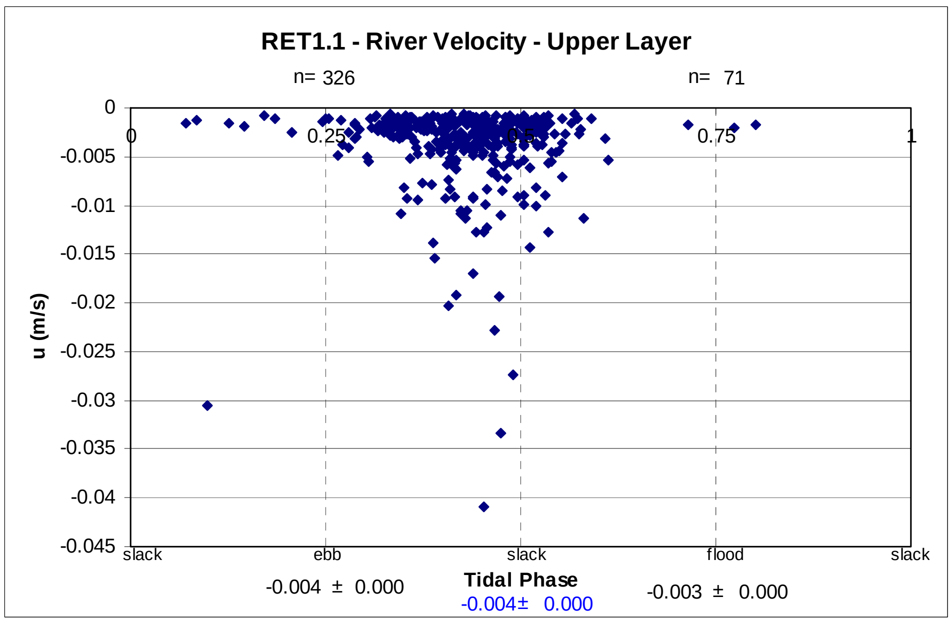

RET1.1 - Tidal Velocity - Upper Layer
n= 326
n= 71
u (m/s)
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.068 ± 0.002
0.000 ± 0.004
0.068 ± 0.008

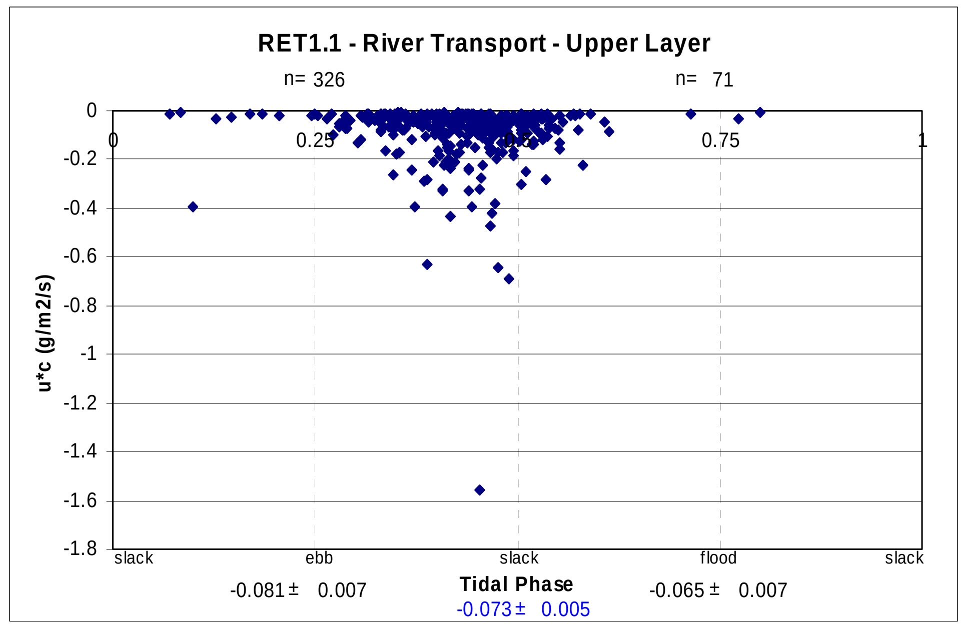

RET1.1 - TSS Concentrations - Upper Layer
n= 326
n= 71
c (mg/l)
80
70
60
50
40
30
20
10
0
slack
0
ebb
0.25
slack
0.5
flood
0.75
slack
1
20.002 ± 0.501
Tidal Phase
19.289± 0.578
18.575 ± 1.041

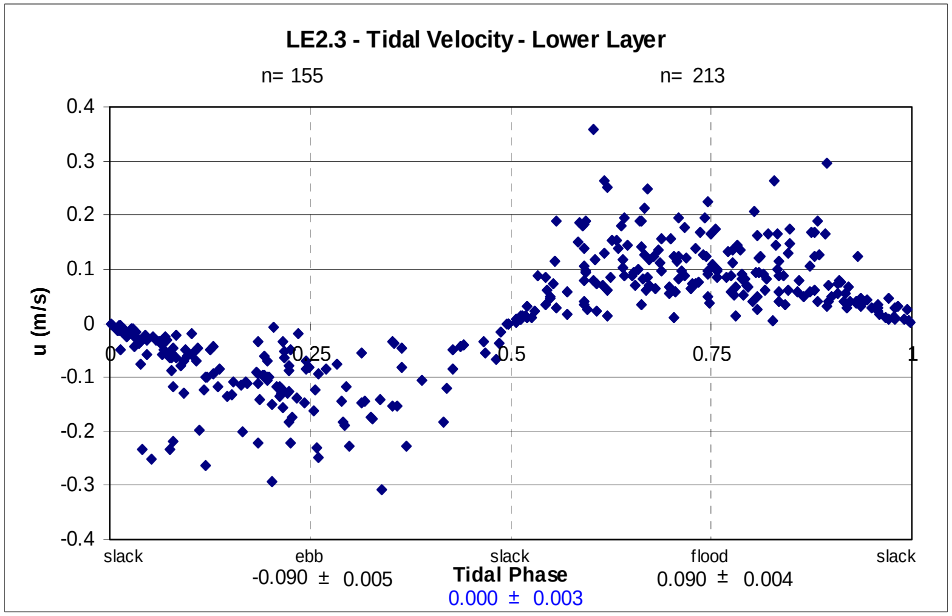

RET1.1 - Subtidal Velocity - Upper Layer
n= 326
n= 71
u (m/s)
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
-0.16
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.034 ± 0.001
-0.035± 0.001
-0.035 ± 0.003

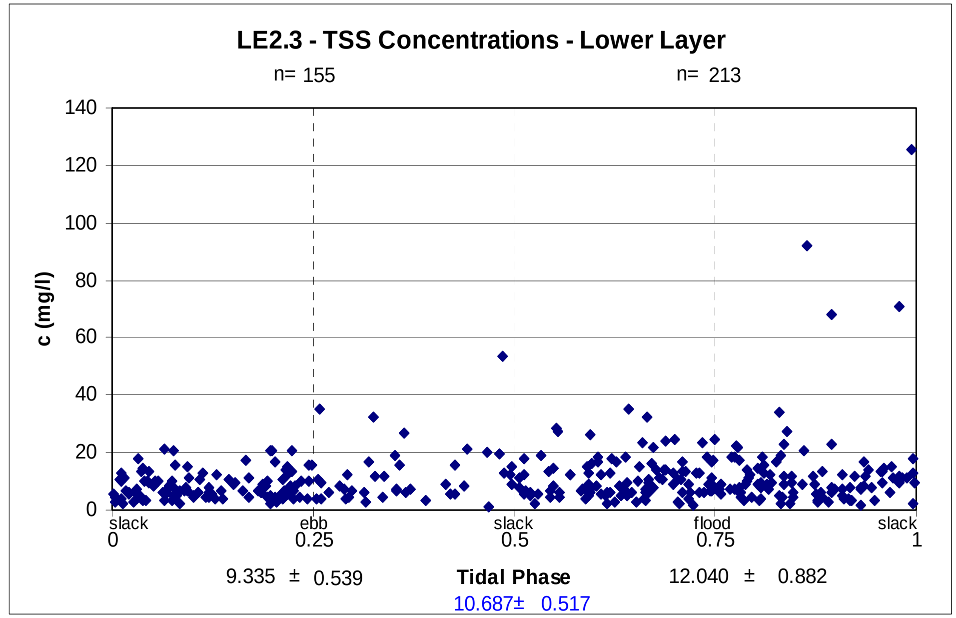

RET1.1 - Tidal Transport - Upper Layer
n= 326
n= 71
u*c (g/m2/s)
6
4
2
0
-2
-4
-6
-8
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.341 ± 0.056
-0.098 ± 0.071
1.145 ± 0.131

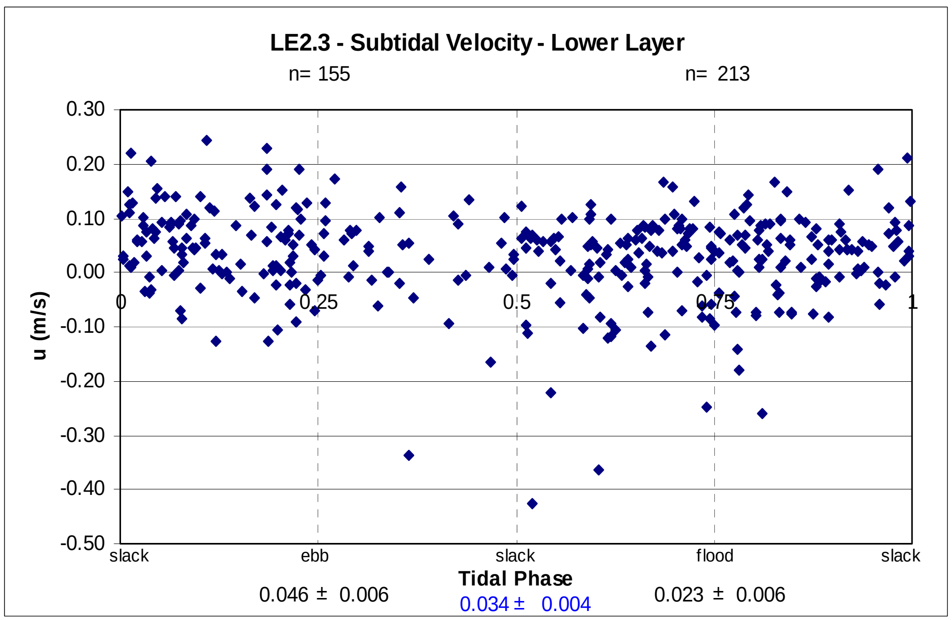

RET1.1 - Subtidal Transport - Upper Layer
n= 326
n= 71
u*c (g/m2/s)
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.712 ± 0.044
-0.657± 0.032
-0.603 ± 0.046

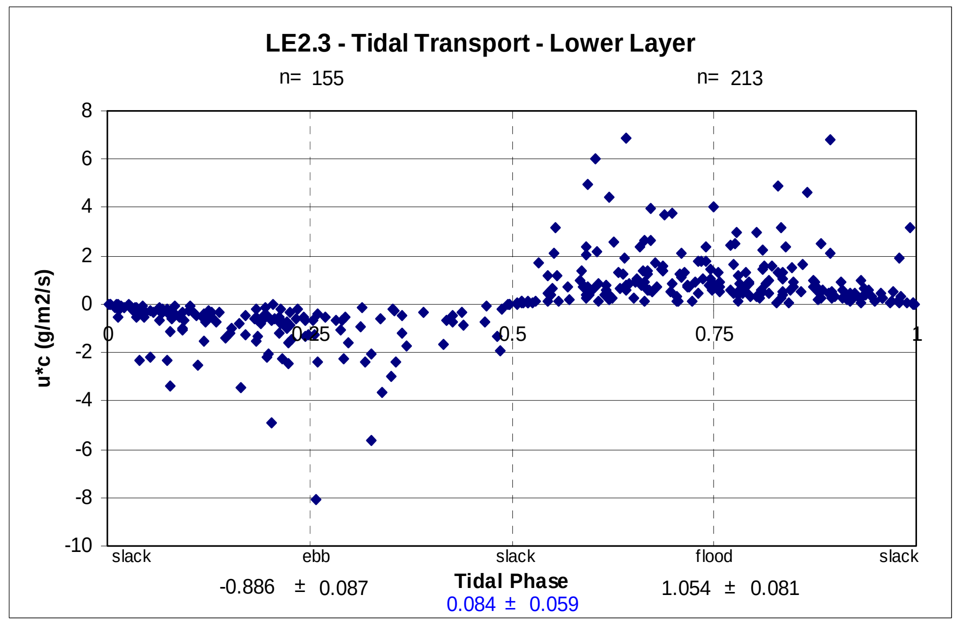

RET1.1 - River Velocity - Upper Layer
n= 326
n= 71
u (m/s)
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.004 ± 0.000
-0.004± 0.000
-0.003 ± 0.000

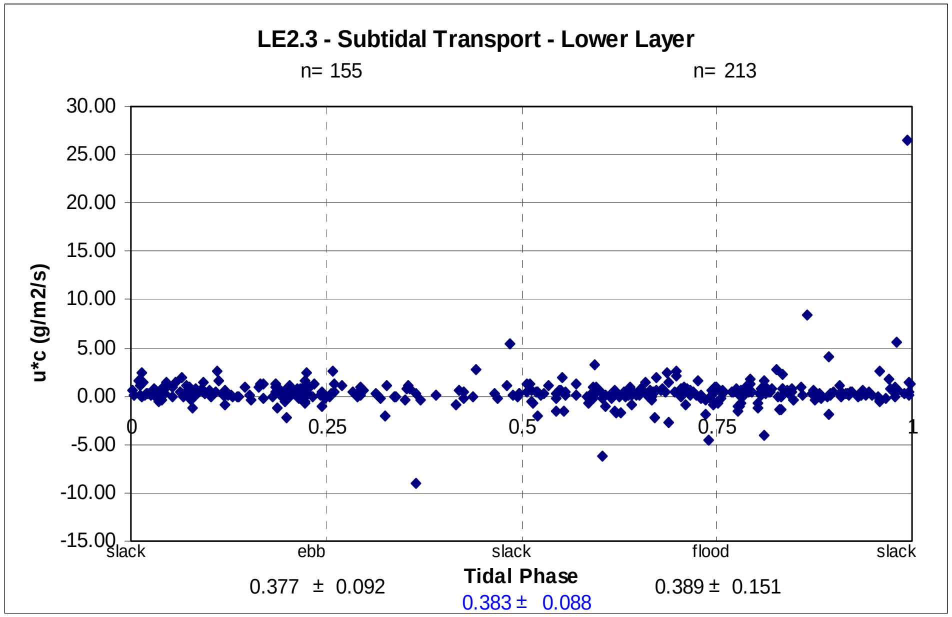

RET1.1 - River Transport - Upper Layer
n= 326
n= 71
u*c (g/m2/s)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.081 ± 0.007
-0.073± 0.005
-0.065 ± 0.007

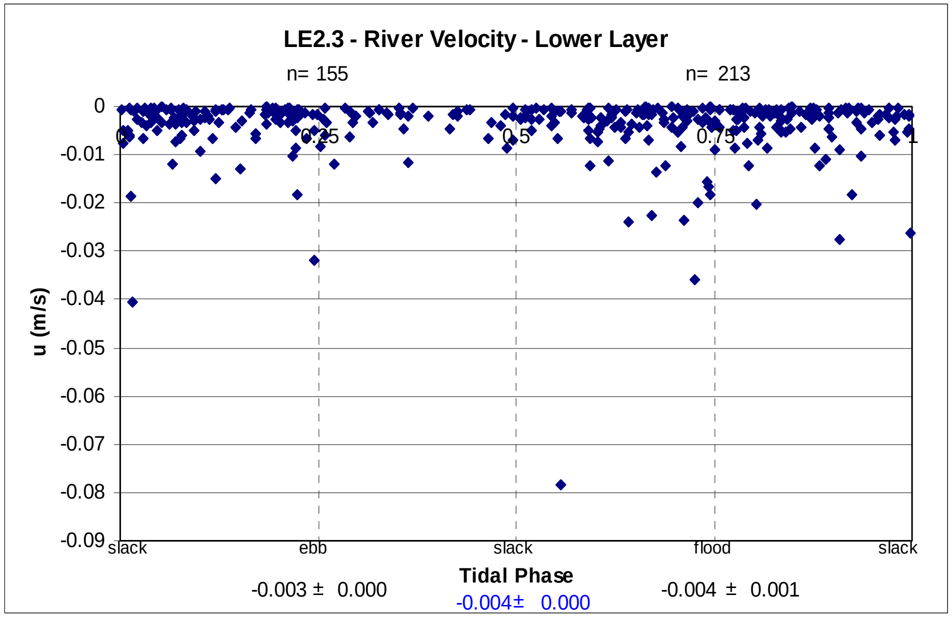

LE2.3 - Tidal Velocity - Lower Layer
n= 155
n= 213
u (m/s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.090 ± 0.005
Tidal Phase
0.090 ± 0.004
0.000 ± 0.003

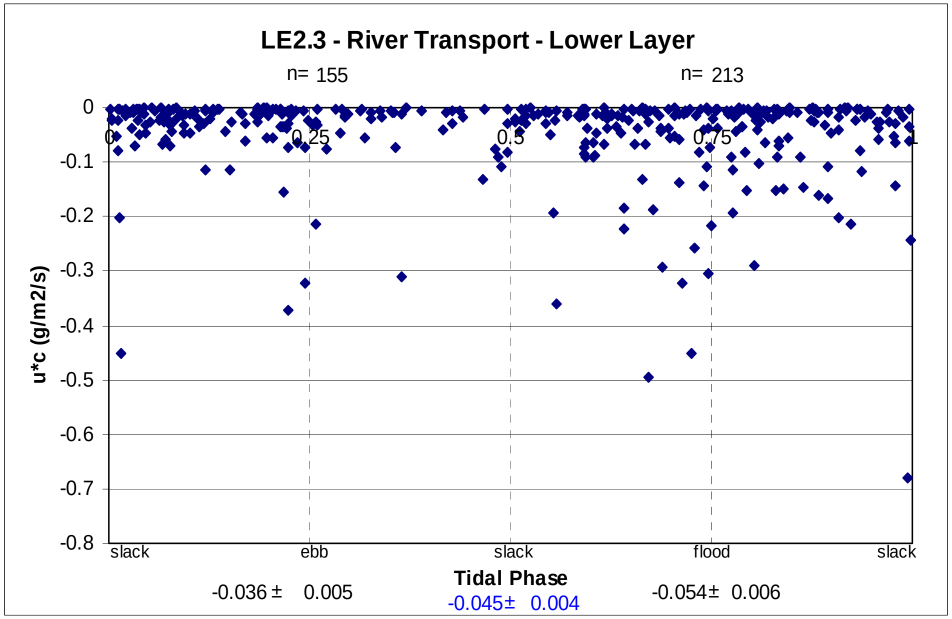

LE2.3 - TSS Concentrations - Lower Layer
n= 155
n= 213
c (mg/l)
140
120
100
80
60
40
20
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
9.335 ± 0.539
Tidal Phase
12.040 ± 0.882
10.687± 0.517

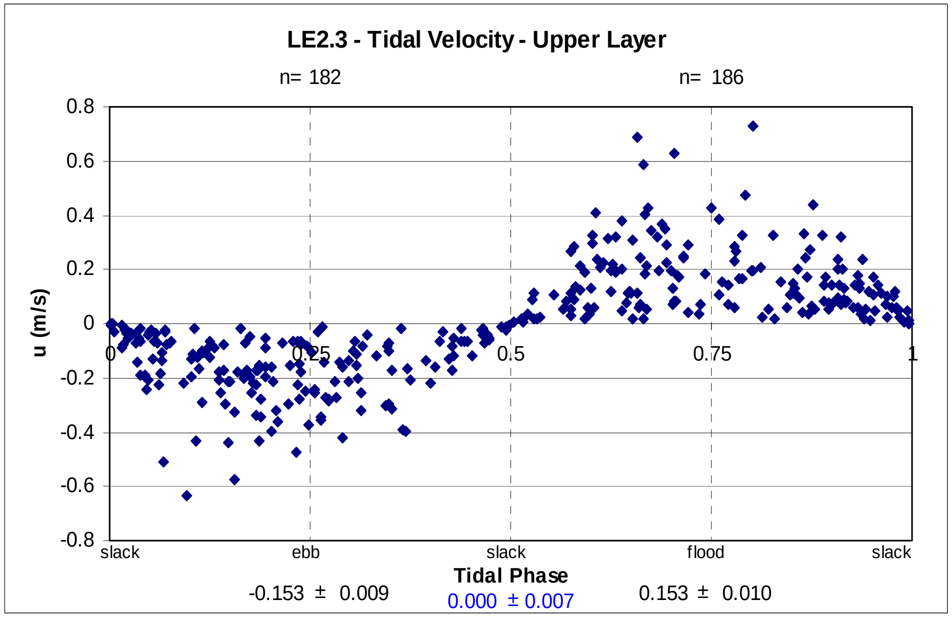

LE2.3 - Subtidal Velocity - Lower Layer
n= 155
n= 213
u (m/s)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.046 ± 0.006
Tidal Phase
0.023 ± 0.006
0.034 ± 0.004

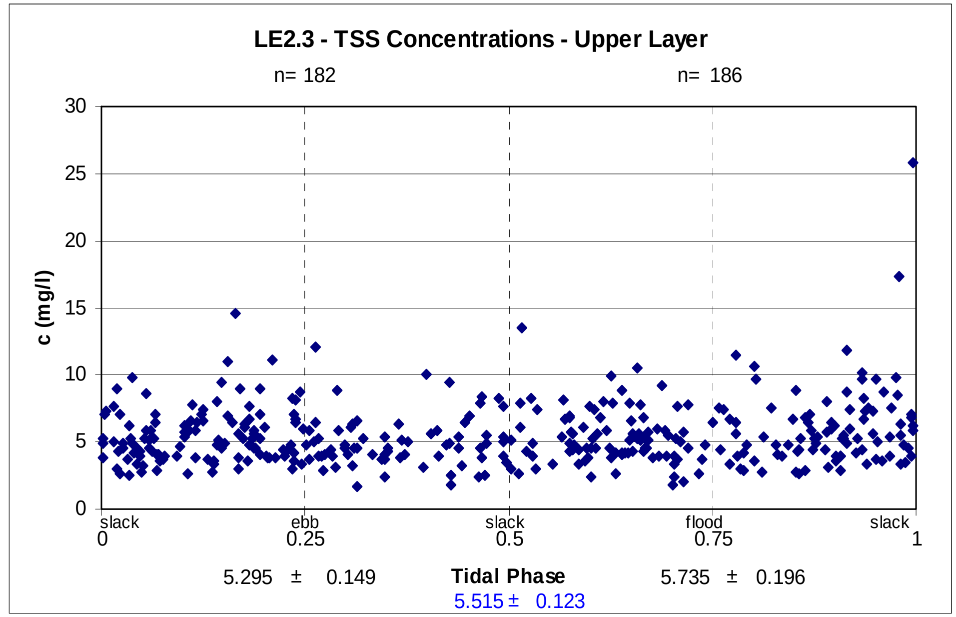

LE2.3 - Tidal Transport - Lower Layer
n= 155
n= 213
u*c (g/m2/s)
8
6
4
2
0
-2
-4
-6
-8
-10
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.886 ± 0.087
Tidal Phase
1.054 ± 0.081
0.084 ± 0.059

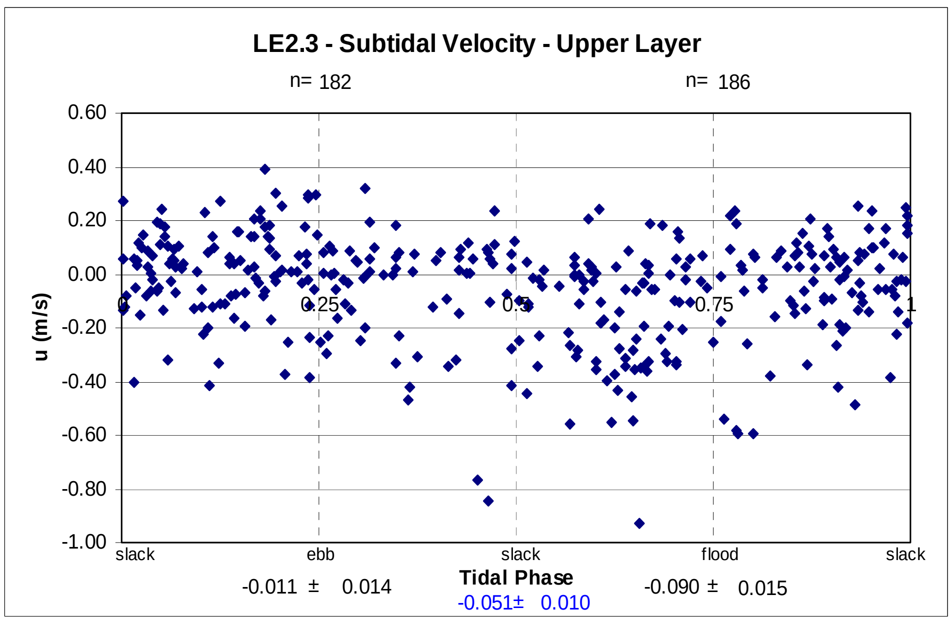

LE2.3 - Subtidal Transport - Lower Layer
n= 155
n= 213
u*c (g/m2/s)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.377 ± 0.092
Tidal Phase
0.383 ± 0.088
0.389 ± 0.151

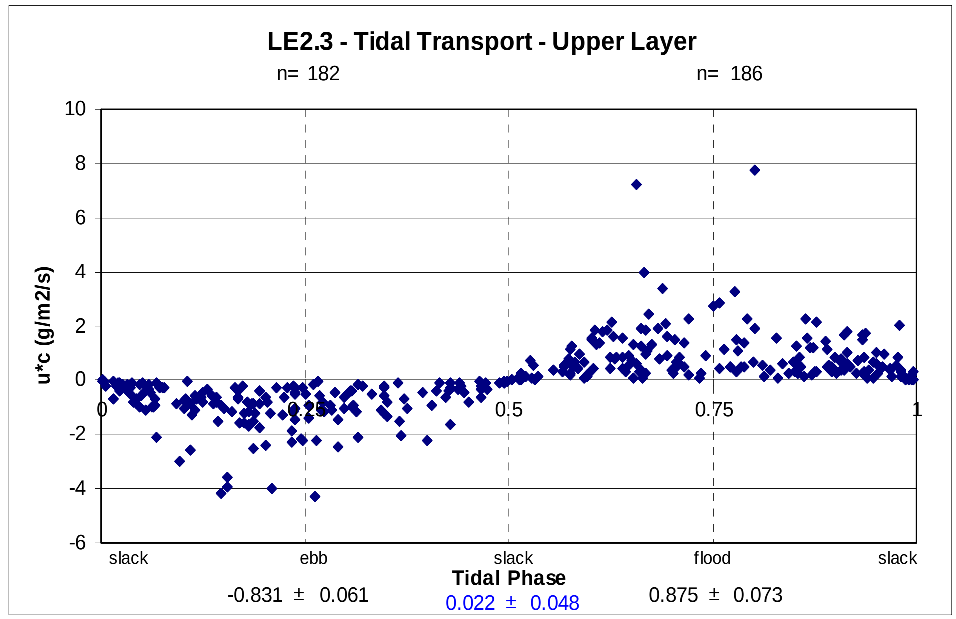

LE2.3 - River Velocity - Lower Layer
n= 155
n= 213
u (m/s)
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.003 ± 0.000
Tidal Phase
-0.004± 0.000
-0.004 ± 0.001

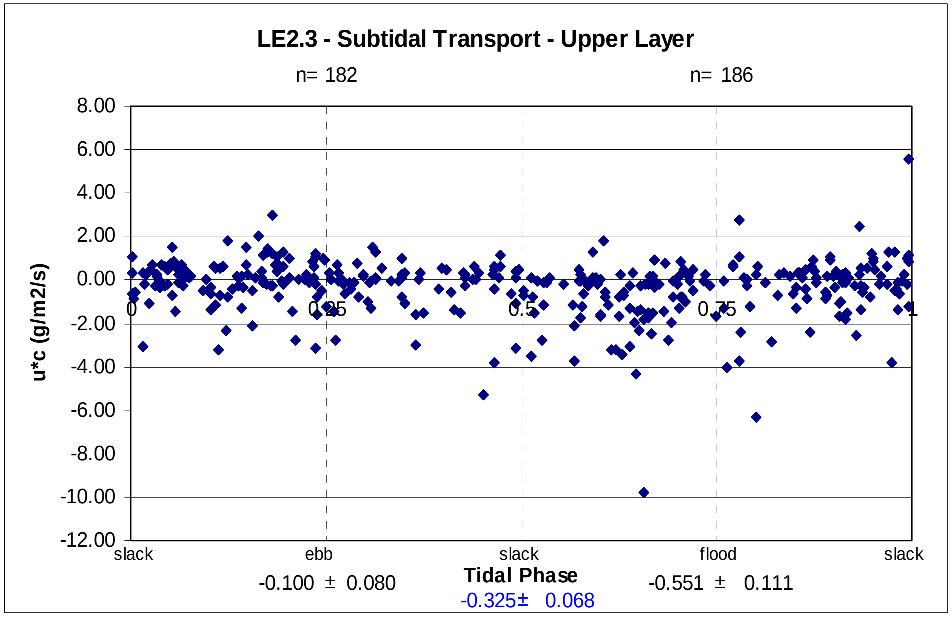

LE2.3 - River Transport - Lower Layer
n= 155
n= 213
u*c (g/m2/s)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.036 ± 0.005
Tidal Phase
-0.045± 0.004
-0.054± 0.006

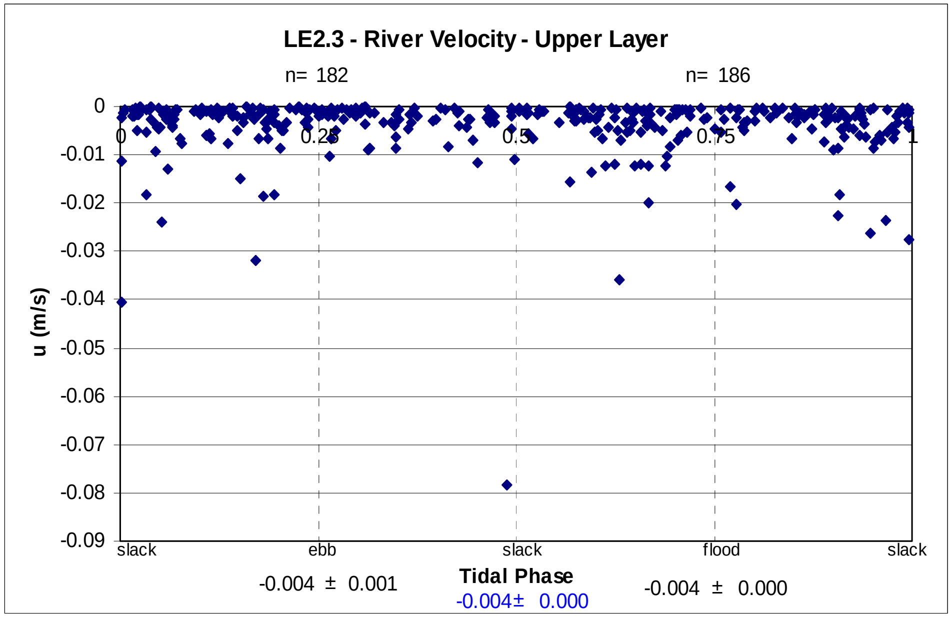

LE2.3 - Tidal Velocity - Upper Layer
n= 182
n= 186
u (m/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.153 ± 0.009
0.000 ± 0.007
0.153 ± 0.010

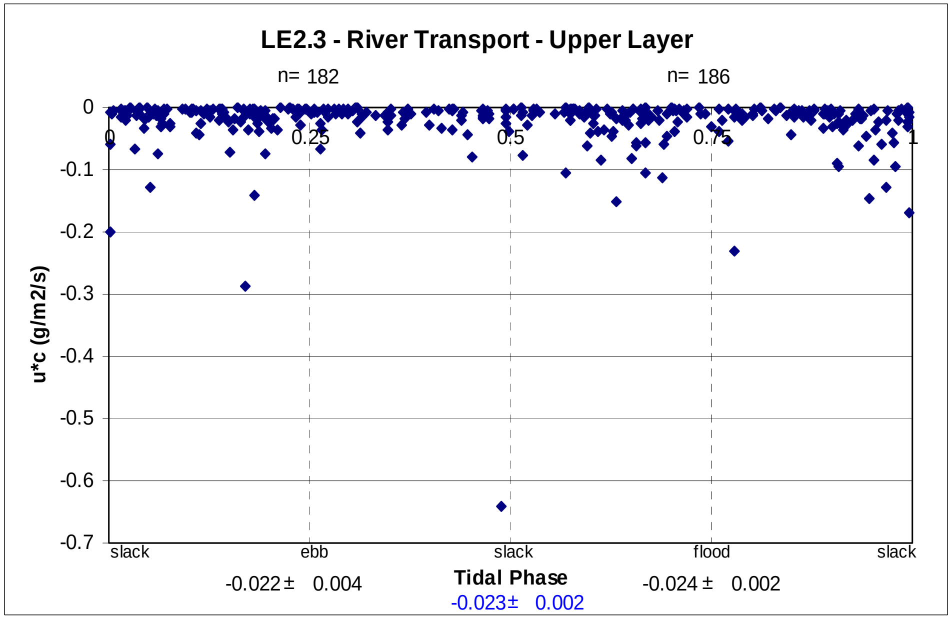

LE2.3 - TSS Concentrations - Upper Layer
n= 182
n= 186
c (mg/l)
30
25
20
15
10
5
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
Tidal Phase
5.295 ± 0.149
5.515 ± 0.123
5.735 ± 0.196

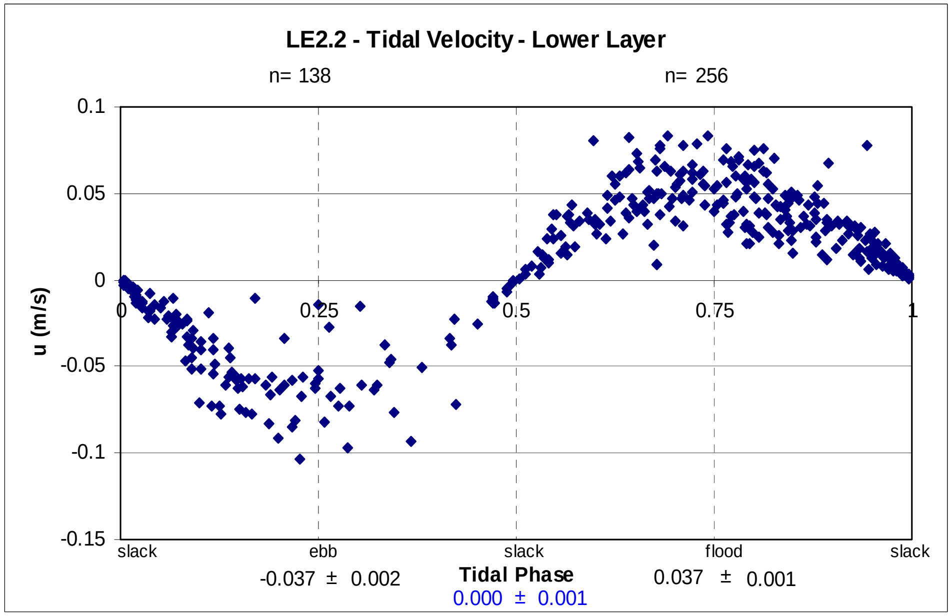

LE2.3 - Subtidal Velocity - Upper Layer
n= 182
n= 186
u (m/s)
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.011 ± 0.014
-0.051± 0.010
-0.090 ± 0.015

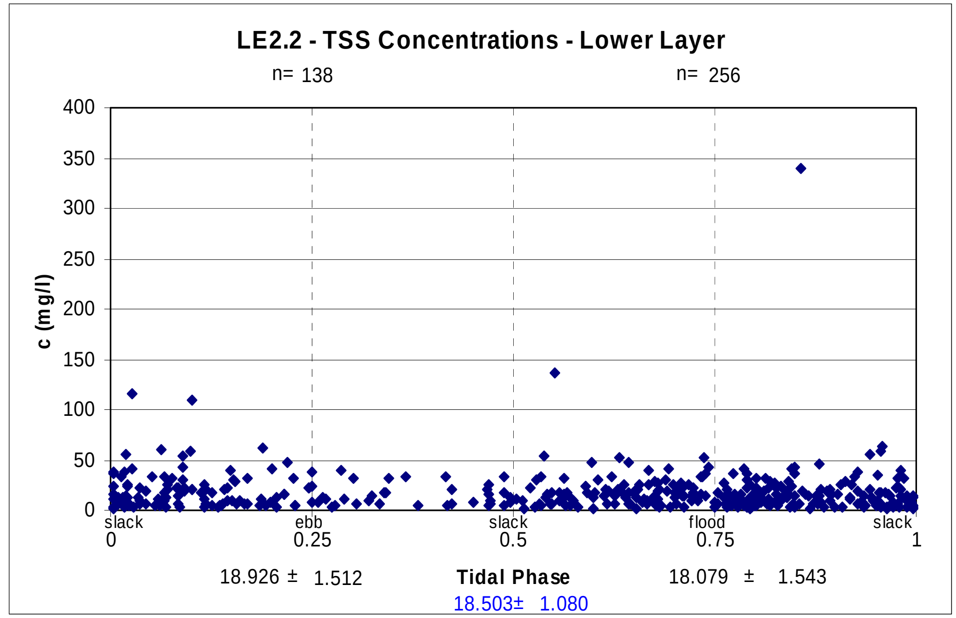

LE2.3 - Tidal Transport - Upper Layer
n= 182
n= 186
u*c (g/m2/s)
10
8
6
4
2
0
-2
-4
-6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.831 ± 0.061
0.022 ± 0.048
0.875 ± 0.073

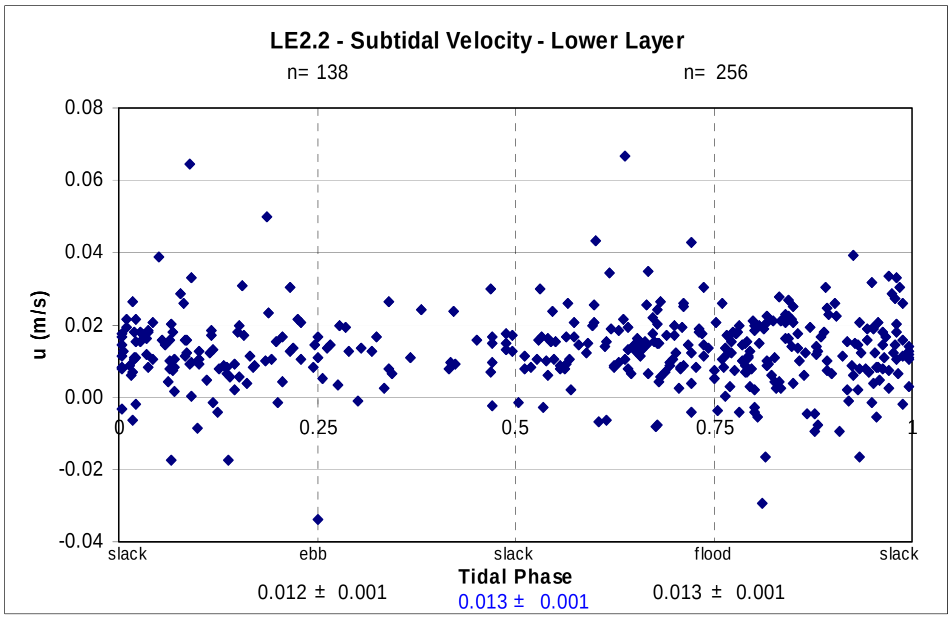

LE2.3 - Subtidal Transport - Upper Layer
n= 182
n= 186
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.100 ± 0.080
-0.325± 0.068
-0.551 ± 0.111

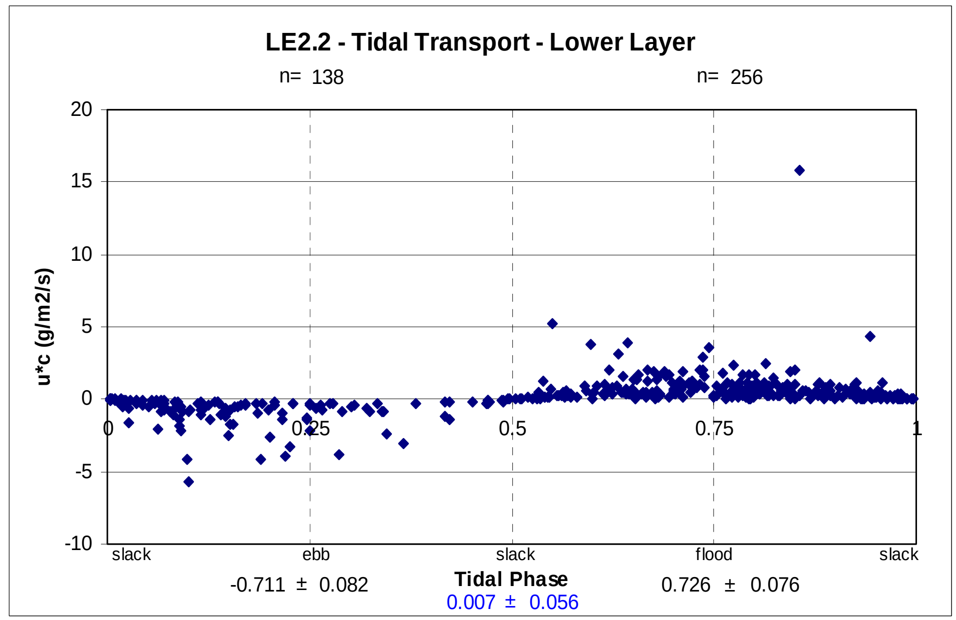

LE2.3 - River Velocity - Upper Layer
n= 182
n= 186
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.004 ± 0.001
-0.004± 0.000
-0.004 ± 0.000

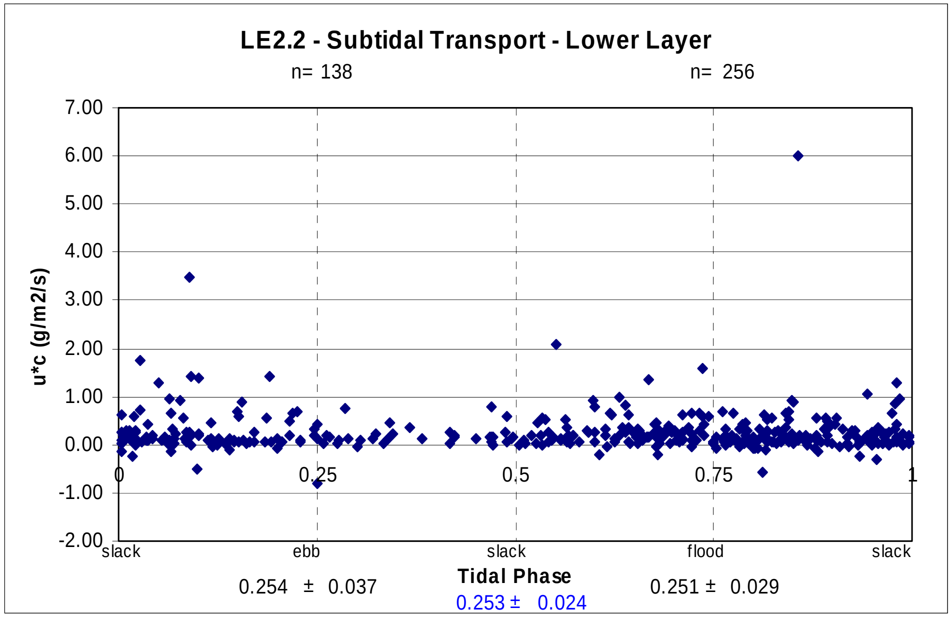

LE2.3 - River Transport - Upper Layer
n= 182
n= 186
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.022 ± 0.004
-0.023± 0.002
-0.024 ± 0.002

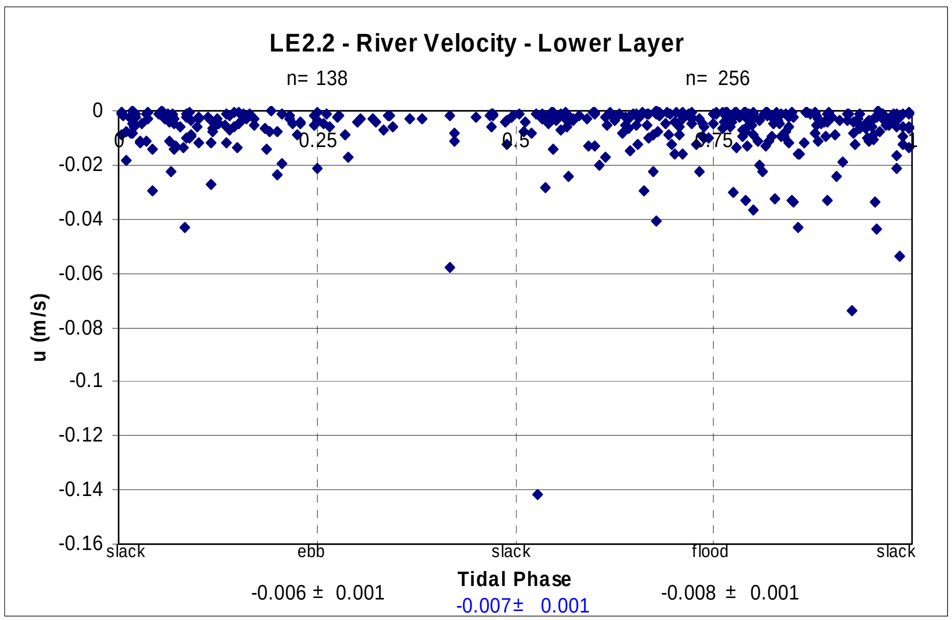

LE2.2 - Tidal Velocity - Lower Layer
n= 138
n= 256
0.1
0.05
0
-0.05
-0.1
-0.15
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.037 ± 0.002
Tidal Phase
0.037 ± 0.001
0.000 ± 0.001

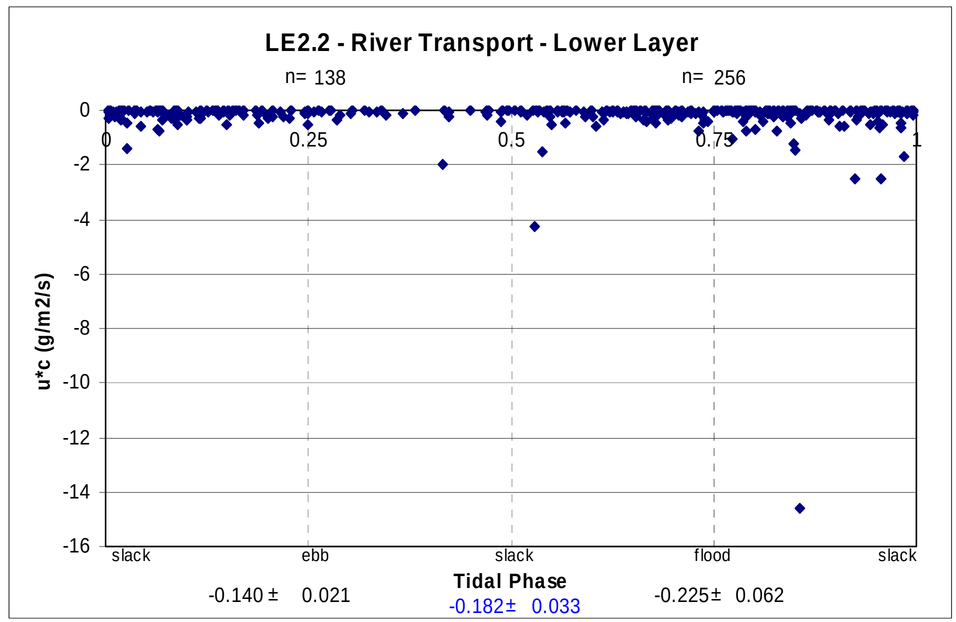

LE2.2 - TSS Concentrations - Lower Layer
n= 138
n= 256
400
350
300
250
200
150
100
50
0
c (mg/l)
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
18.926 ± 1.512
Tidal Phase
18.079 ± 1.543
18.503± 1.080

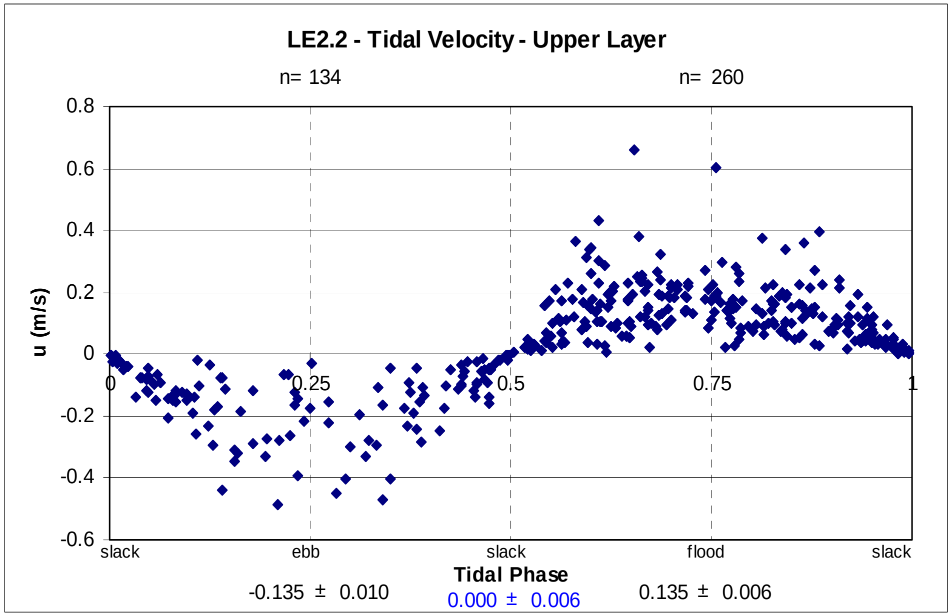

LE2.2 - Subtidal Velocity - Lower Layer
n= 138
n= 256
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.012 ± 0.001
Tidal Phase
0.013 ± 0.001
0.013 ± 0.001

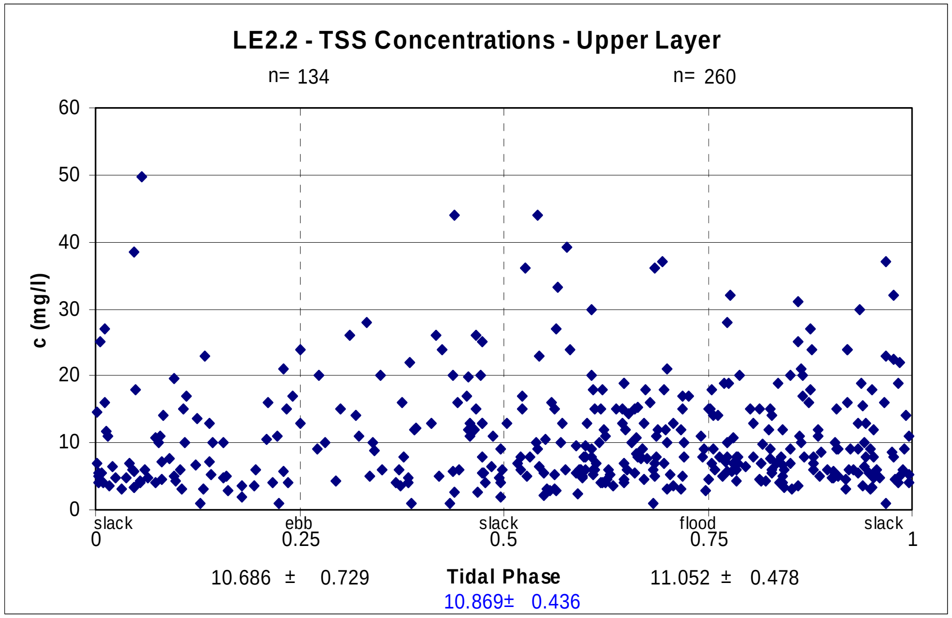

LE2.2 - Tidal Transport - Lower Layer
n= 138
n= 256
20
15
10
5
0
-5
-10
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.711 ± 0.082
Tidal Phase
0.726 ± 0.076
0.007 ± 0.056

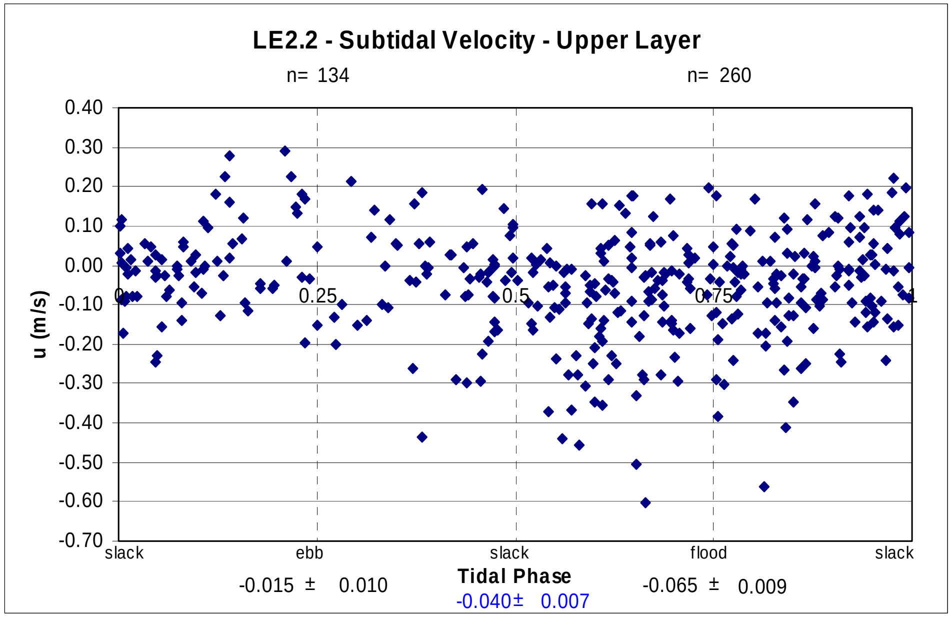

LE2.2 - Subtidal Transport - Lower Layer
n= 138
n= 256
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.254 ± 0.037
0.253 ± 0.024
0.251 ± 0.029

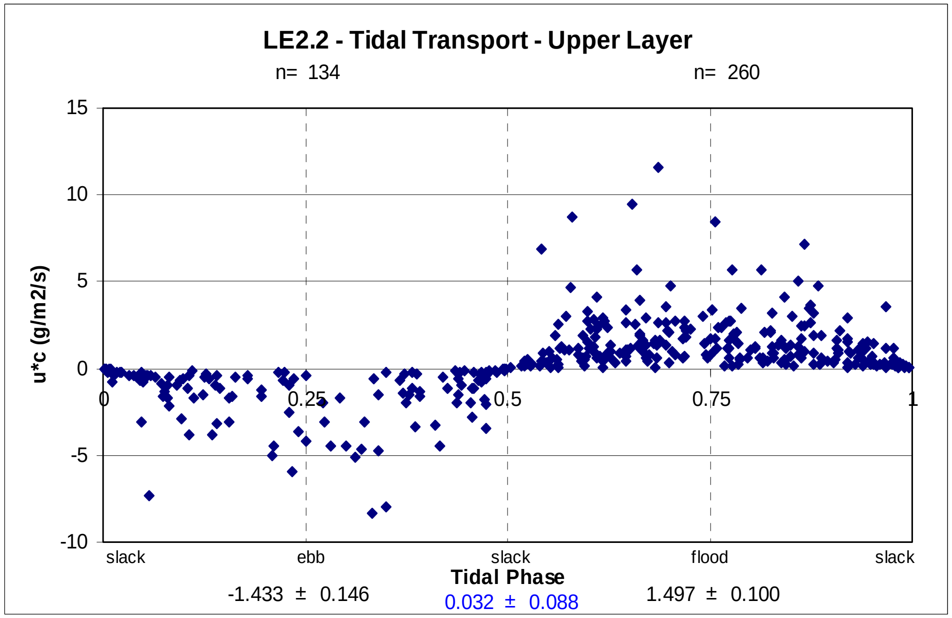

LE2.2 - River Velocity - Lower Layer
n= 138
n= 256
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.006 ± 0.001
-0.007 ± 0.001
-0.008 ± 0.001

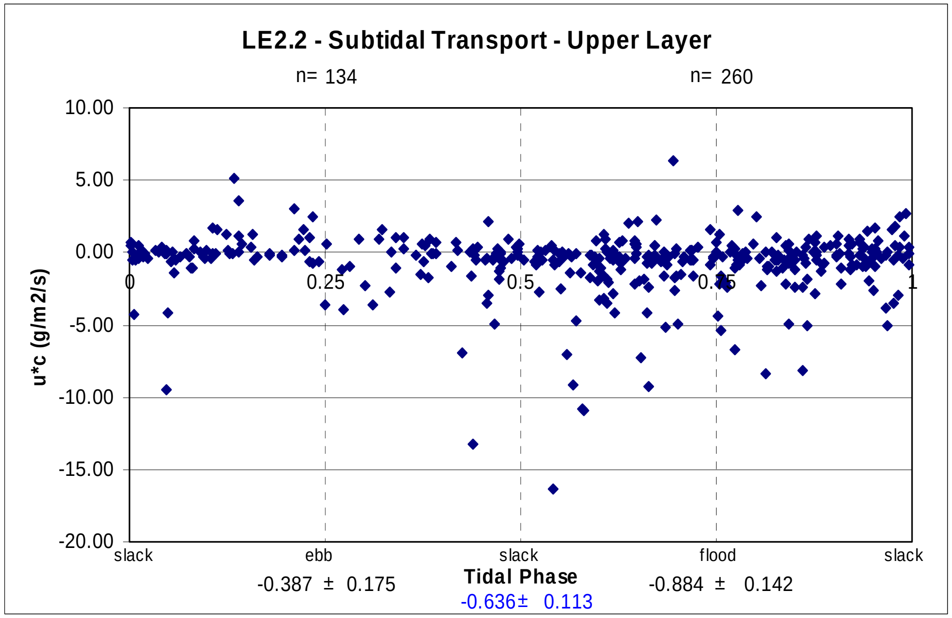

LE2.2 - River Transport - Lower Layer
n= 138
n= 256
0
-2
-4
-6
-8
-10
-12
-14
-16
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.140 ± 0.021
-0.182 ± 0.033
-0.225 ± 0.062

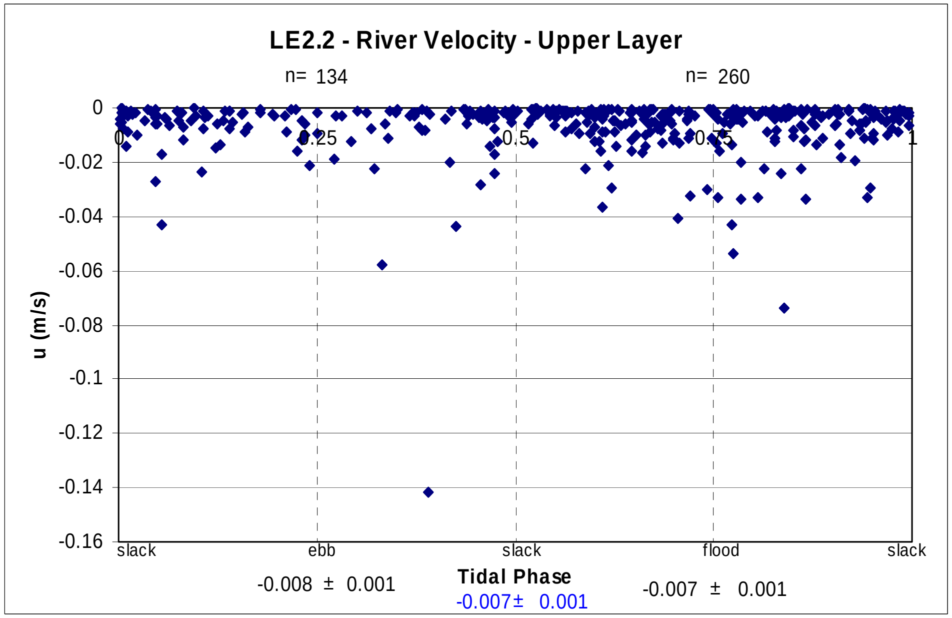

LE2.2 - Tidal Velocity - Upper Layer
n= 134
n= 260
u (m/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.135 ± 0.010
0.000 ± 0.006
0.135 ± 0.006

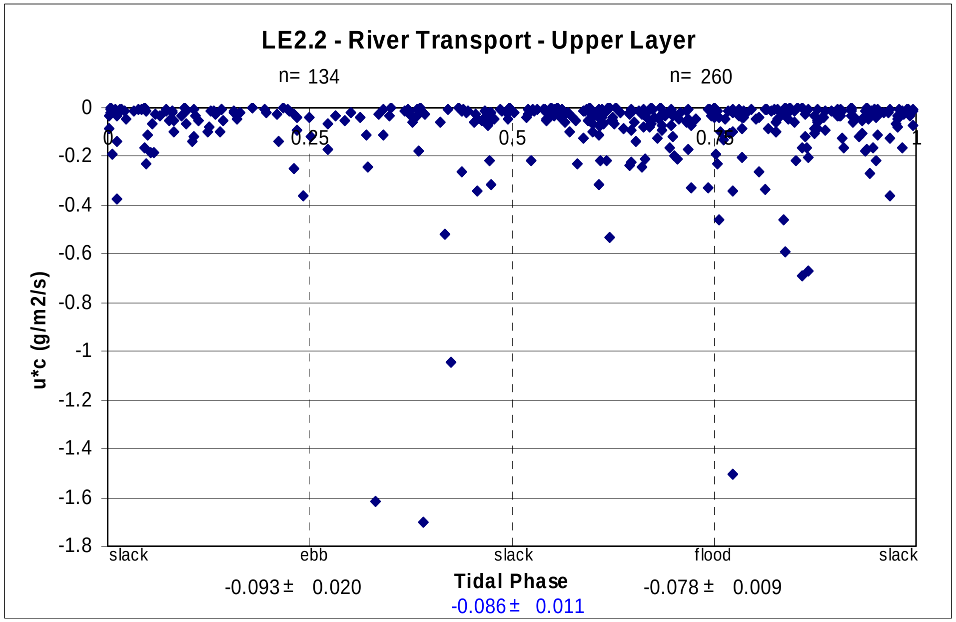

LE2.2 - TSS Concentrations - Upper Layer
n= 134
n= 260
c (mg/l)
60
50
40
30
20
10
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
10.686 ± 0.729
Tidal Phase
11.052 ± 0.478
10.869± 0.436

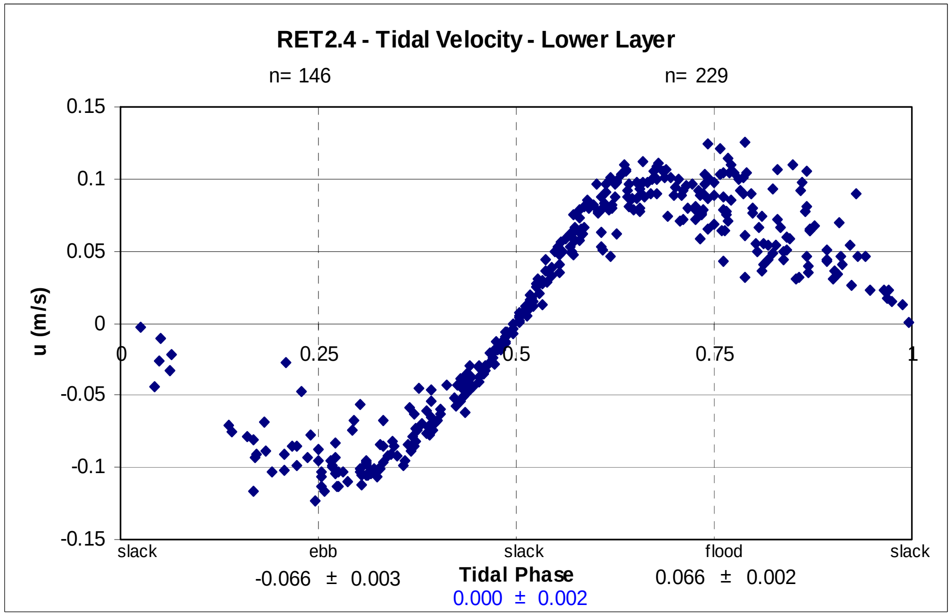

LE2.2 - Subtidal Velocity - Upper Layer
n= 134
n= 260
u (m/s)
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.015 ± 0.010
-0.040± 0.007
-0.065 ± 0.009

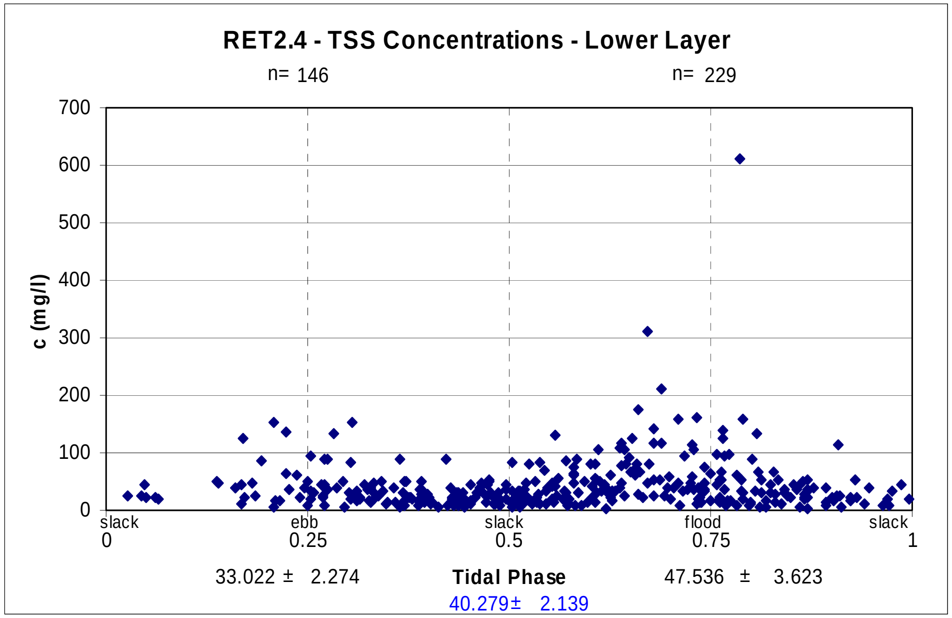

LE2.2 - Tidal Transport - Upper Layer
n= 134
n= 260
u*c (g/m2/s)
15
10
5
0
-5
-10
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.433 ± 0.146
0.032 ± 0.088
1.497 ± 0.100

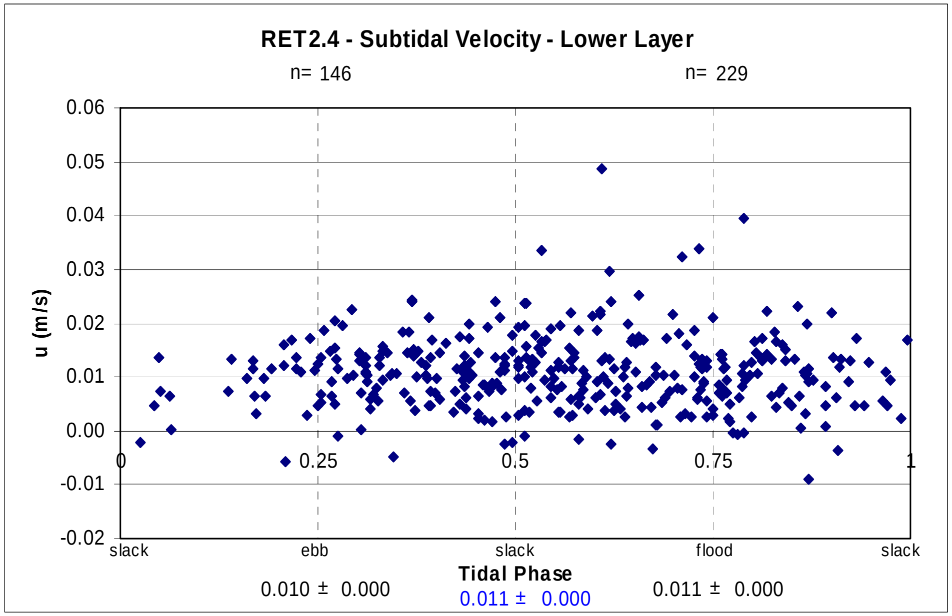

LE2.2 - Subtidal Transport - Upper Layer
n= 134
n= 260
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.387 ± 0.175
-0.636± 0.113
-0.884 ± 0.142

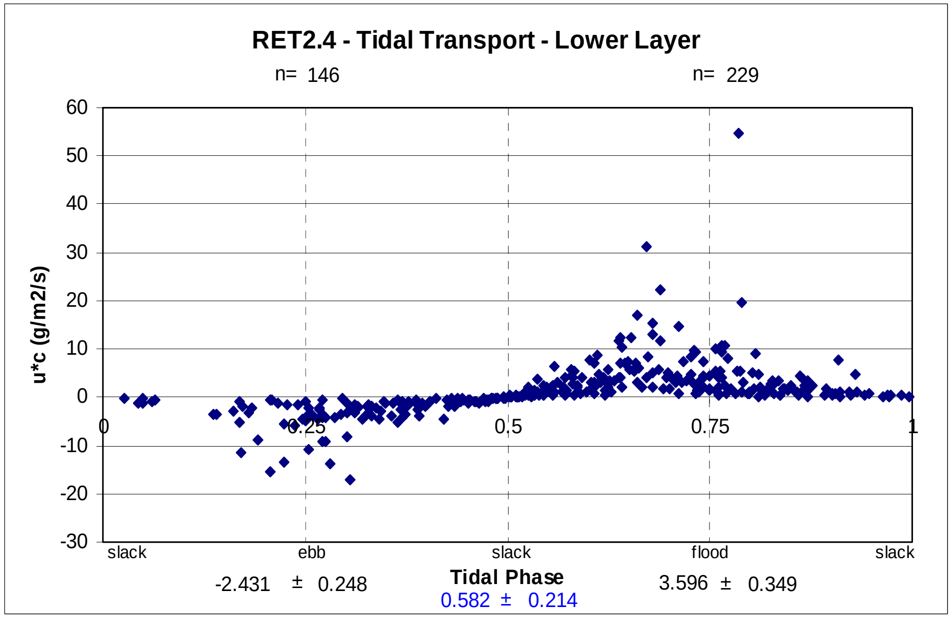

LE2.2 - River Velocity - Upper Layer
n= 134
n= 260
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.008 ± 0.001
-0.007± 0.001
-0.007 ± 0.001

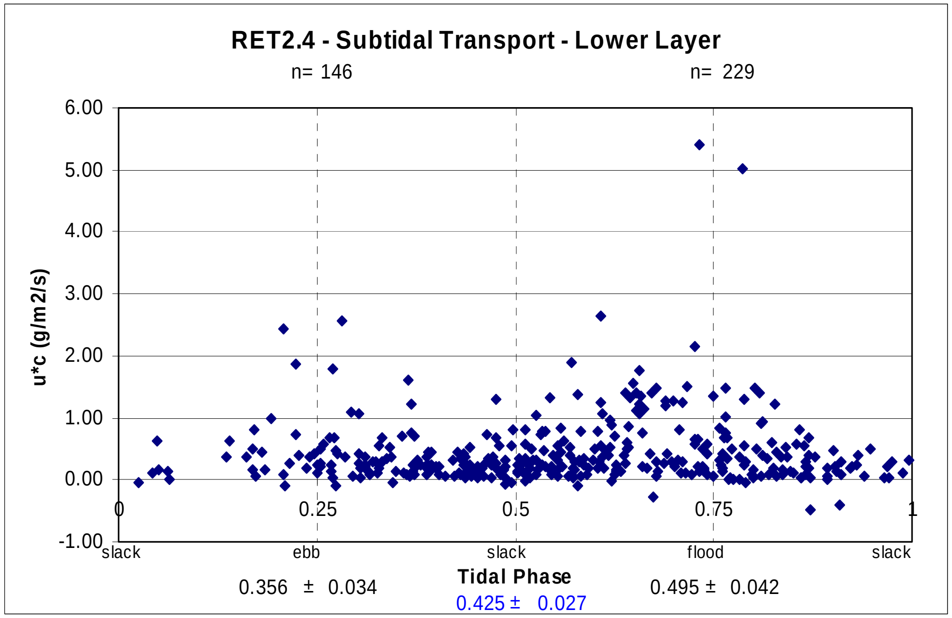

LE2.2 - River Transport - Upper Layer
n= 134
n= 260
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.093 ± 0.020
-0.086 ± 0.011
-0.078 ± 0.009

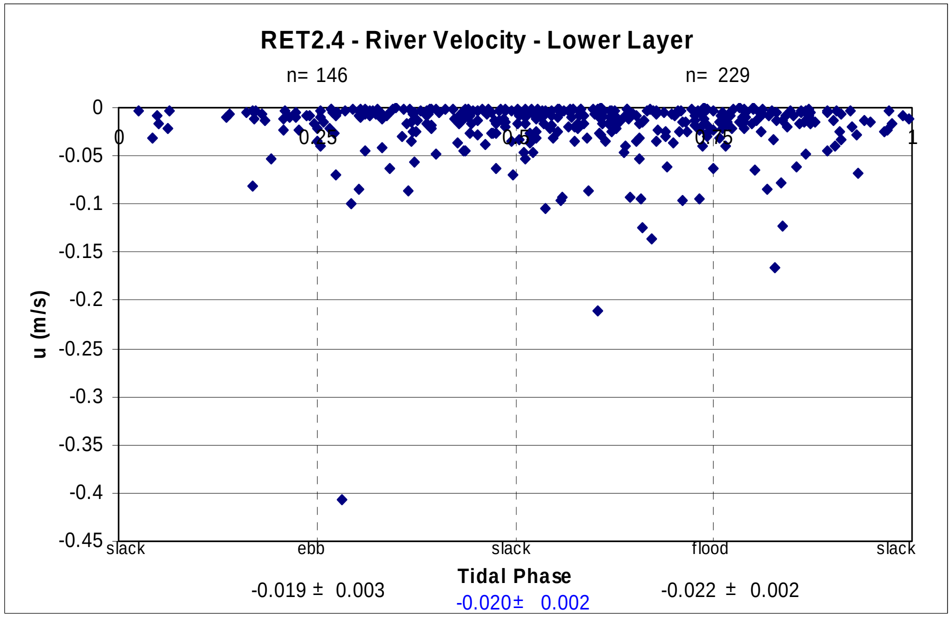

RET2.4 - Tidal Velocity - Lower Layer
n= 146
n= 229
u (m/s)
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.066 ± 0.003
Tidal Phase
0.066 ± 0.002
0.000 ± 0.002

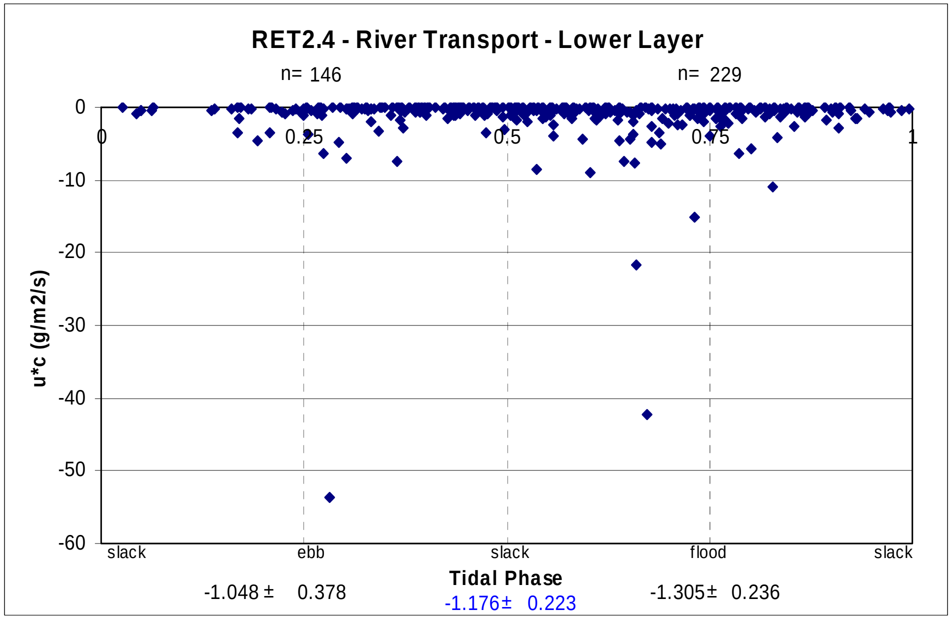

RET2.4 - TSS Concentrations - Lower Layer
n= 146
n= 229
c (mg/l)
700
600
500
400
300
200
100
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
33.022 ± 2.274
Tidal Phase
47.536 ± 3.623
40.279± 2.139

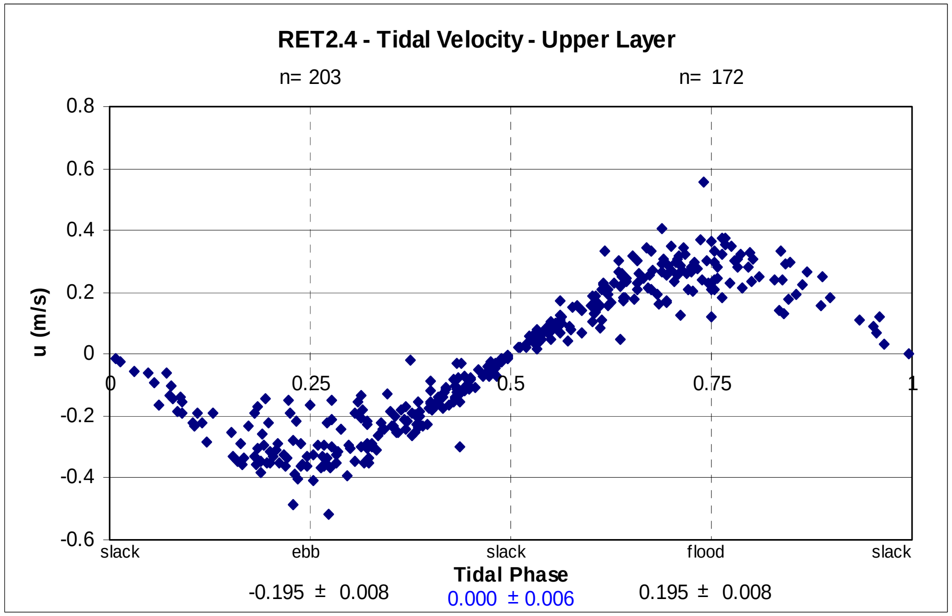

RET2.4 - Subtidal Velocity - Lower Layer
n= 146
n= 229
u (m/s)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.010 ± 0.000
Tidal Phase
0.011 ± 0.000
0.011 ± 0.000

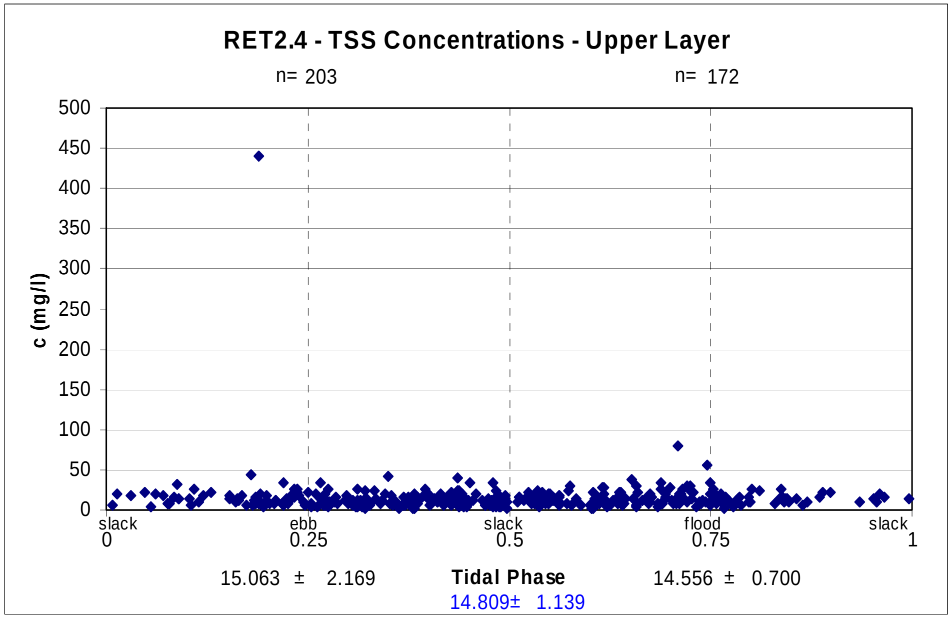

RET2.4 - Tidal Transport - Lower Layer
n= 146
n= 229
u*c (g/m2/s)
60
50
40
30
20
10
0
-10
-20
-30
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-2.431 ± 0.248
Tidal Phase
3.596 ± 0.349
0.582 ± 0.214

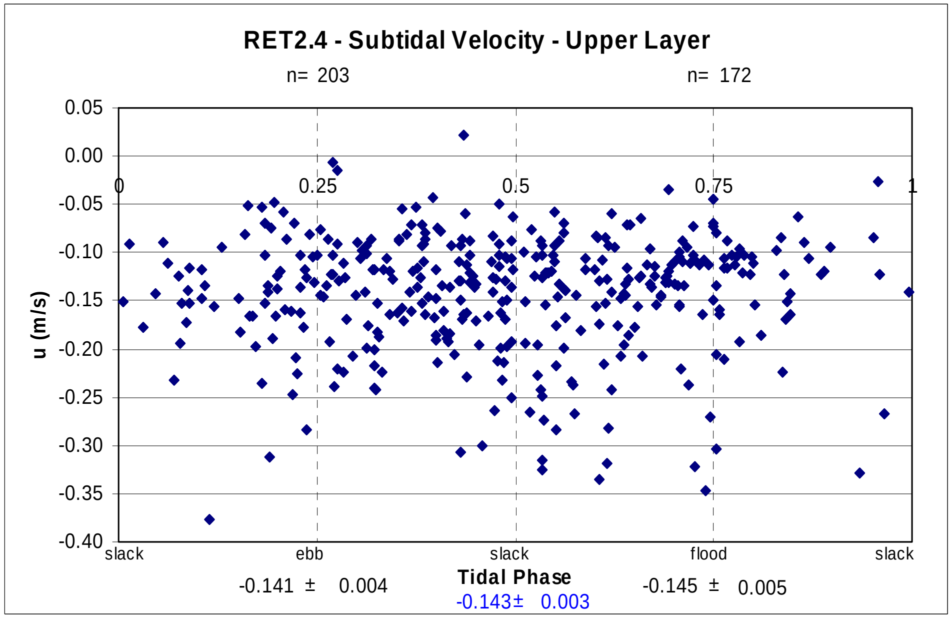

RET2.4 - Subtidal Transport - Lower Layer
n= 146
n= 229
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.356 ± 0.034
0.425 ± 0.027
0.495 ± 0.042

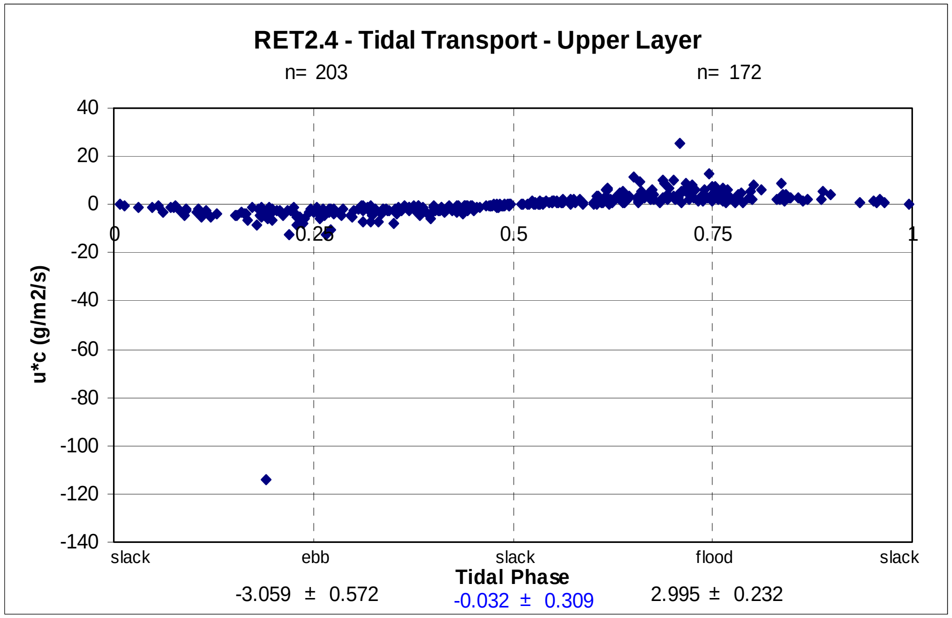

RET2.4 - River Velocity - Lower Layer
n= 146
n= 229
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.019 ± 0.003
-0.020± 0.002
-0.022 ± 0.002

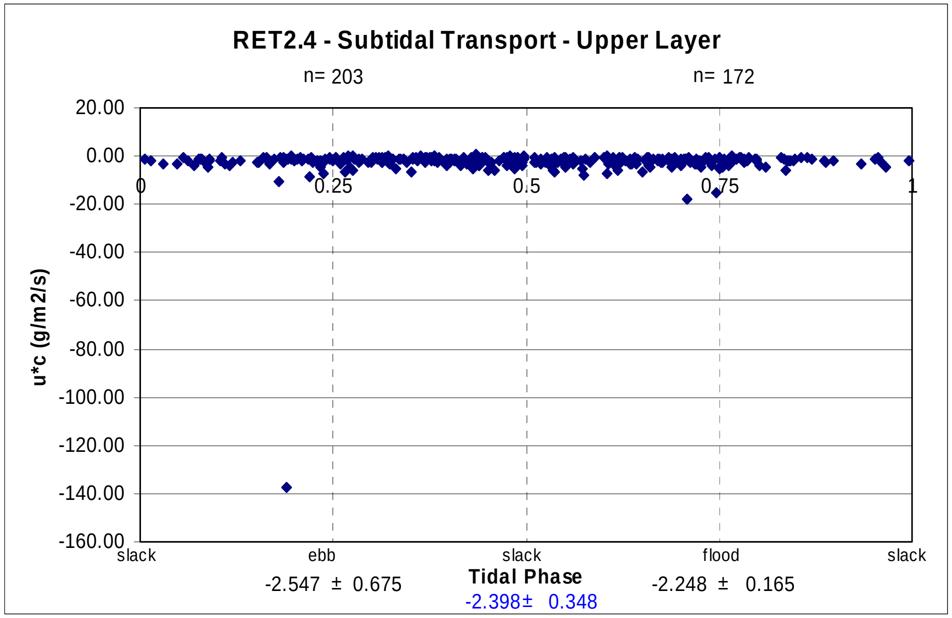

RET2.4 - River Transport - Lower Layer
n= 146
n= 229
0
-10
-20
-30
-40
-50
-60
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.048 ± 0.378
-1.176± 0.223
-1.305± 0.236


RET2.4 - Tidal Velocity - Upper Layer
n= 203
n= 172
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.195 ± 0.008
0.000 ± 0.006
0.195 ± 0.008

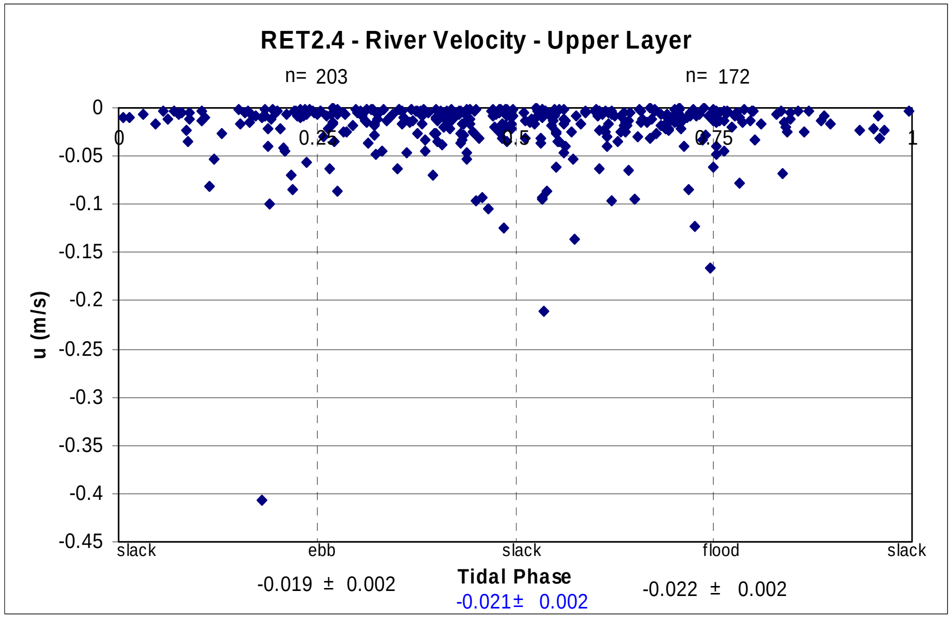

RET2.4 - TSS Concentrations - Upper Layer
n= 203
n= 172
c (mg/l)
slack
ebb
slack
flood
slack
Tidal Phase
15.063 ± 2.169
14.809± 1.139
14.556 ± 0.700


RET2.4 - Subtidal Velocity - Upper Layer
n= 203
n= 172
u (m/s)
slack
ebb
slack
flood
slack
Tidal Phase
-0.141 ± 0.004
-0.143± 0.003
-0.145 ± 0.005

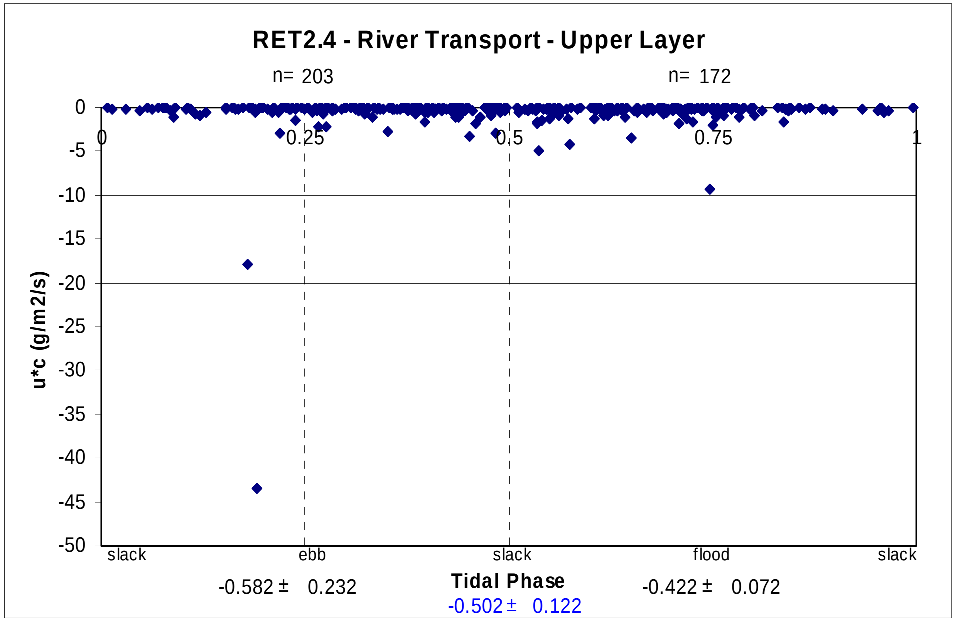

RET2.4 - Tidal Transport - Upper Layer
n= 203
n= 172
u*c (g/m2/s)
slack
ebb
slack
flood
slack
Tidal Phase
-3.059 ± 0.572
-0.032 ± 0.309
2.995 ± 0.232



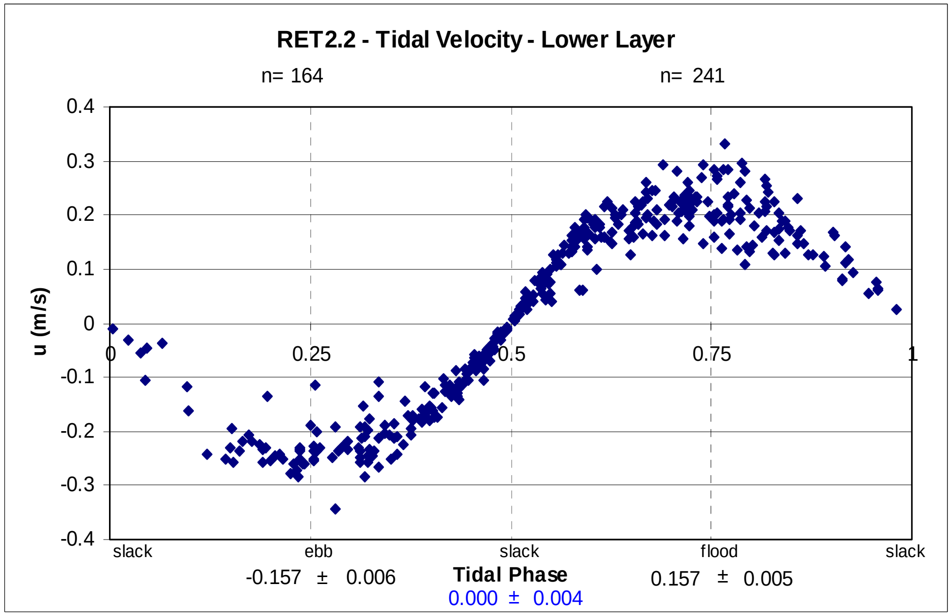
RET2.4 - Subtidal Transport - Upper Layer
n= 203
n= 172
u*c (g/m2/s)
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
-160.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-2.547 ± 0.675
-2.398± 0.348
-2.248 ± 0.165

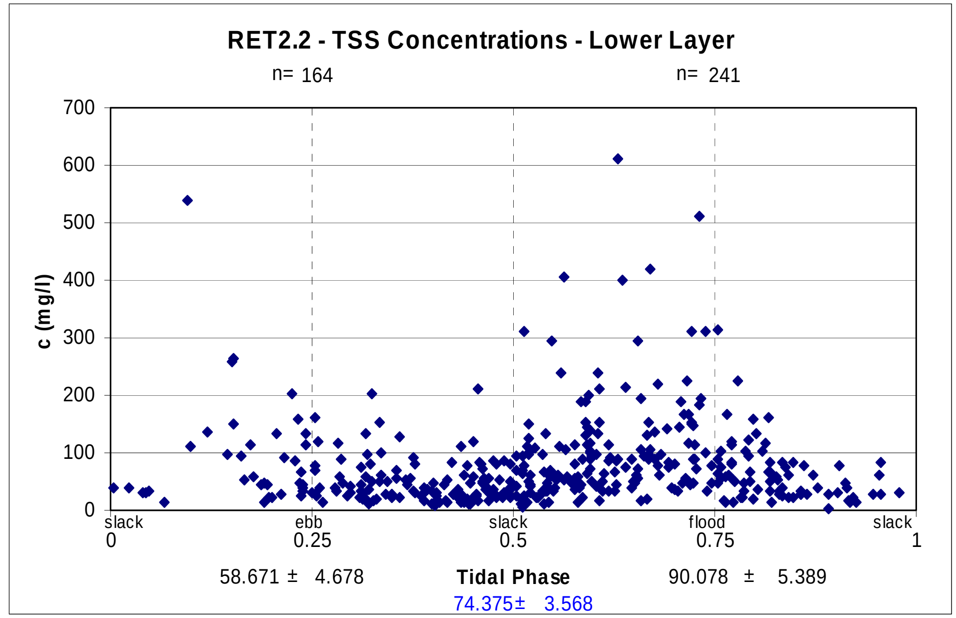


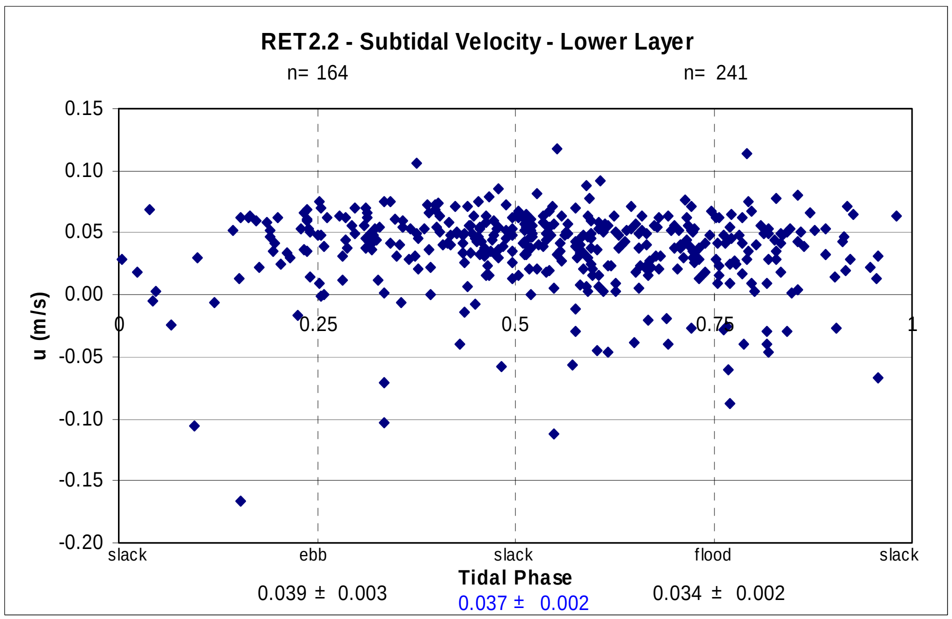
RET2.4 - River Velocity - Upper Layer
n= 203
n= 172
u (m/s)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.019 ± 0.002
-0.021± 0.002
-0.022 ± 0.002

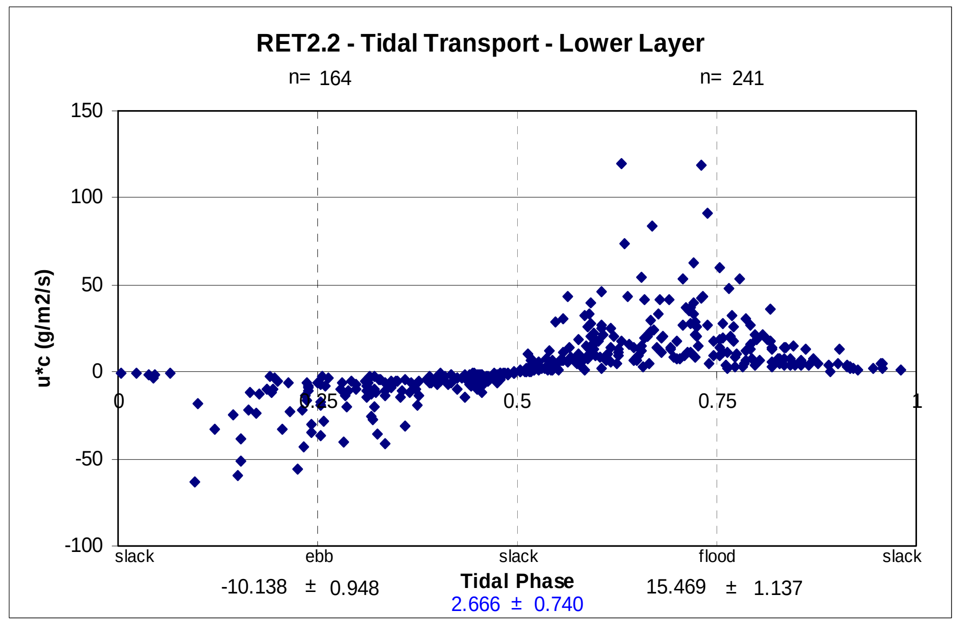


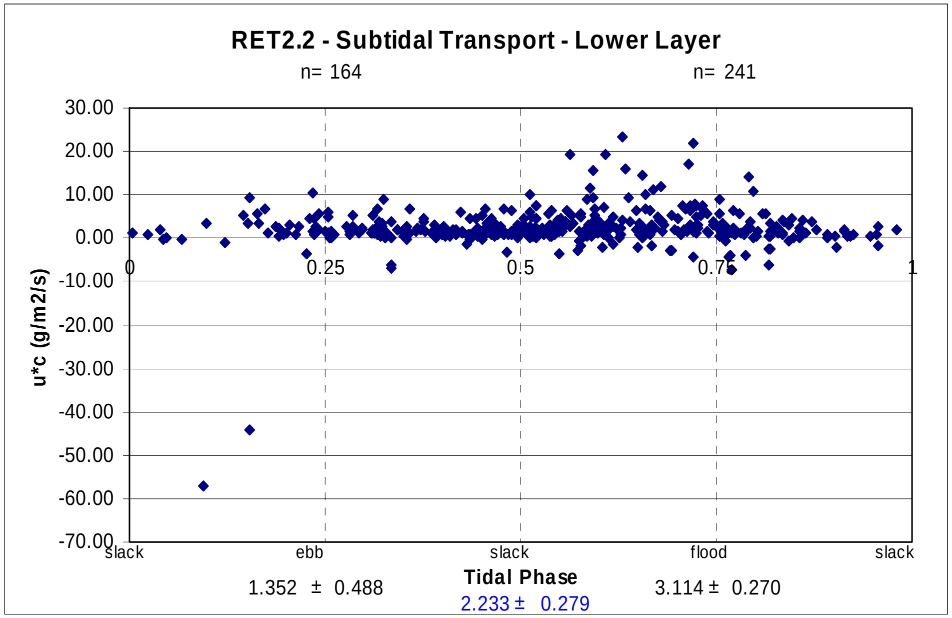
RET2.4 - River Transport - Upper Layer
n= 203
n= 172
u*c (g/m2/s)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.582 ± 0.232
-0.502 ± 0.122
-0.422 ± 0.072

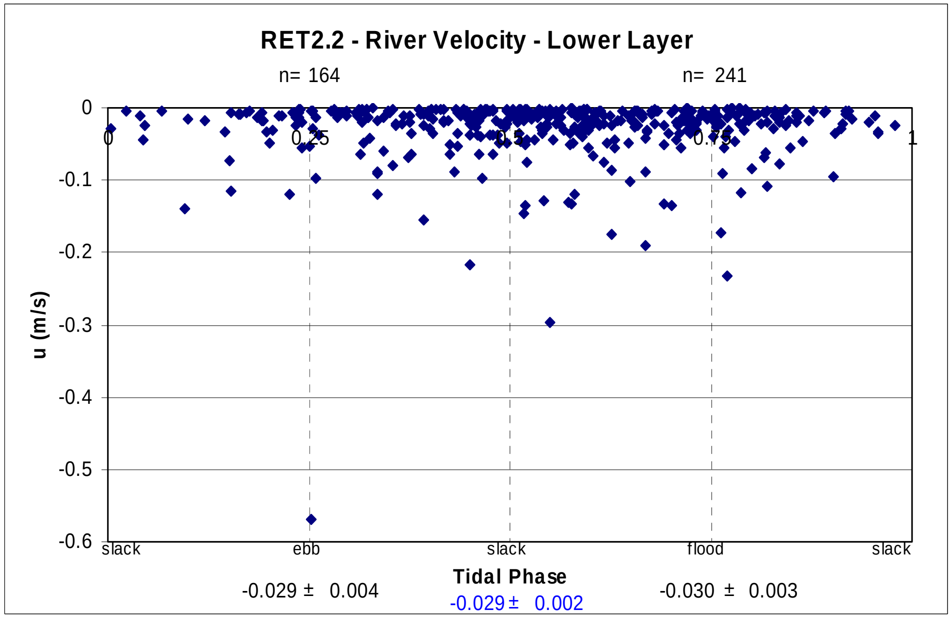

RET2.2 - Tidal Velocity - Lower Layer
n= 164
n= 241
u (m/s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-0.157 ± 0.006
Tidal Phase
0.157 ± 0.005
0.000 ± 0.004

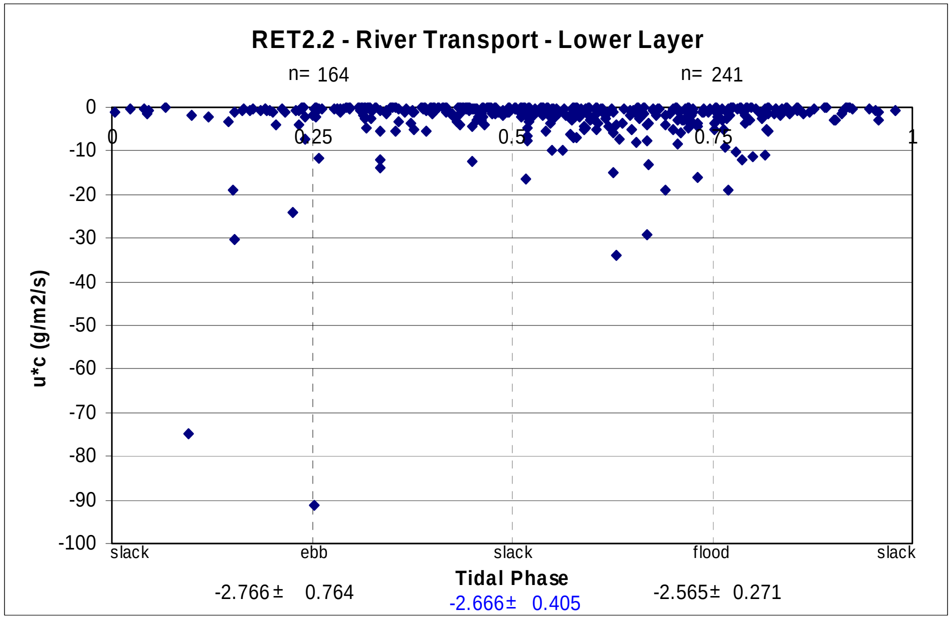

RET2.2 - TSS Concentrations - Lower Layer
n= 164
n= 241
c (mg/l)
700
600
500
400
300
200
100
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
58.671 ± 4.678
Tidal Phase
90.078 ± 5.389
74.375± 3.568

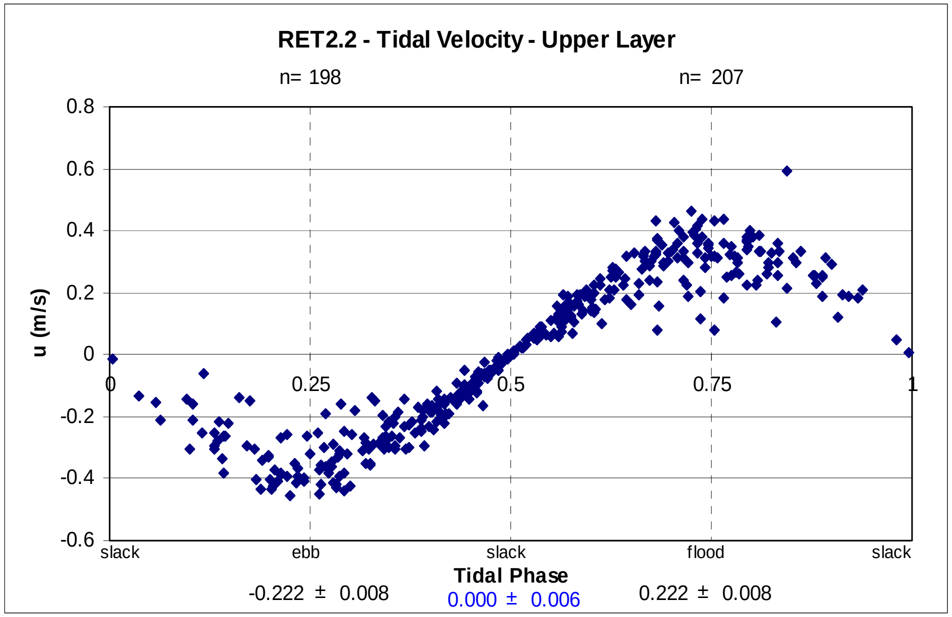

RET2.2 - Subtidal Velocity - Lower Layer
n= 164
n= 241
u (m/s)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
0.039 ± 0.003
Tidal Phase
0.034 ± 0.002
0.037 ± 0.002

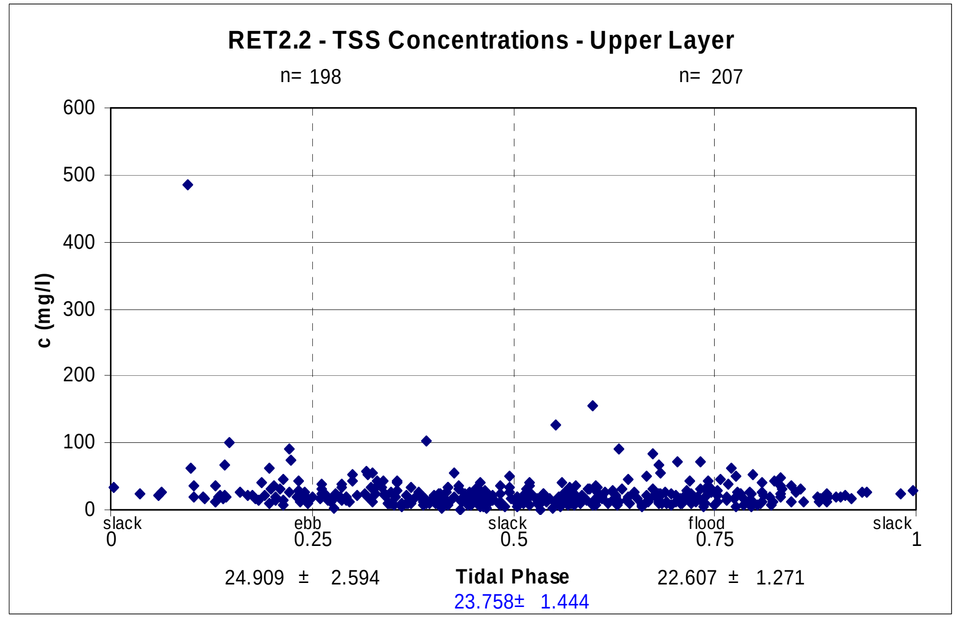

RET2.2 - Tidal Transport - Lower Layer
n= 164
n= 241
u*c (g/m2/s)
150
100
50
0
-50
-100
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
-10.138 ± 0.948
Tidal Phase
15.469 ± 1.137
2.666 ± 0.740

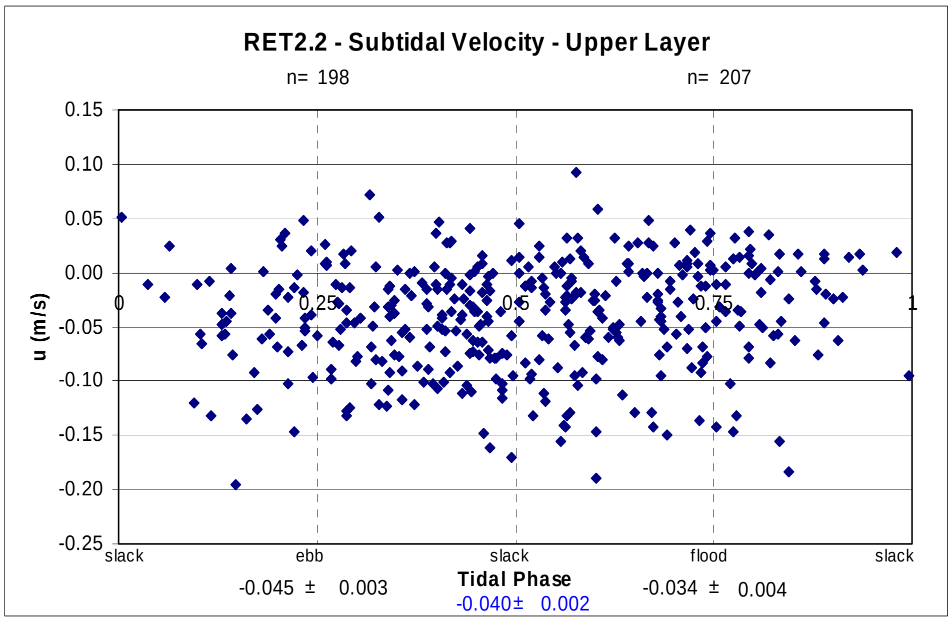

RET2.2 - Subtidal Transport - Lower Layer
n= 164
n= 241
u*c (g/m2/s)
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
1.352 ± 0.488
2.233 ± 0.279
3.114 ± 0.270

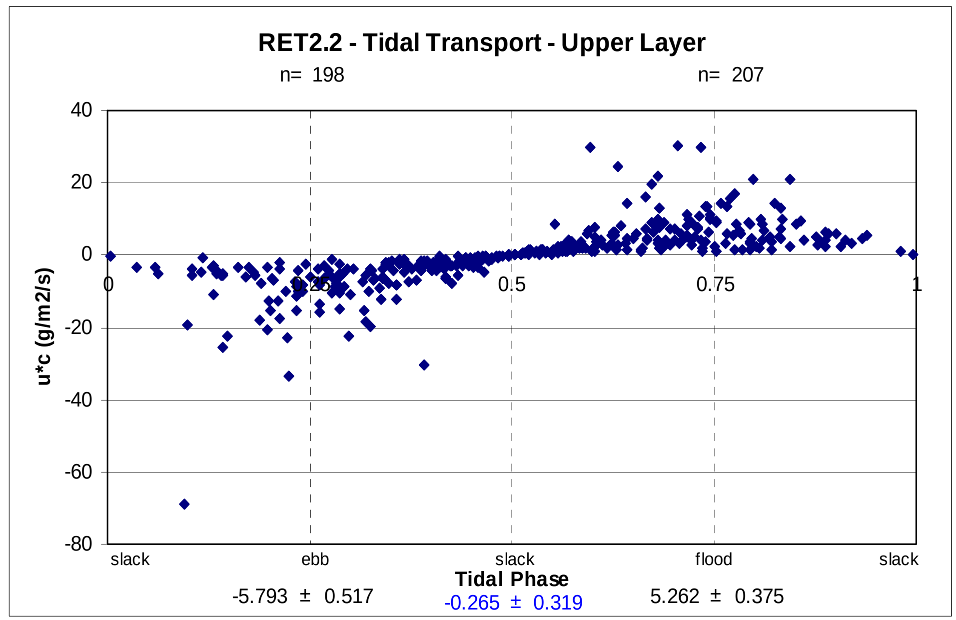

RET2.2 - River Velocity - Lower Layer
n= 164
n= 241
u (m/s)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.029 ± 0.004
-0.029 ± 0.002
-0.030 ± 0.003

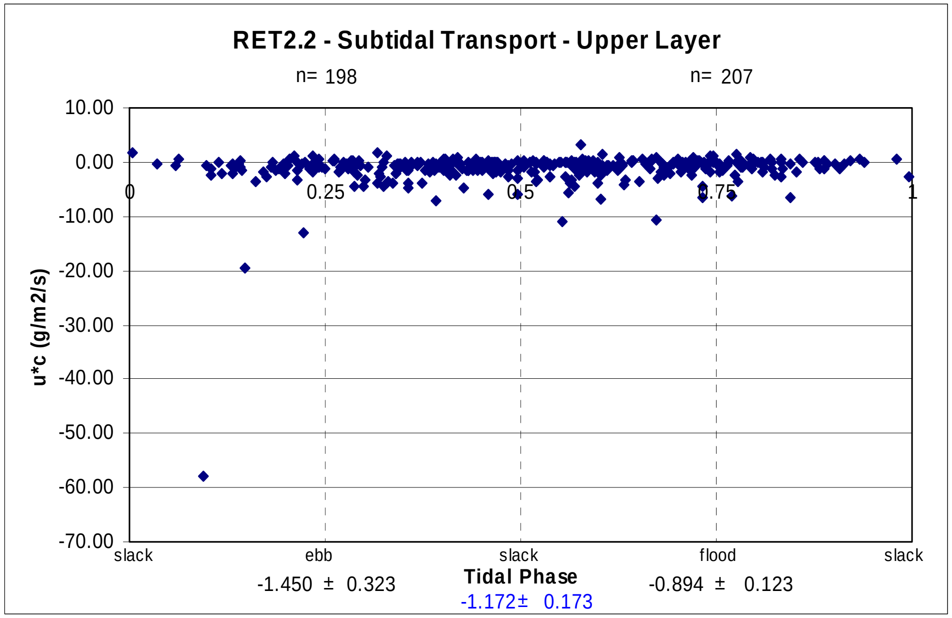

RET2.2 - River Transport - Lower Layer
n= 164
n= 241
u*c (g/m2/s)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-2.766 ± 0.764
-2.666 ± 0.405
-2.565 ± 0.271


RET2.2 - Tidal Velocity - Upper Layer
n= 198
n= 207
u (m/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.222 ± 0.008
0.000 ± 0.006
0.222 ± 0.008

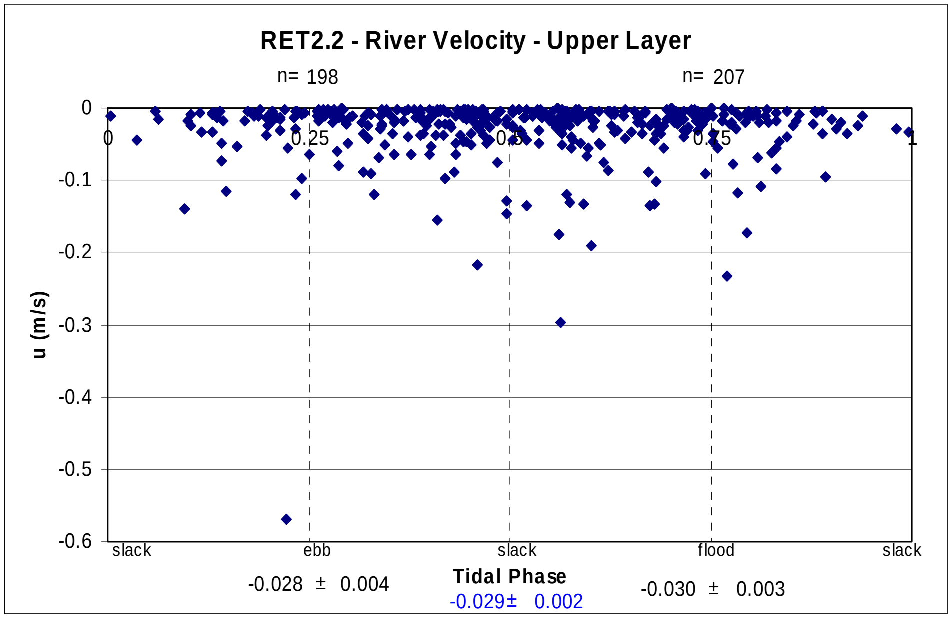

RET2.2 - TSS Concentrations - Upper Layer
n= 198
n= 207
c (mg/l)
600
500
400
300
200
100
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
24.909 ± 2.594
Tidal Phase
22.607 ± 1.271
23.758± 1.444


RET2.2 - Subtidal Velocity - Upper Layer
n= 198
n= 207
u (m/s)
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.045 ± 0.003
-0.040± 0.002
-0.034 ± 0.004

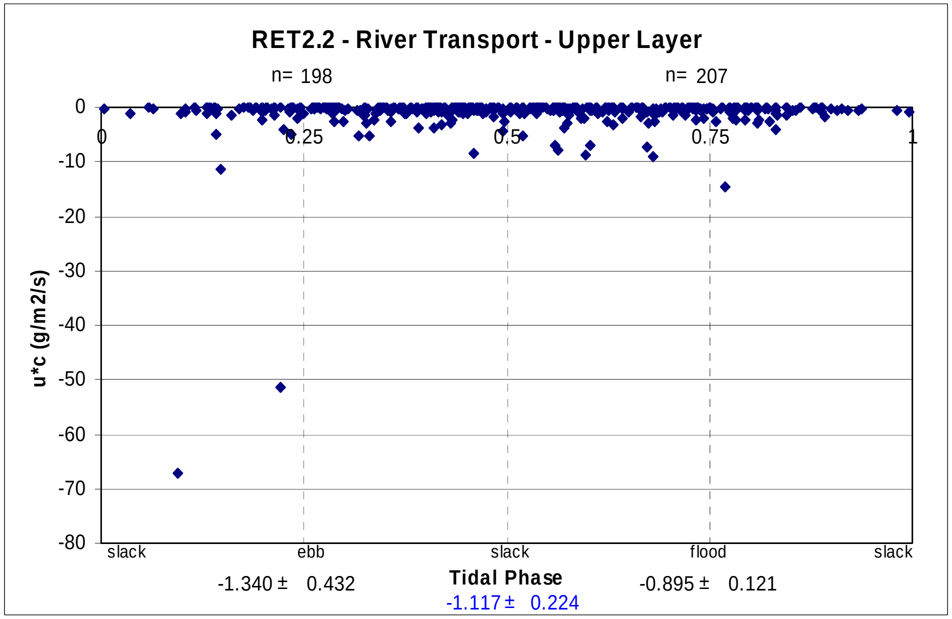

RET2.2 - Tidal Transport - Upper Layer
n= 198
n= 207
u*c (g/m2/s)
40
20
0
-20
-40
-60
-80
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-5.793 ± 0.517
-0.265 ± 0.319
5.262 ± 0.375



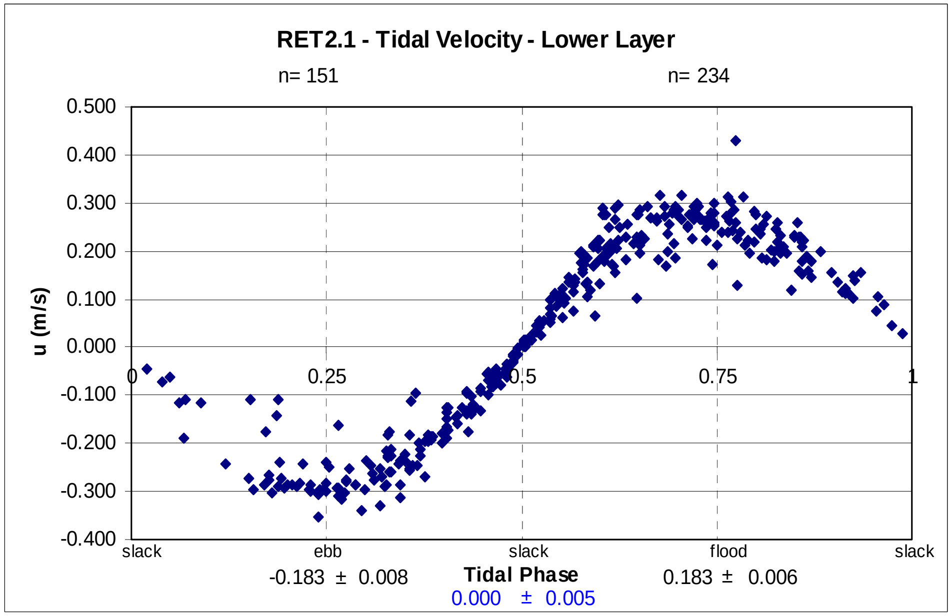
RET2.2 - Subtidal Transport - Upper Layer
n= 198
n= 207
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.450 ± 0.323
-0.894 ± 0.123
-1.172± 0.173

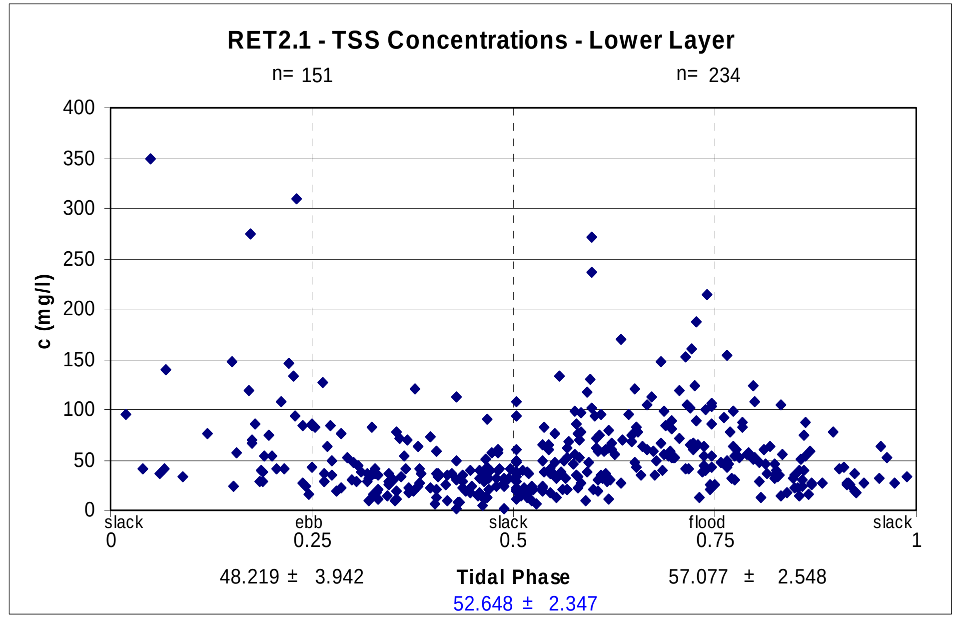


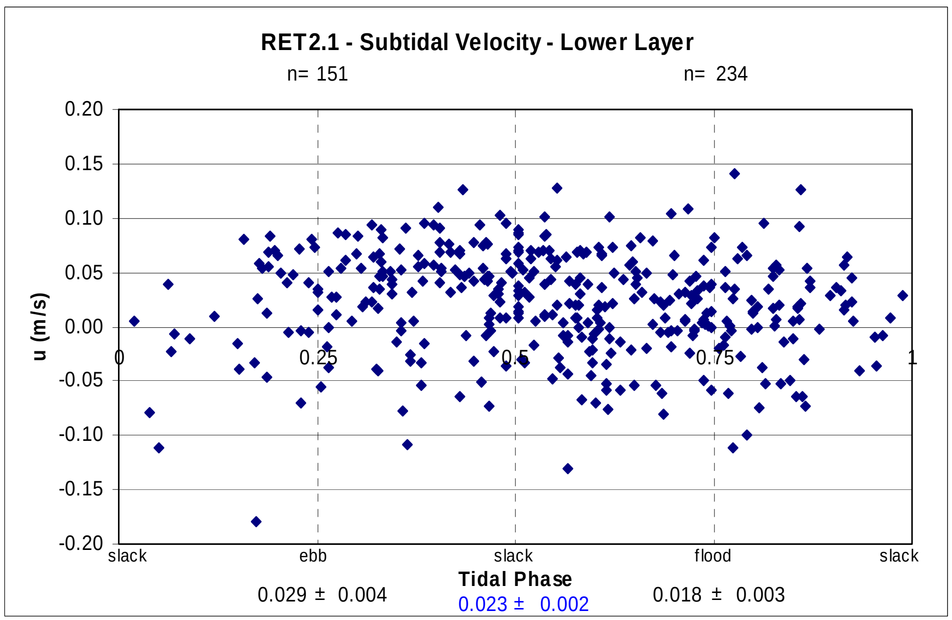
RET2.2 - River Velocity - Upper Layer
n= 198
n= 207
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.028 ± 0.004
-0.030 ± 0.003
-0.029± 0.002

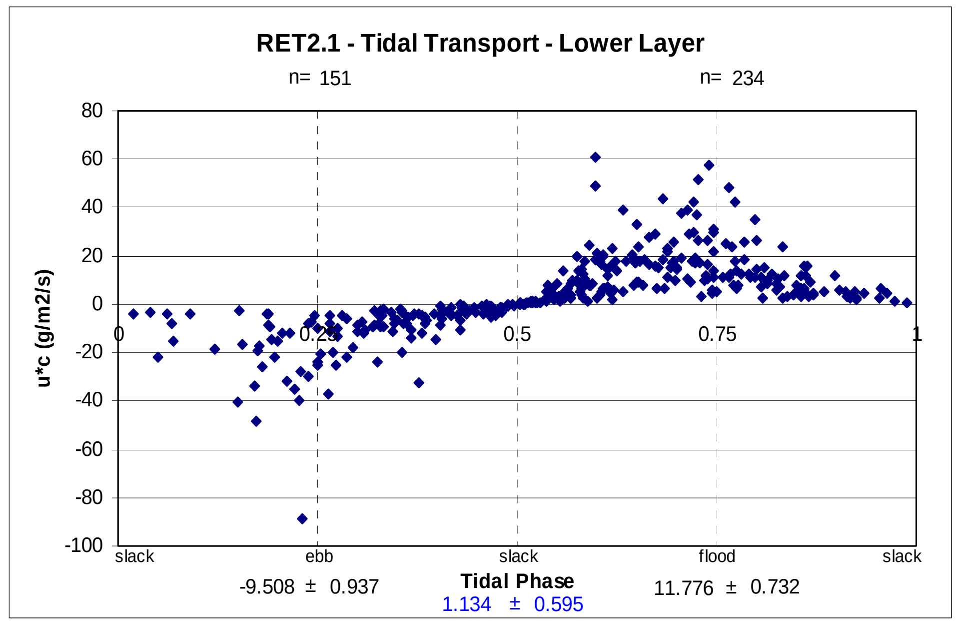


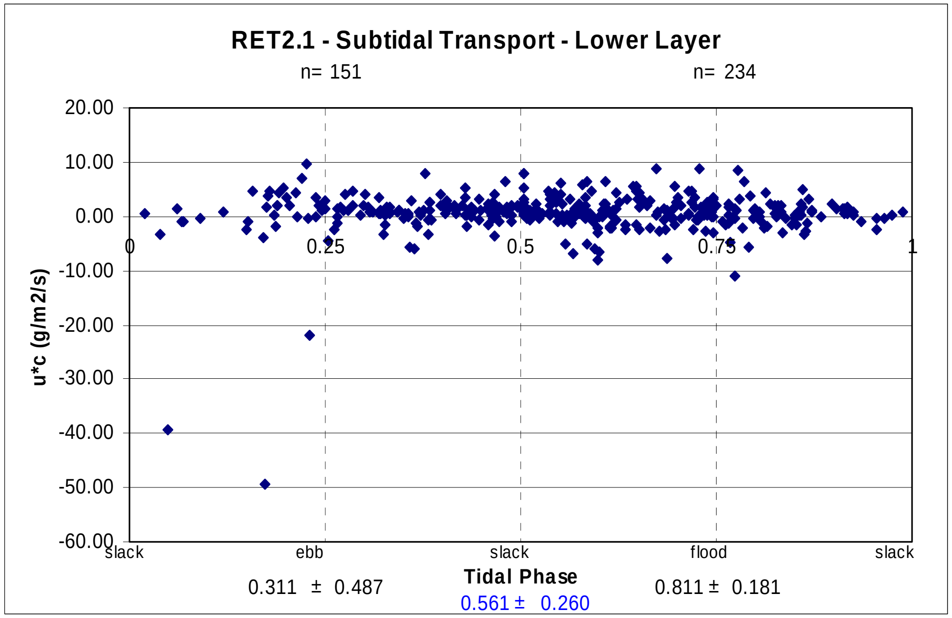
RET2.2 - River Transport - Upper Layer
n= 198
n= 207
0
-10
-20
-30
-40
-50
-60
-70
-80
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.340 ± 0.432
-0.895 ± 0.121
-1.117 ± 0.224

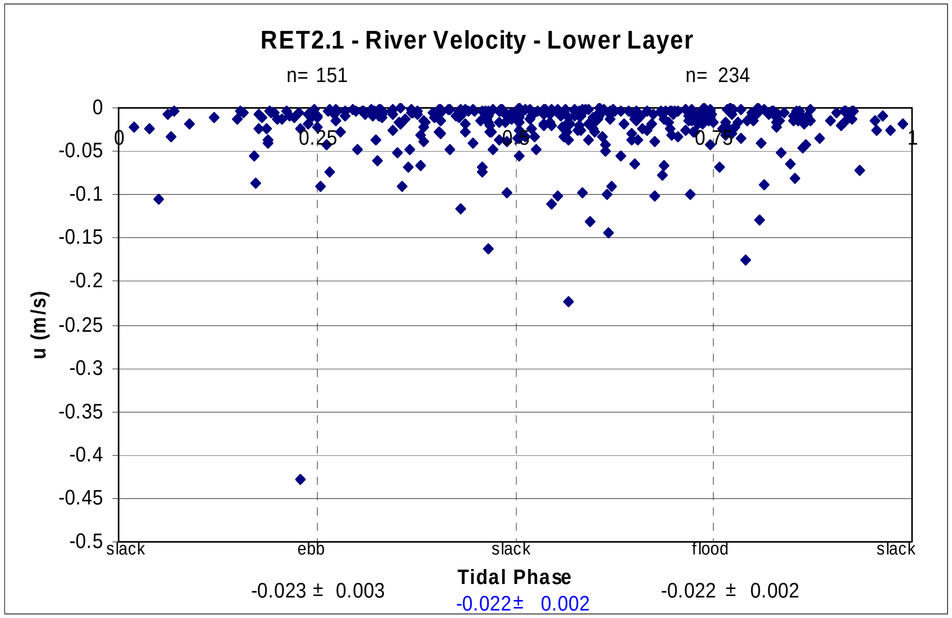

RET2.1 - Tidal Velocity - Lower Layer
n= 151
n= 234
u (m/s)
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.183 ± 0.008
0.183 ± 0.006
0.000 ± 0.005

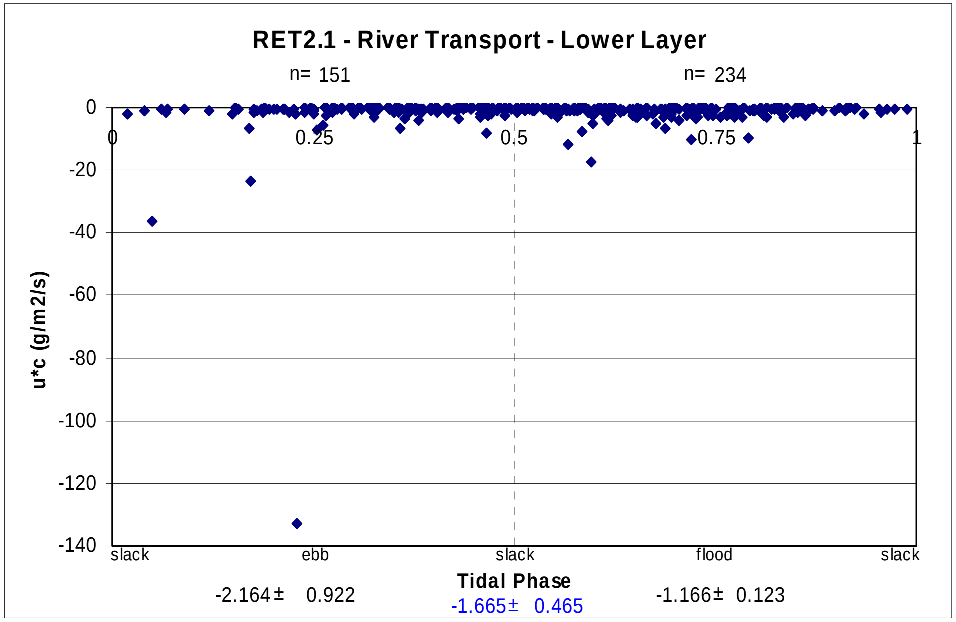

RET2.1 - TSS Concentrations - Lower Layer
n= 151
n= 234
c (mg/l)
400
350
300
250
200
150
100
50
0
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
Tidal Phase
48.219 ± 3.942
57.077 ± 2.548
52.648 ± 2.347

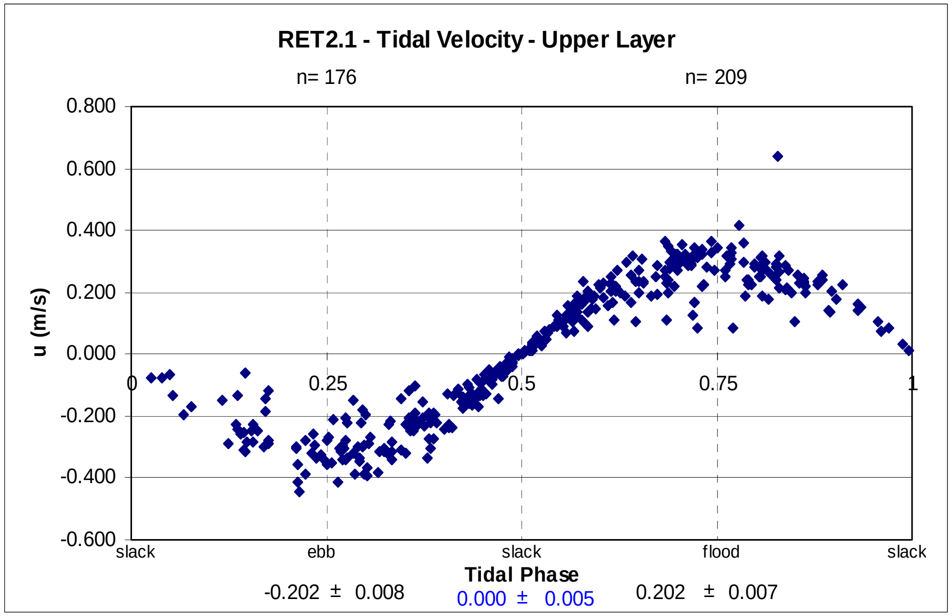

RET2.1 - Subtidal Velocity - Lower Layer
n= 151
n= 234
u (m/s)
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
0.029 ± 0.004
0.018 ± 0.003
0.023 ± 0.002

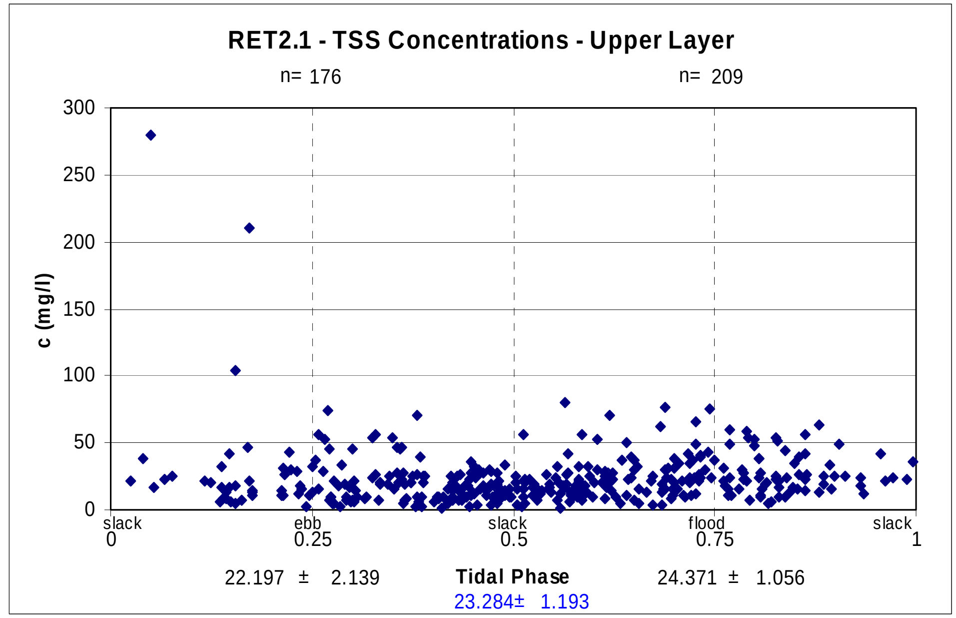

RET2.1 - Tidal Transport - Lower Layer
n= 151
n= 234
u*c (g/m2/s)
80
60
40
20
0
-20
-40
-60
-80
-100
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-9.508 ± 0.937
11.776 ± 0.732
1.134 ± 0.595

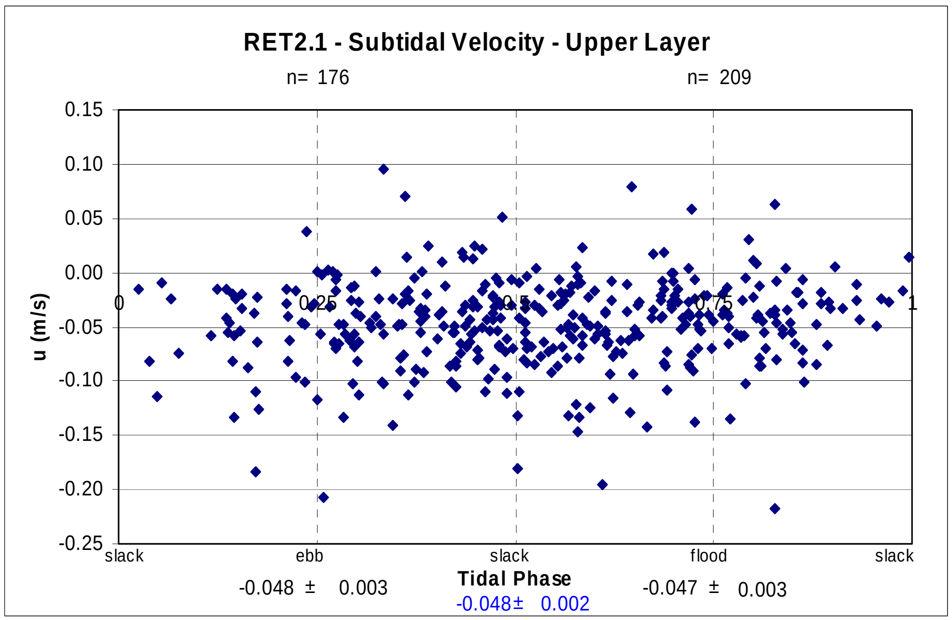

RET2.1 - Subtidal Transport - Lower Layer
n= 151
n= 234
u*c (g/m2/s)
Tidal Phase
slack
ebb
slack
flood
slack
0.311 ± 0.487
0.561 ± 0.260
0.811 ± 0.181

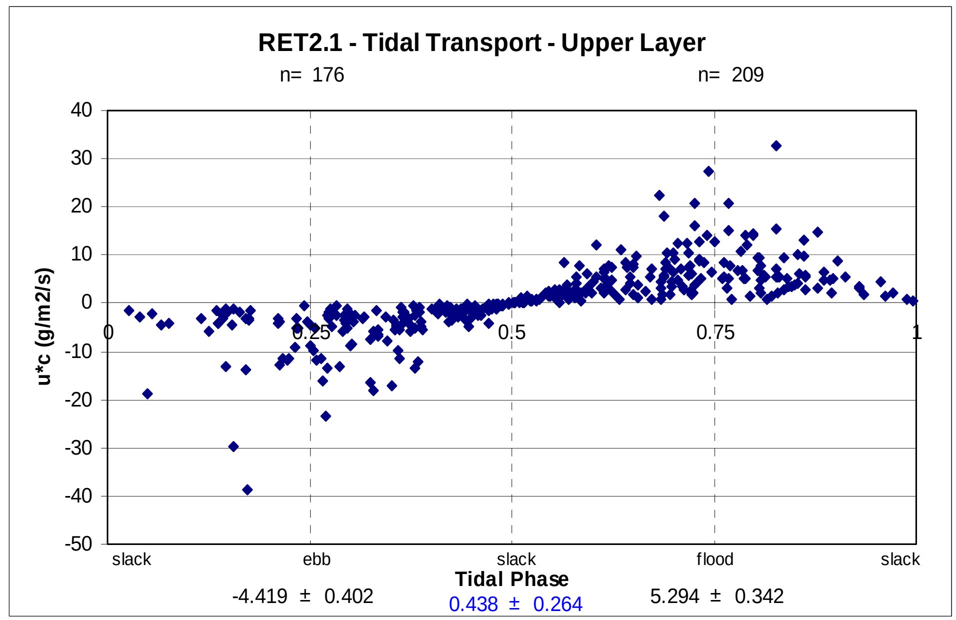

RET2.1 - River Velocity - Lower Layer
n= 151
n= 234
u (m/s)
Tidal Phase
slack
ebb
slack
flood
slack
-0.023 ± 0.003
-0.022 ± 0.002
-0.022 ± 0.002

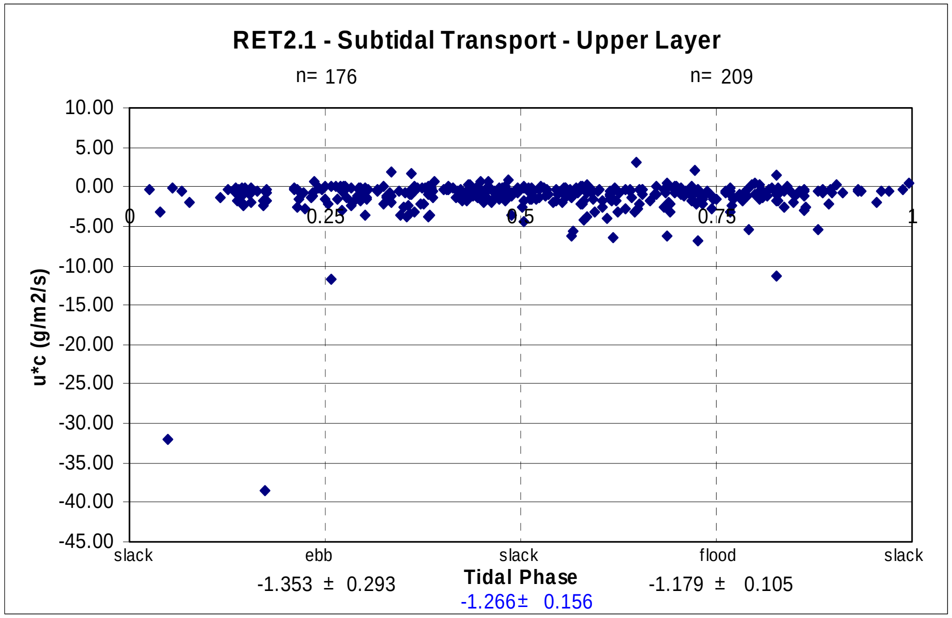

RET2.1 - River Transport - Lower Layer
n= 151
n= 234
u*c (g/m2/s)
Tidal Phase
slack
ebb
slack
flood
slack
-2.164 ± 0.922
-1.665 ± 0.465
-1.166 ± 0.123

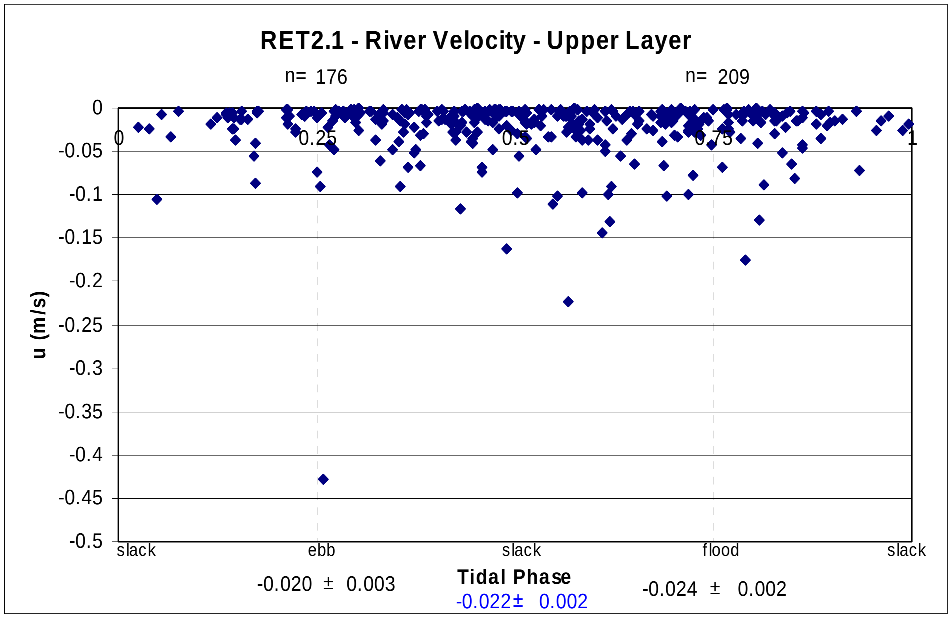

RET2.1 - Tidal Velocity - Upper Layer
n= 176
n= 209
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.202 ± 0.008
0.000 ± 0.005
0.202 ± 0.007

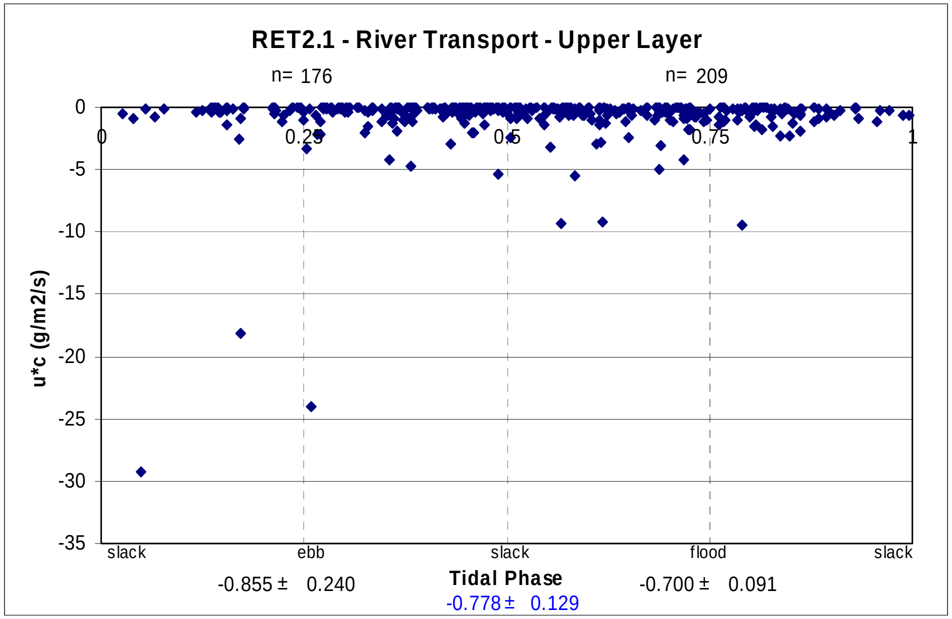

RET2.1 - TSS Concentrations - Upper Layer
n= 176
n= 209
300
250
200
150
100
50
0
c (mg/l)
slack
ebb
slack
flood
slack
0
0.25
0.5
0.75
1
22.197 ± 2.139
Tidal Phase
24.371 ± 1.056
23.284± 1.193


RET2.1 - Subtidal Velocity - Upper Layer
n= 176
n= 209
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
u (m/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.048 ± 0.003
-0.047 ± 0.003
-0.048± 0.002


RET2.1 - Tidal Transport - Upper Layer
n= 176
n= 209
40
30
20
10
0
-10
-20
-30
-40
-50
u*c (g/m2/s)
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-4.419 ± 0.402
5.294 ± 0.342
0.438 ± 0.264

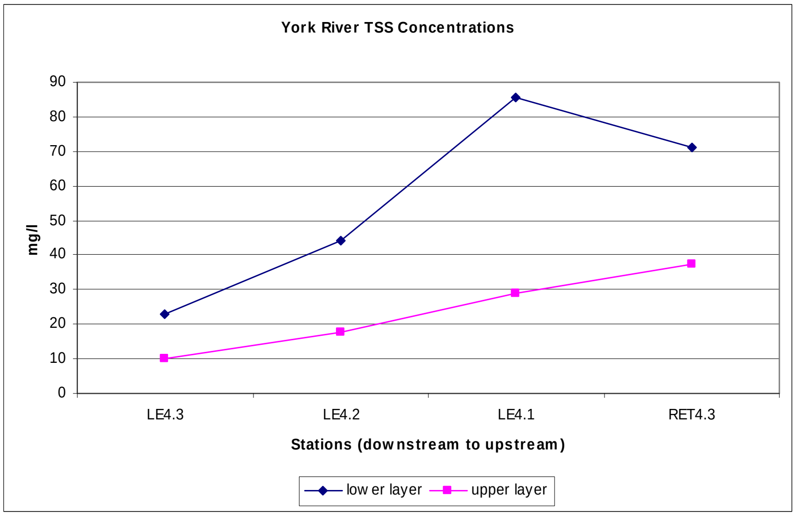

RET2.1 - Subtidal Transport - Upper Layer
n= 176
n= 209
u*c (g/m2/s)
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-1.353 ± 0.293
-1.179 ± 0.105
-1.266± 0.156

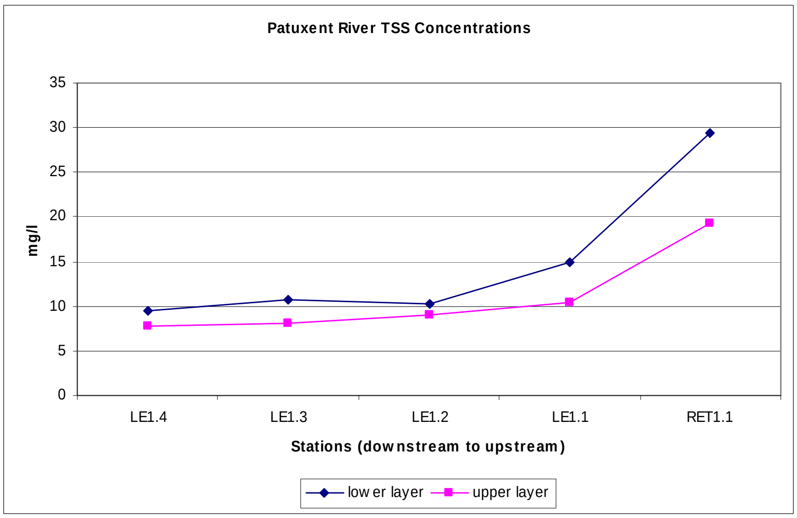

RET2.1 - River Velocity - Upper Layer
n= 176
n= 209
u (m/s)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.020 ± 0.003
-0.024 ± 0.002
-0.022± 0.002


RET2.1 - River Transport - Upper Layer
n= 176
n= 209
u*c (g/m2/s)
0
-5
-10
-15
-20
-25
-30
-35
0
0.25
0.5
0.75
1
slack
ebb
slack
flood
slack
Tidal Phase
-0.855 ± 0.240
-0.700 ± 0.091
-0.778 ± 0.129

Appendix 2

Summary graphs of concentration (mg/l), velocities (m/s), transport processes ($g/m^2/s$) and loads (g/s) for upper and lower layers for each river. Positive values are flood-directed and negative values are ebb-directed. On all graphs, stations are in order from downstream to upstream.





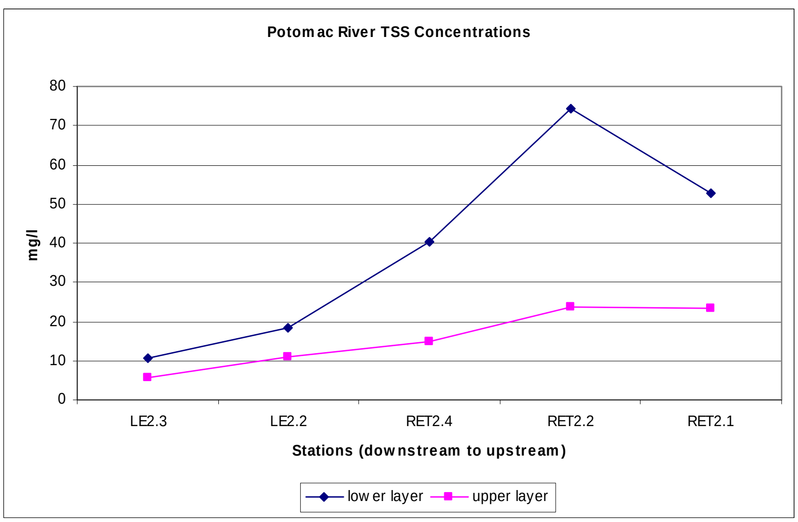


Figure A1. Mean TSS concentrations for each station from downstream to upstream. Positive numbers are flood-directed; negative numbers are ebb-directed.

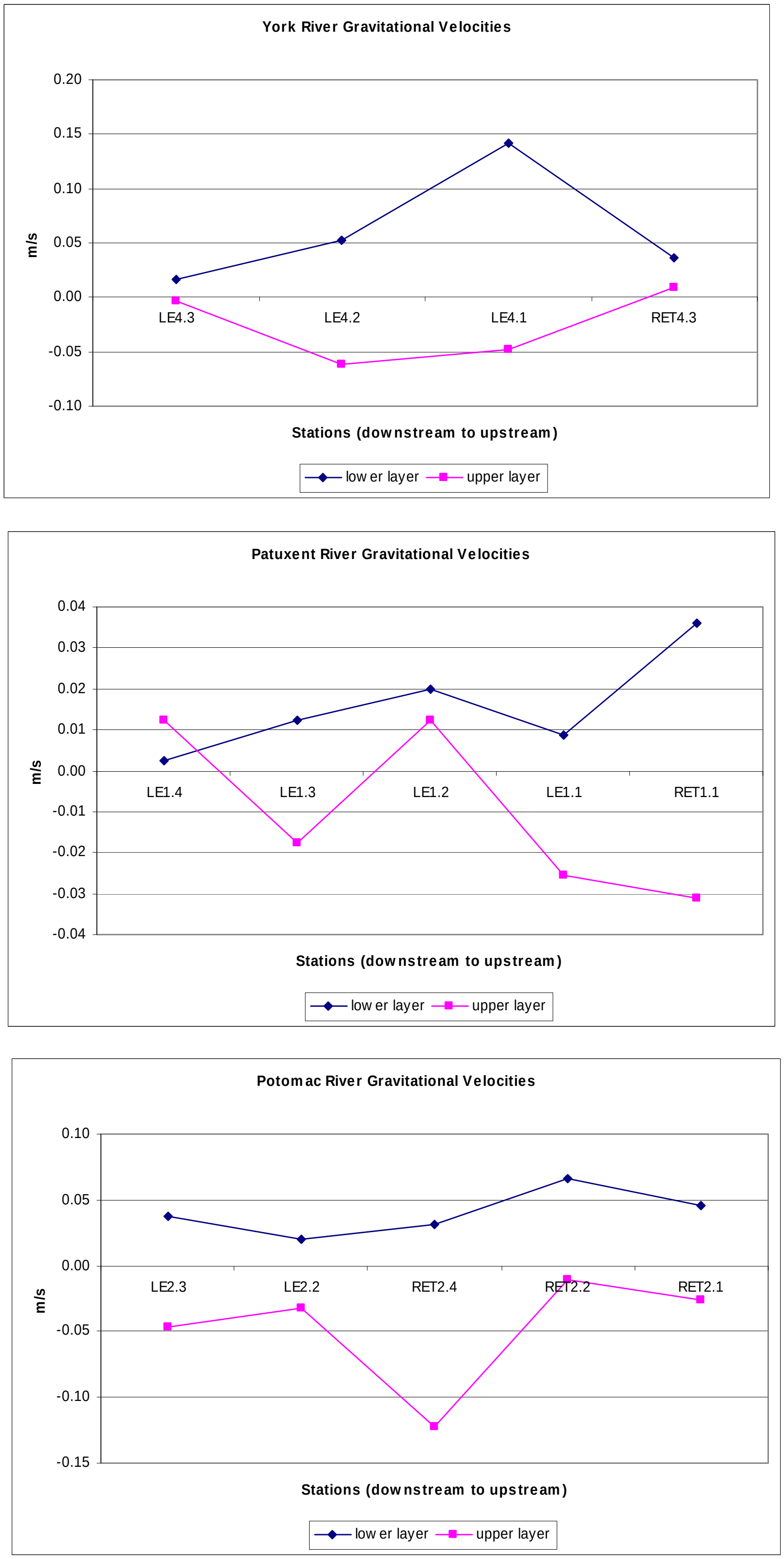


Figure A2. Gravitational velocities for each station from downstream to upstream. Positive numbers are flood-directed; negative numbers are ebb-directed.

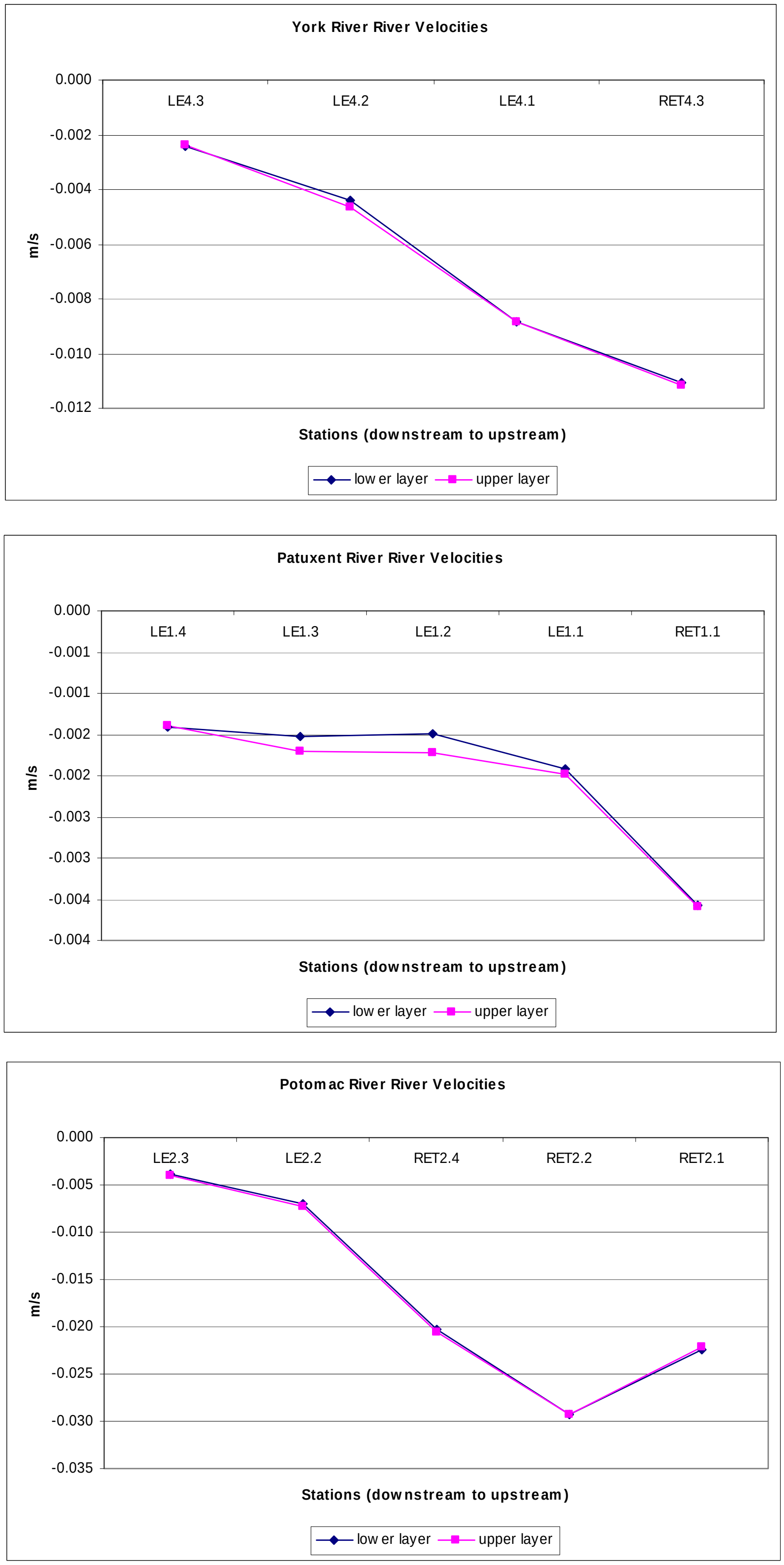


Figure A3. River velocities for each station from downstream to upstream. Positive numbers are flood-directed; negative numbers are ebb-directed.

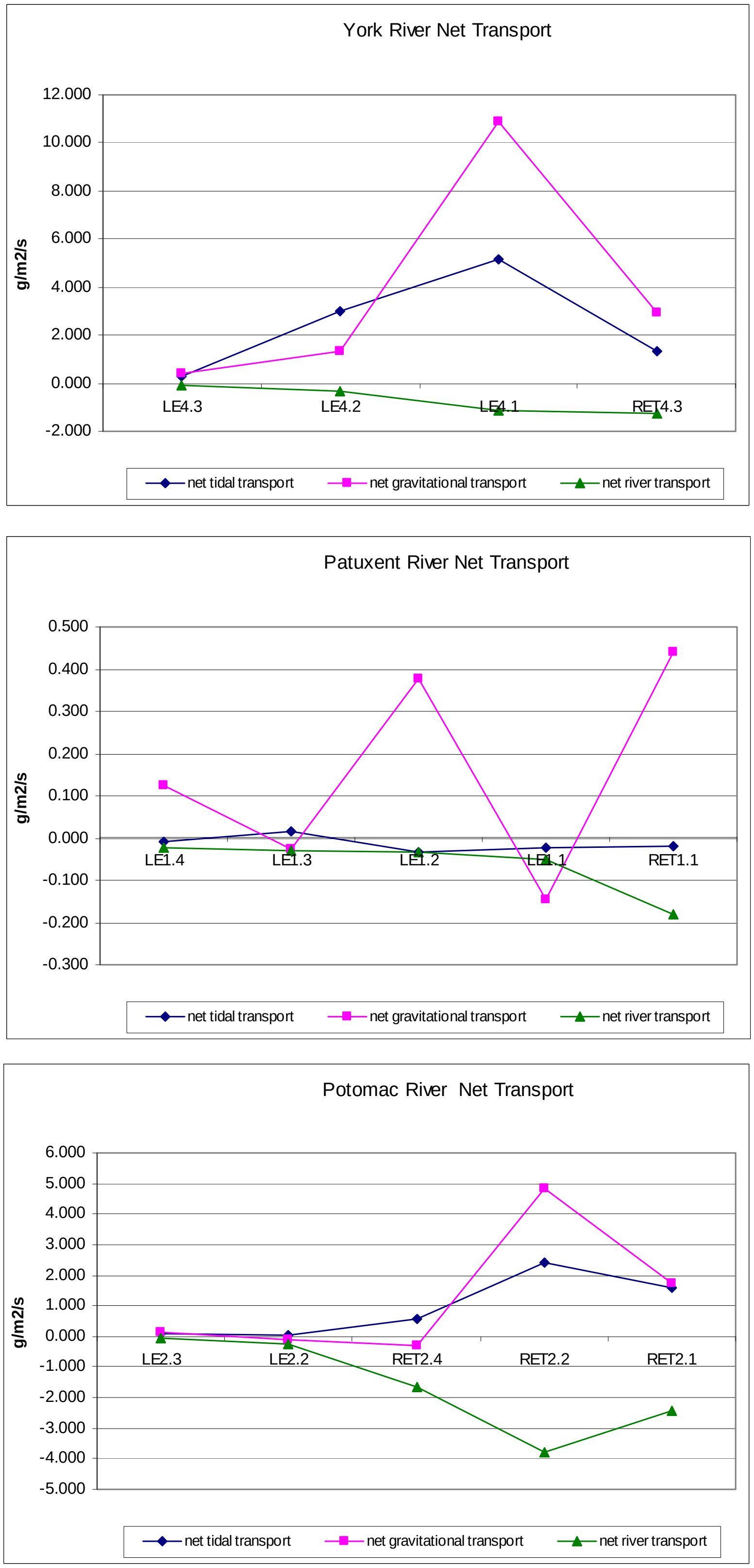
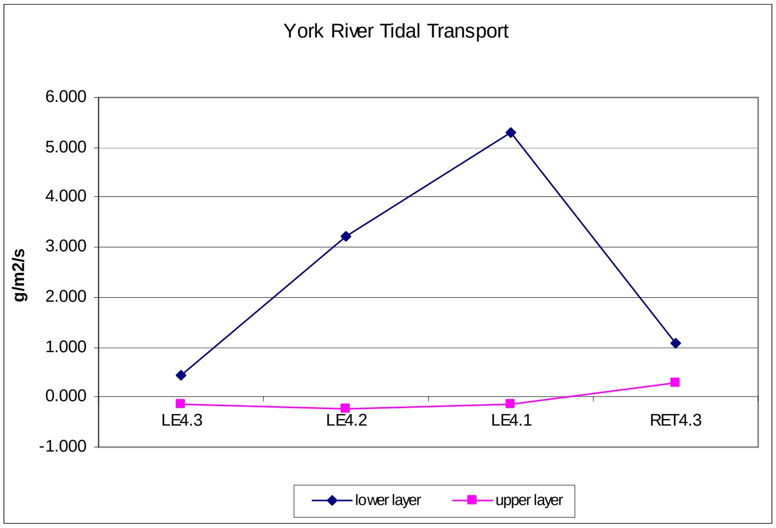
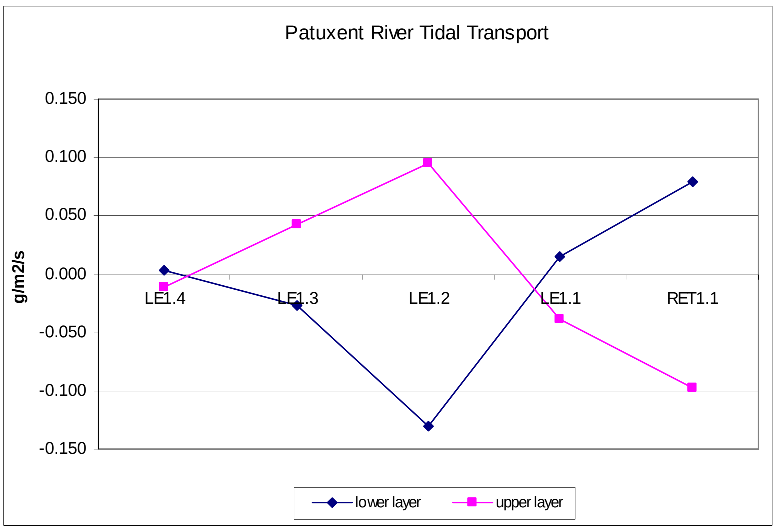


Figure A4. Net transport for each river.





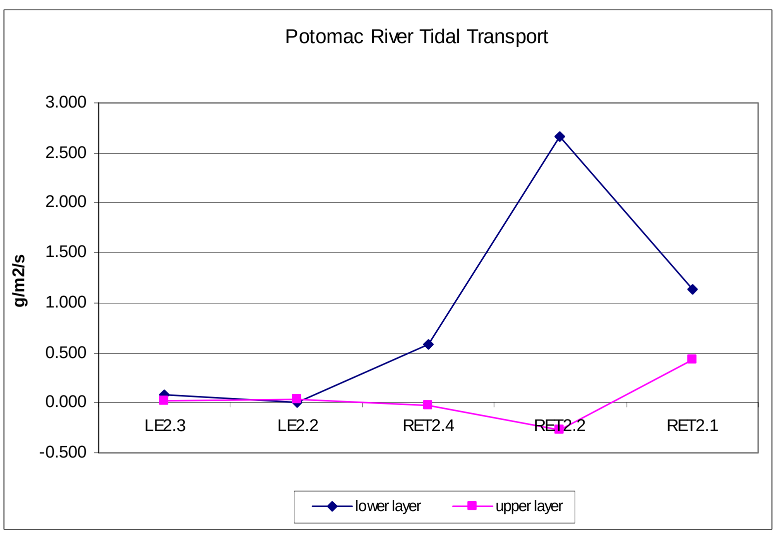


Figure A5. Tidal transport for each river.

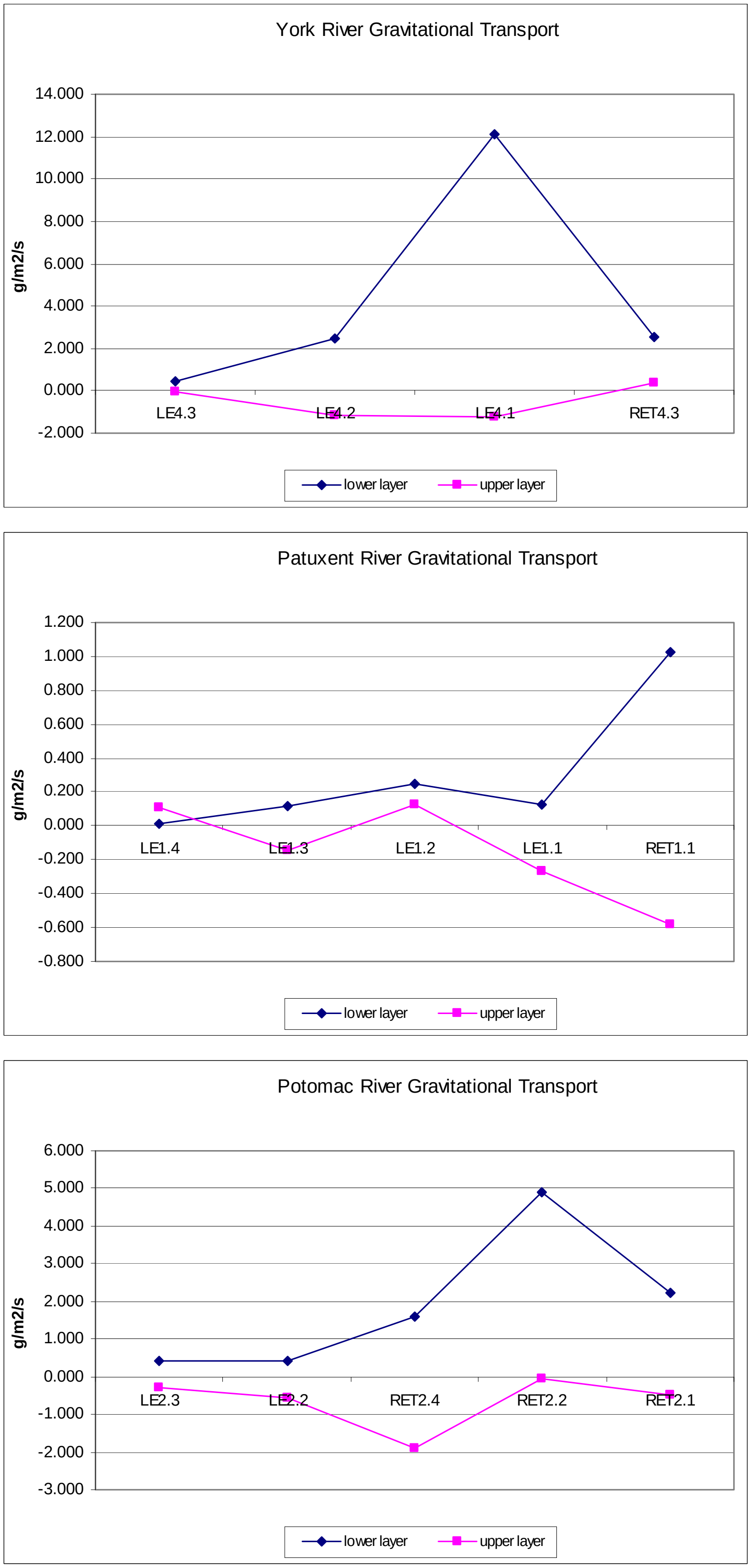
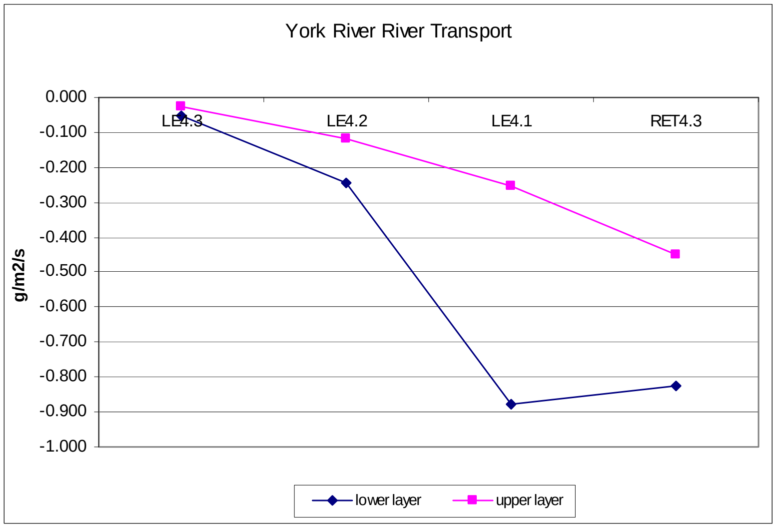
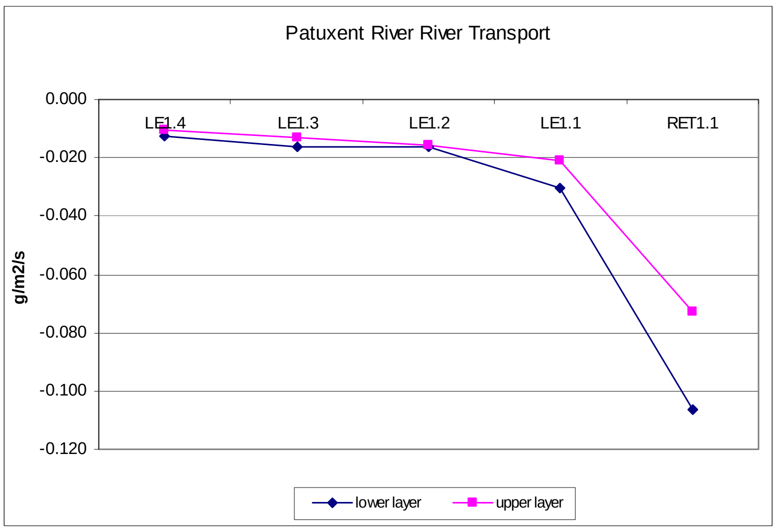


Figure A6. Gravitational transport for each river.





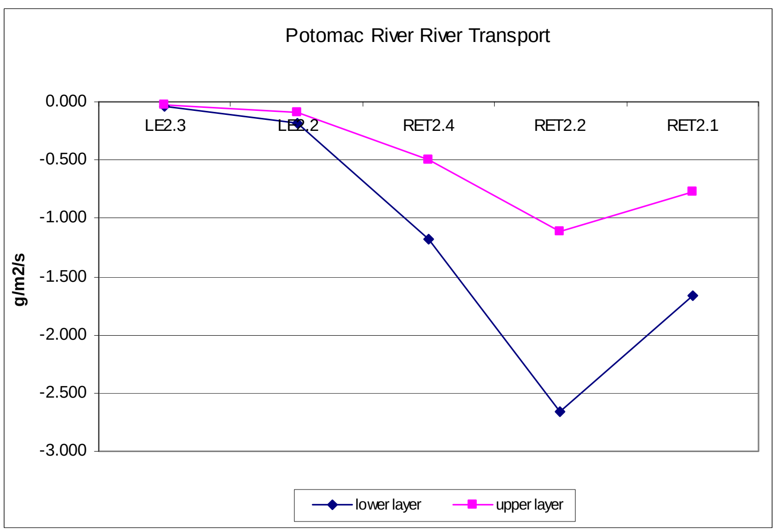
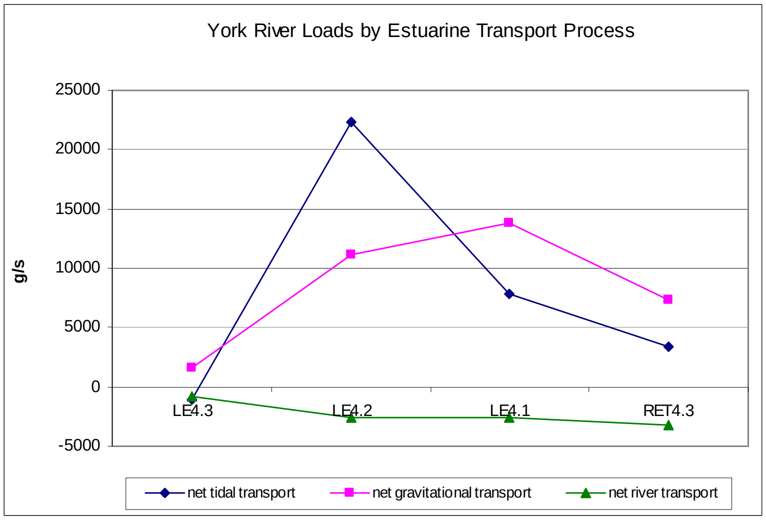
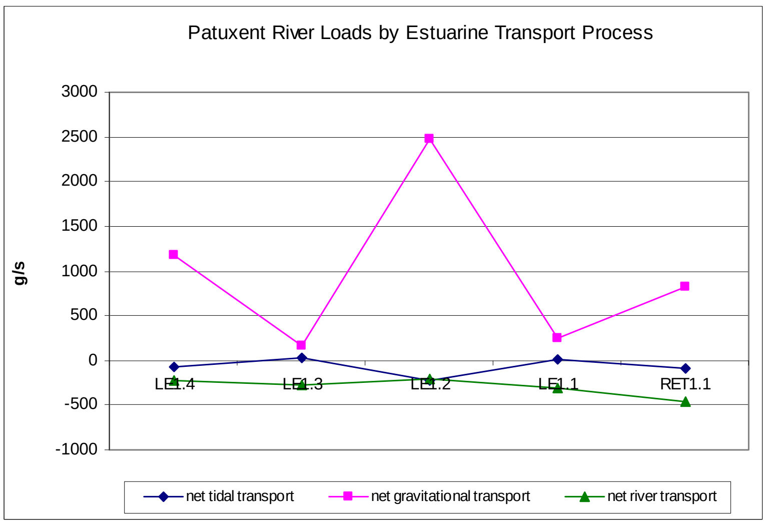


Figure A7. River transport for each river.





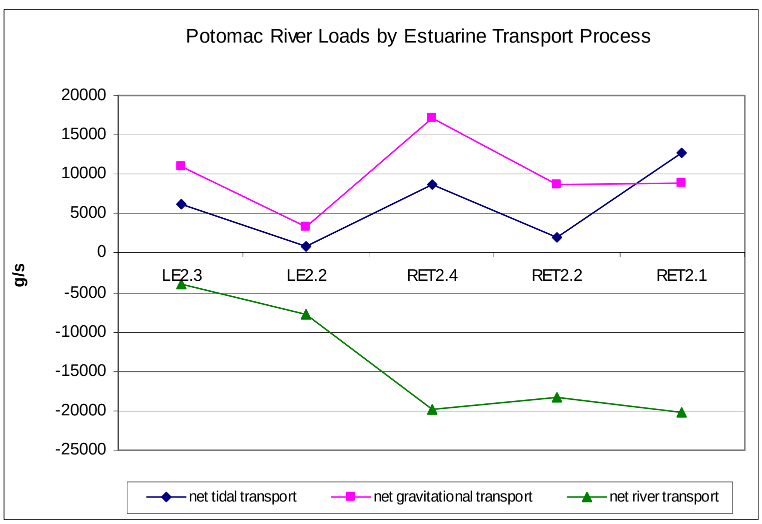


Figure A8. Sediment loads for each station. (These are the same graphs as Figure 9 in the report. They are included here for consistency with other graphs.)

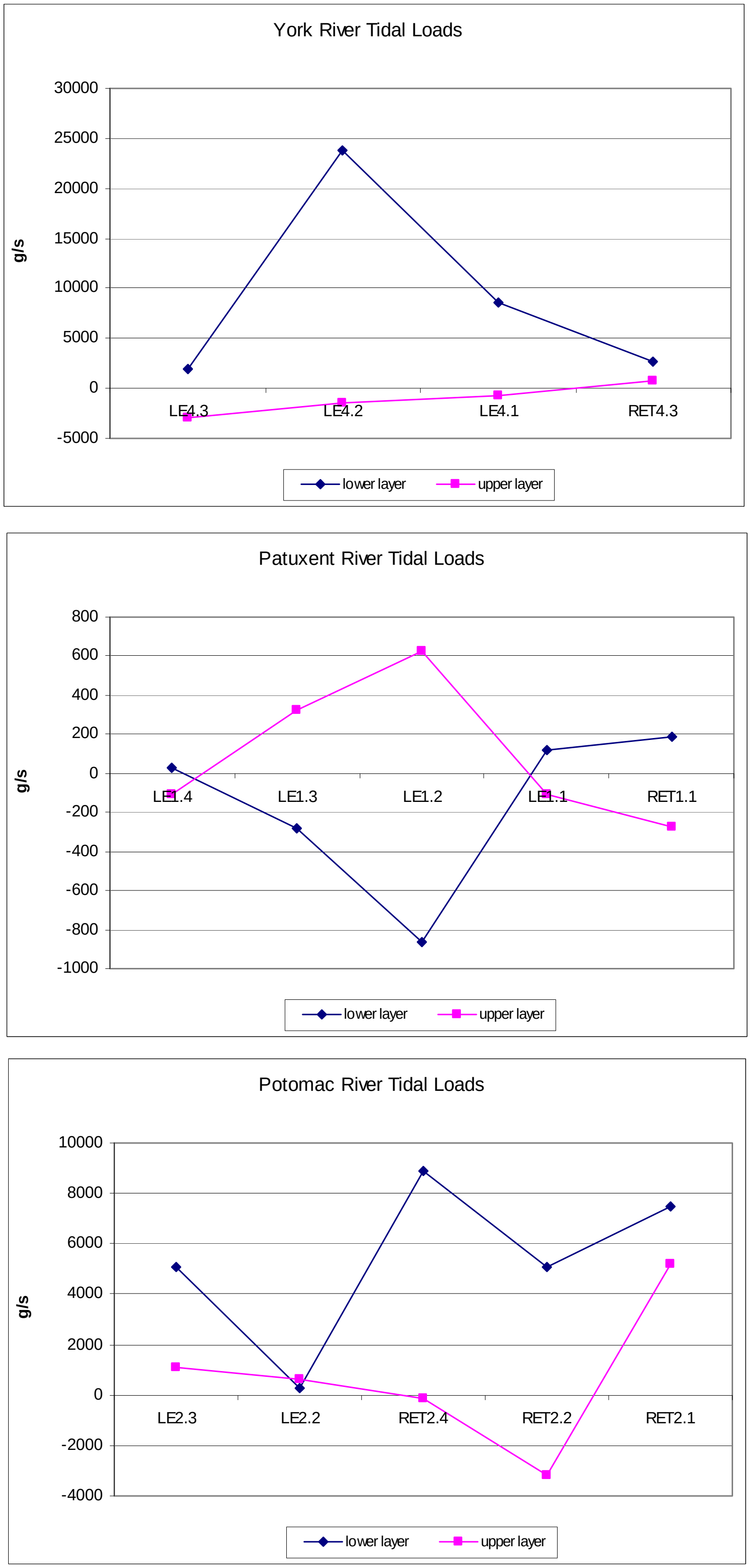
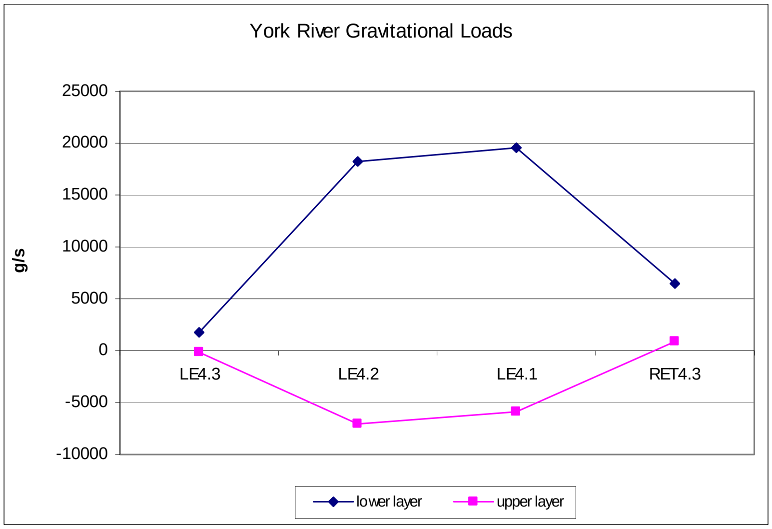
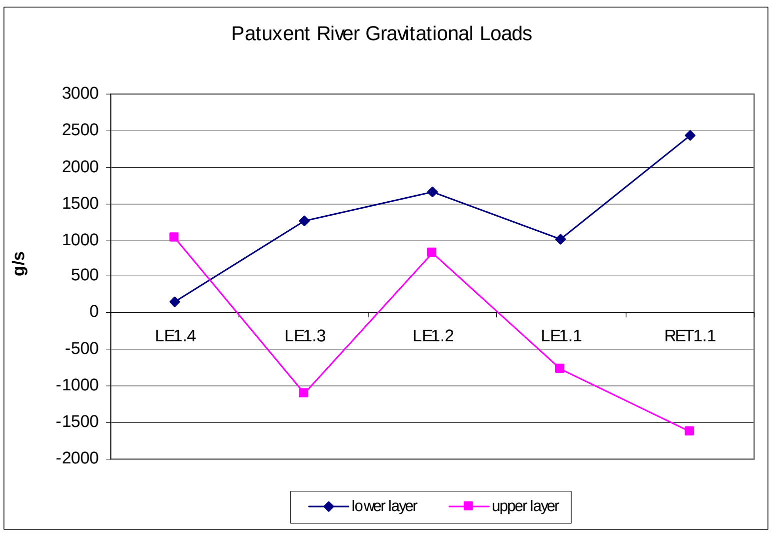


Figure A9. Tidal loads for each river.





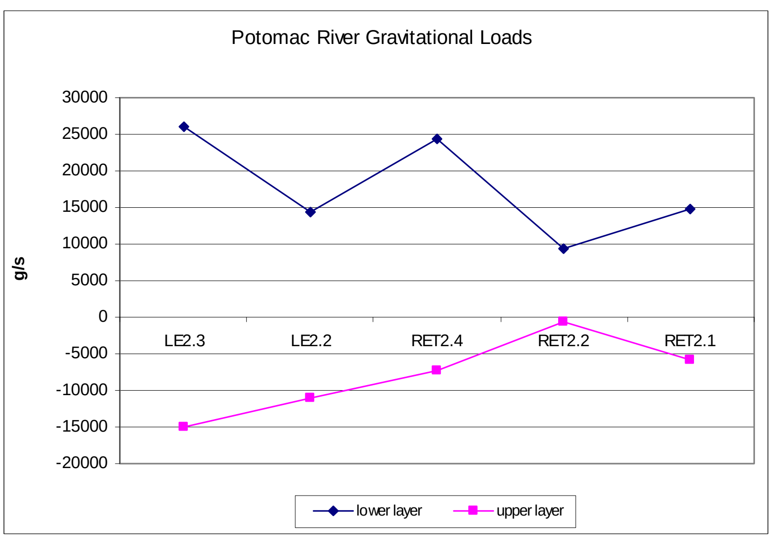


Figure A10. Gravitational loads for each river.

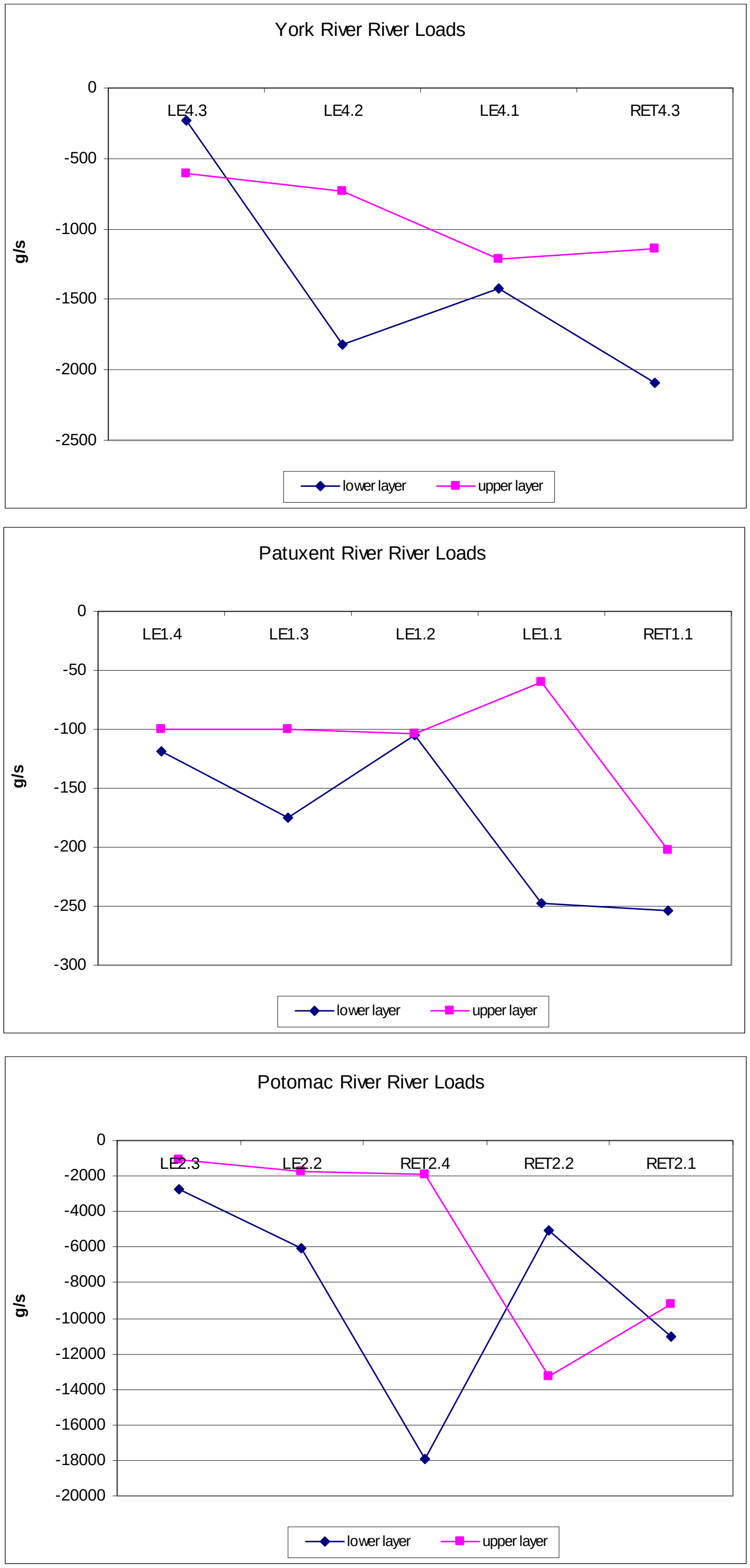


Figure A11. River loads for each river.