N.H. Sea Grant Research Project Post Completion Report

Today's date: 27 February 2013

Project number: R/CE-141

Project title: Nutrient, trace metal and particle release from sediments in the Great Bay Estuary and Riverine System

Project initiation date: 2/1/2010

Principal investigator: Linda Kalnejais

Affiliation: UNH

Associate investigator(s) and affiliation(s):
Diane Foster, UNH

Brief project overview/Abstract:
The quantity of nutrients and trace metals that are released from the sediments of the Great Bay is unknown. This project aims to quantify if the sediments are an important source for these species with a combination of geochemical measurements, novel erosion chamber experiments and physical observations of fluid stresses at the sediment-water interface. The release due to both chemical reactions in the sediment and sediment resuspension will be determined to provide information on the flux from sediments under both quiescent and stormy conditions.

Objectives:
The goal of this project is to determine the chemical and physical mechanisms that release nutrients and trace-metals from the fine-grained sediments of the estuary of the Great Bay, and to assess if the sediments are a significant source of these contaminants to the Great Bay aquatic ecosystem.

Research findings/progress to date:
The field investigations to understand the mechanisms which lead to the release of nutrients and metals from the sediments of the Great Bay have all been completed. All chemical analyses have been finalized and the data analysis on all physical observations has also been completed. Meagan Wengrove and Vincent Percuoco, the two Masters students funded by this grant have both successfully defended their Masters theses. The flux of nutrients from the sediments has been quantified at our representative sites for diffusive conditions and the potential for release due to resuspension has been measured. Our unique approach that combines geochemical measurements with physical field observations has produced the best estimates of sediment flux available for a water body to date as well as providing unprecedented information on boundary layer development in the field.

Geochemical Results

The geochemical conditions in the sediments of the Great Bay have been investigated at three sites selected to represent the range of fine-grained sediments within the Great Bay (Figure 1). At each of these three sites, duplicate sediment cores were sampled so as not to disturb the sediment water interface. The sediments were sectioned and the porewater analyzed for nutrients so that the chemical reactions occurring in the sediments could be identified, and the diffusive flux of nutrients across the sediment water interface could be calculated (Figure 2). Diagenetic modeling of the sediment profiles suggests that the dominant processes controlling the profiles are remineralization of organic matter, diffusion and adsorption to sediment particles (Percuoco, 2012).

The diffusive fluxes calculated for each site are shown in Table 1. The fluxes are of the same magnitude as those measured by Lyons et al. (1982) using benthic chambers. Benthic chamber estimates include irrigation fluxes, so our results that are for diffusive release only, suggest that the fluxes from sediments has likely increased since the 1980’s as irrigation is not included in our estimates. However, core incubation experiments undertaken by Laurent Officer for his senior thesis to quantify irrigation fluxes following the method of Giblin et al. (1997), found fluxes at JEL in summer within the range of diffusive fluxes measured at JEL.

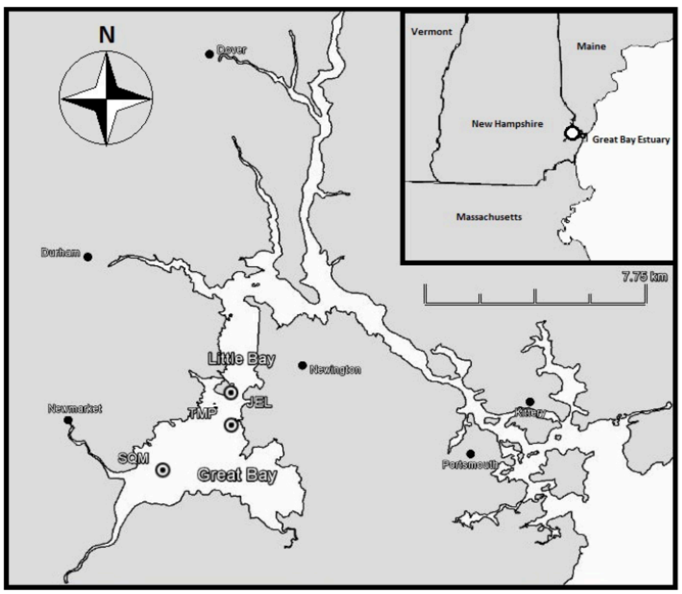

Figure 1. Map of the Great Bay showing location of sampling sites, JEL- Jackson Estuarine Lab, SQM – Squamscott River site and TMP – Thomas Point.

To determine if sediments are a significant source of nutrients, a coarse estimate of the total loading due to the diffusive fluxes can be calculated by taking a seasonal average and applying the flux rates to the area of muddy sediment in the Bay (5334 acres, 61% of the Bay). The load calculated can be compared with estimates from the loads from rivers (from Oczkowski, 2002), the spring loads of dissolved inorganic nitrogen and phosphate from sediments are 50-80% of the load from rivers running into the Great Bay, while in the fall the loads from sediments are greater than riverine inputs.

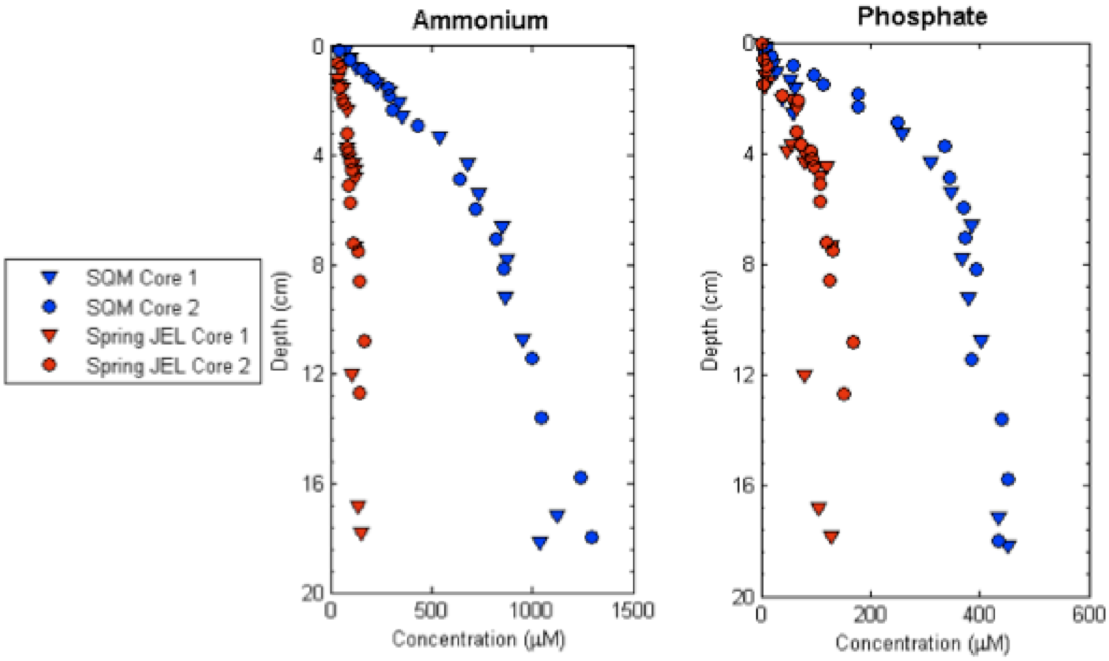

Figure 2. Porewater profiles of ammonium and phosphate from two sites, selected to show the range of concentrations measured in the porewaters.

Table 1. Diffusive flux (mmol/m2/day) calculated from porewater profiles from the two cores collected from each site. The r^2 value provides information on the Pearson correlation coefficient of the nutrient concentration vs depth at the sediment water interface.

Site	SQM		Spring JEL		Fall JEL		TMP	
Core	1	2	1	2	1	2	1	2
Ammonium	1.7±0.1	1.8±0.1	0.2±0.0	0.2±0.0	2.0±0.0	1.5±0.1	0.3±0.0	0.2±0.0
r^2	0.97	0.98	0.72	0.87	0.99	0.83	1.00	0.78
Phosphate	0.2±0.0	0.5±0.0	0.1±0.0	0.1±0.01	0.0±0.0	0.1±0.0	0.1±0.0	0
r^2	0.93	0.96	0.55	0.73	0.68	0.92	0.95	-
Nitrate	-0.1	0	0.1	0.1±0.0	0.1±0.00	0.1	0	0
r^2	-	-	-	0.82	0.97	-	-	-
Silica	1.7±0.1	1.3±0.1	0.4±0.1	0.3±0.0	1.0±0.0	0.9±0.1	0.5±0.0	0.7±0.1
r^2	0.98	0.86	0.79	0.74	0.96	0.97	0.90	0.89

Diffusive fluxes represent the release of solutes from sediments under quiescent conditions. To determine the release when the sediment is subjected to a fluid shear, erosion chamber experiments were undertaken at each site and sampling event. The erosion chamber described by Kalnejais et al. (2007) was used to impose incrementally increasing shear stresses at the sediment water interface. The experimental setup of Kalnejais et al. (2007) was improved with the addition of a Hydrolab datalogger recording turbidity, pH and oxygen concentration during the erosion experiment, so that a continuous record of water quality changes during the experiment was obtained (Figure 3).

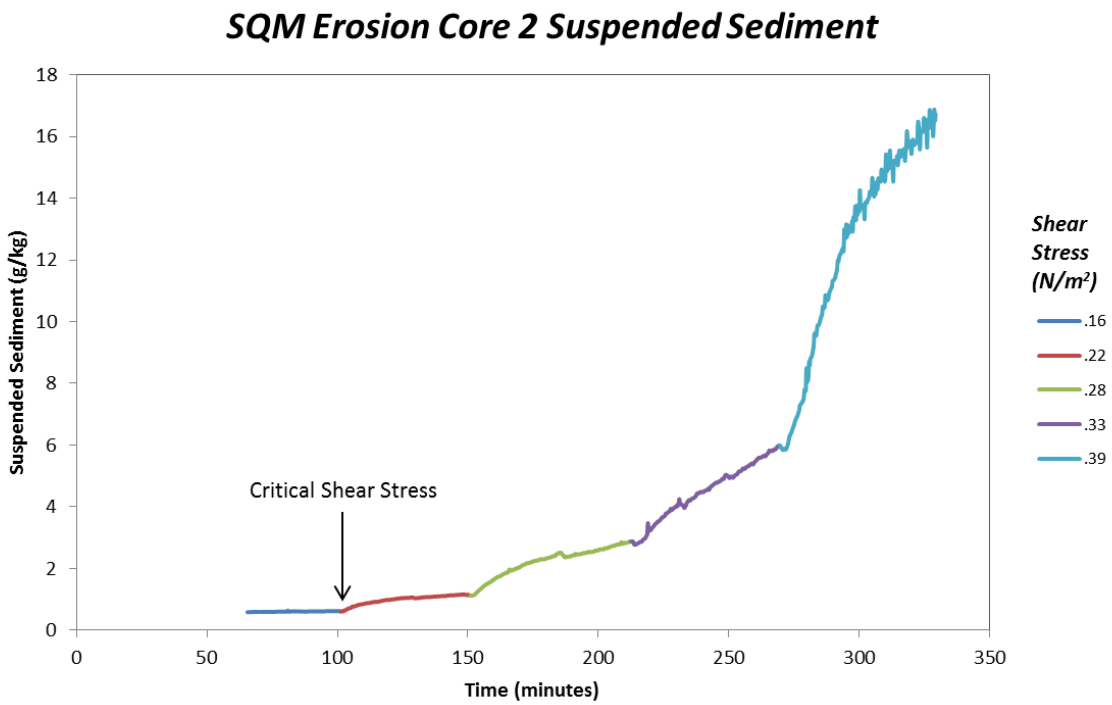

Figure 3 . Plot of the suspended sediment during the SQM erosion experiment recorded by the Hydrolab turbidity sensor.

Water samples were collected throughout the erosion experiments and analyzed for nutrients in the dissolved, and metals in the particulate phase (Figure 4). For all experiments sediment resuspension is responsible for greater dissolved flux of ammonium, silica and manganese than that predicted by advection of eroded pore waters to overlying water or molecular diffusion. For these species after the critical stress is exceeded the rate of release increases as shear stress increases. This finding emphasizes the need to study the interaction between physical processes and chemical processes to understand the sources of ammonium and silica to the estuary. Nitrate, phosphate and dissolved iron show variable behavior that is likely dependent on the underlying sediment geochemistry and removal in the water column due to particle scavenging. To determine the overall loading the resuspension release contributes to the Bay, the erosion chamber data needs to be coupled to records of shear stress. Long-term physical observations of velocity profiles or hydrodynamic modeling is required to generate records of shear stress. To provide a ‘back-of-the-envelope’ estimate of the importance of resuspension, the data from the in-situ instrument array can be used. This will be discussed in the following section.

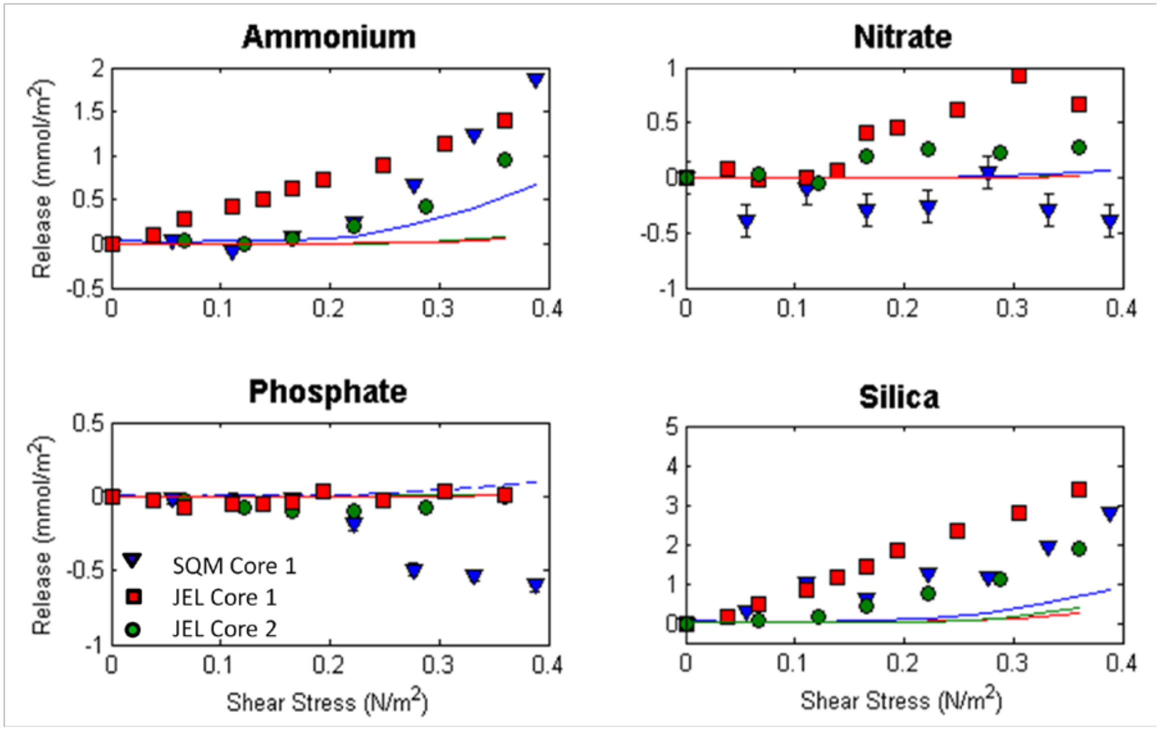

Figure 4. Nutrients released at each shear stress for a selection of sites. Blue and red lines represented the release expected from conservative mixing of porewaters into the overlying waters.

Analysis of the particulates collected during the erosion experiments (Figure 5) indicate that the particles eroded at the critical shear stress are enriched in trace metals by up to a factor of 4 relative to the bulk sediment concentration. As erosion proceeds the concentration of metals in eroded particles tends towards the concentration in the bulk surface sediment. The trace metal enrichment in readily erodible particles is a significant finding, as the erosion threshold does not need a significant storm to be exceeded in the Great Bay (see below), so trace metal enriched particles are mobilized regularly.

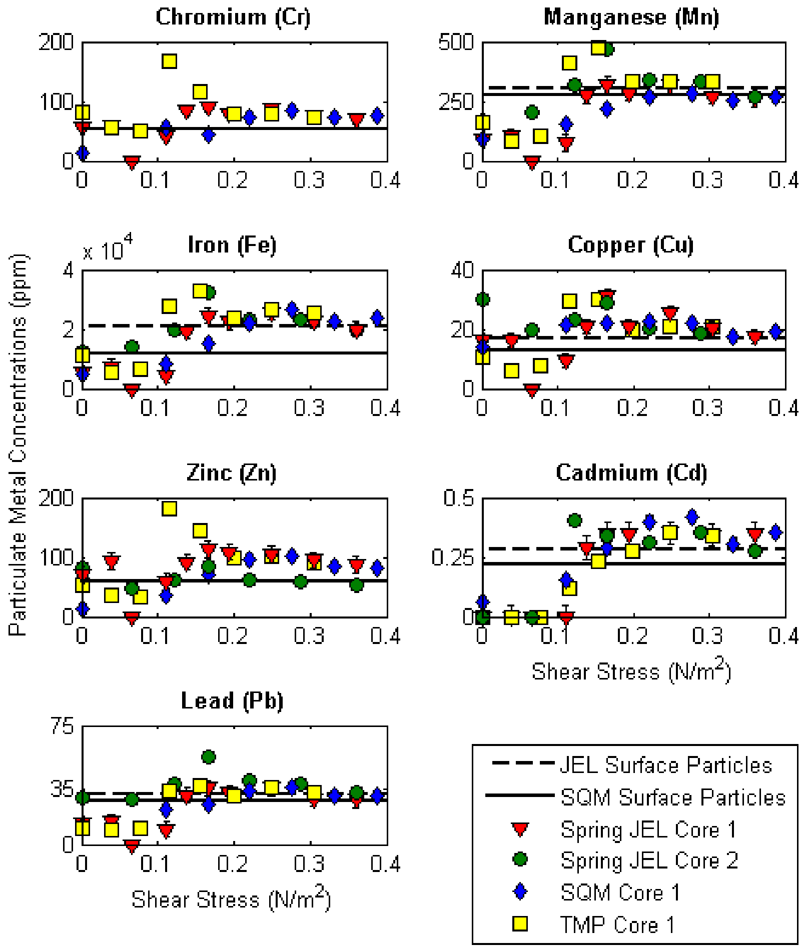

Figure 5. Concentrations of trace metals in eroded particles for three different sites. Lines represent the bulk sediment concentration.

In-Situ Physical Data

The considerable magnitude of the resuspension fluxes measured for ammonium and silica with the erosion chamber make simultaneous in-situ measurements of sediment erosion essential in verifying the accuracy of these estimates. In order to do this the Foster group undertook a field campaign deploying the following instruments; Nortek Vectrino II Profiling Acoustic Doppler Velocimeter, a Vector ADV, Aquadopp HR ADCP, and Imagenex Variable Frequency 2-axis sonar. This was the first field deployment for the Vectrino II. The instruments were deployed off the Jackson Estuarine Lab in the configuration shown in Figure 6. Three deployments of these instruments were undertaken. The first was simultaneous with the JEL spring geochemical sampling and data was collected over several tidal cycles. During this deployment the shear stresses did not reach the critical shear stress and no sediment resuspension was observed. To ensure a deployment in which sediment resuspension was observed, a second deployment was undertaken in August during tropical storm Irene.

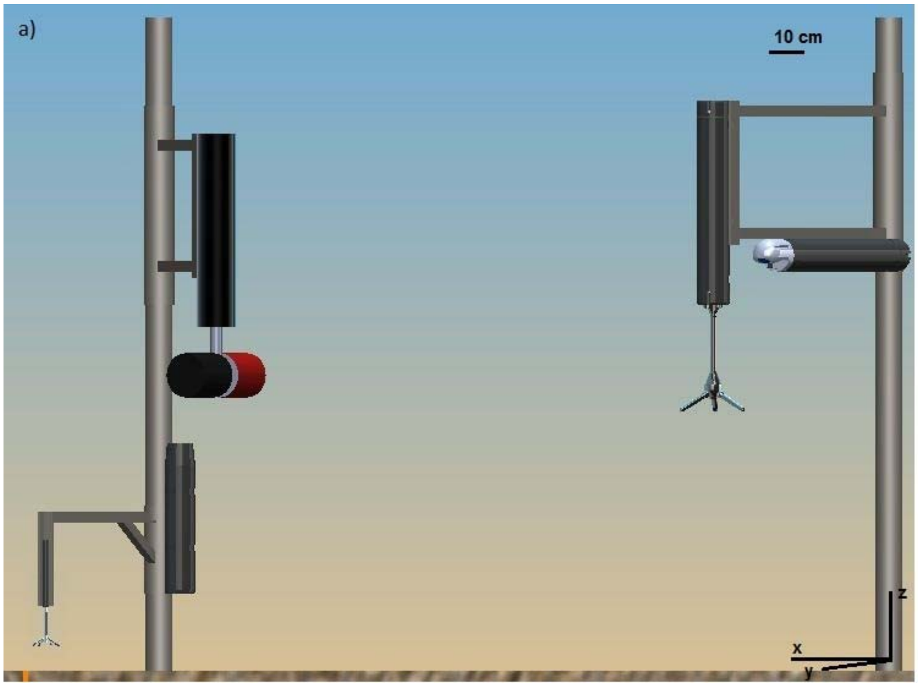

Figure 6: Instrumentation deployment method and relative locations in relation to sediment bed. Vectrino II (left) is 6 cm from bed, Vector (far right) is 0.8 m from bed, Aquadopp HR (horizontal, alignment on right) is 1 m from bed.

The measured linear along-shore velocity profiles for both non-storm (June sampling) and storm (Tropical Storm Irene sampling) data sets are shown in Figures 7 and 8. The data shows the presence of the viscous sublayer in the water column during non-storm conditions, and the absence of the sublayer in the water column during storm conditions. The bed was mobile during the storm conditions, agreeing with the erosion chamber estimated for the erosion threshold for the sediment.

This is only the second time the viscous sublayer has been directly observed in the marine environment! To prove that the observations in Figure7 really do show a viscous layer, significant data analysis was undertaken so the presence of the viscous layer could be verified by multiple methods. Each method was satisfied for the non-storm condition, thus this project has successfully observed the viscous sublayer.

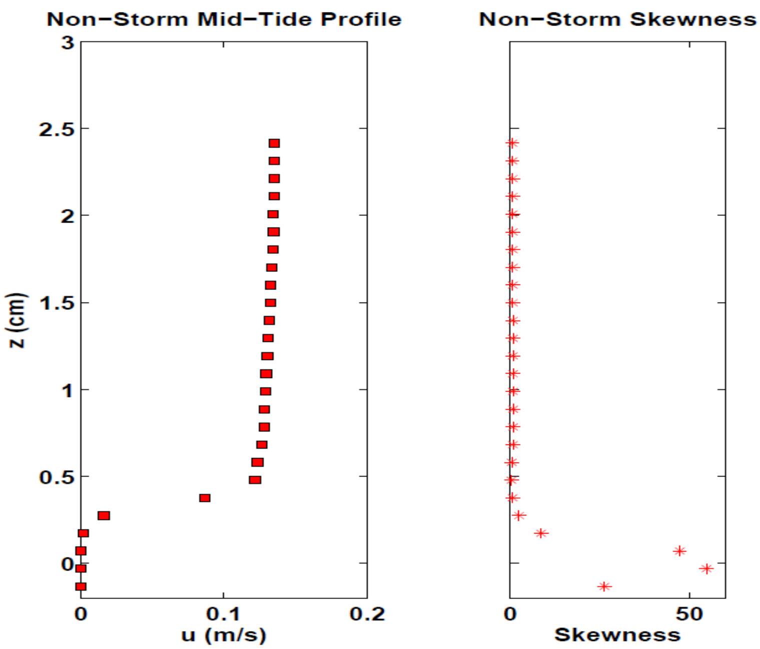

Figure 7: Along-shore, linear velocity profile for non-storm condition (left) and skewness of velocity profile as approaching the bed (right). A high skewness indicates the presence of the viscous sublayer.

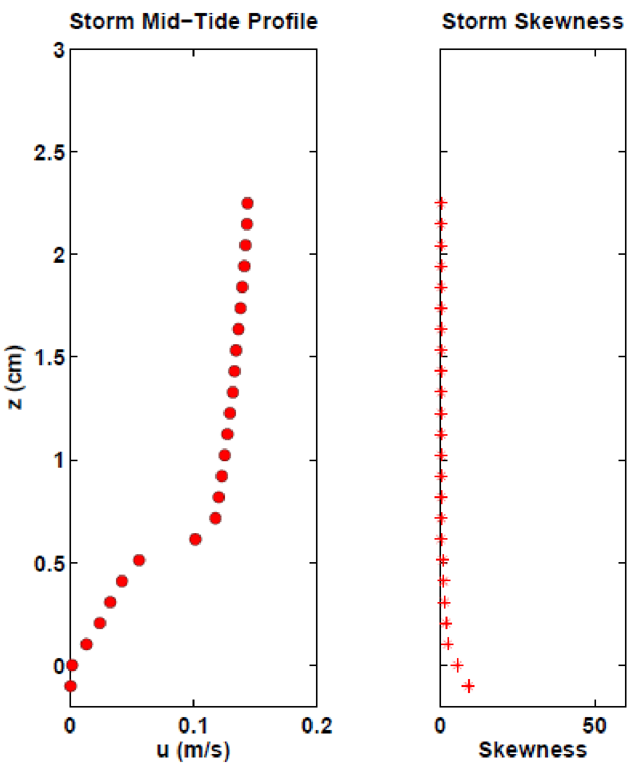

Figure 8: Along-shore, linear velocity profile for storm condition (left) and skewness of velocity profile as approaching the bed (right). A high skewness indicates the presence of the viscous sublayer

The velocity profiles measured in-situ at the JEL site can be used to calculate shear stress and assess the likelihood of resuspension occurring. The time course of shear stress and associated velocity data during Tropical Storm Irene is shown in Figure 9. Stresses reached over 0.5 N/m^2 during the tropical storm on the flooding tide. Stresses during ebb tide are considerably lower. The Vectrino II provides an estimate of the depth to the bed, measured from the acoustic backscatter return (Figure 9 panel e). The bed starts to erode when a shear stress of 0.1 N/m^2 is exceeded, in good agreement with erosion thresholds determined from erosion chamber experiments on sediments from the JEL site two days prior to the arrival of the storm. The bed eroded by 1 mm during the storm.

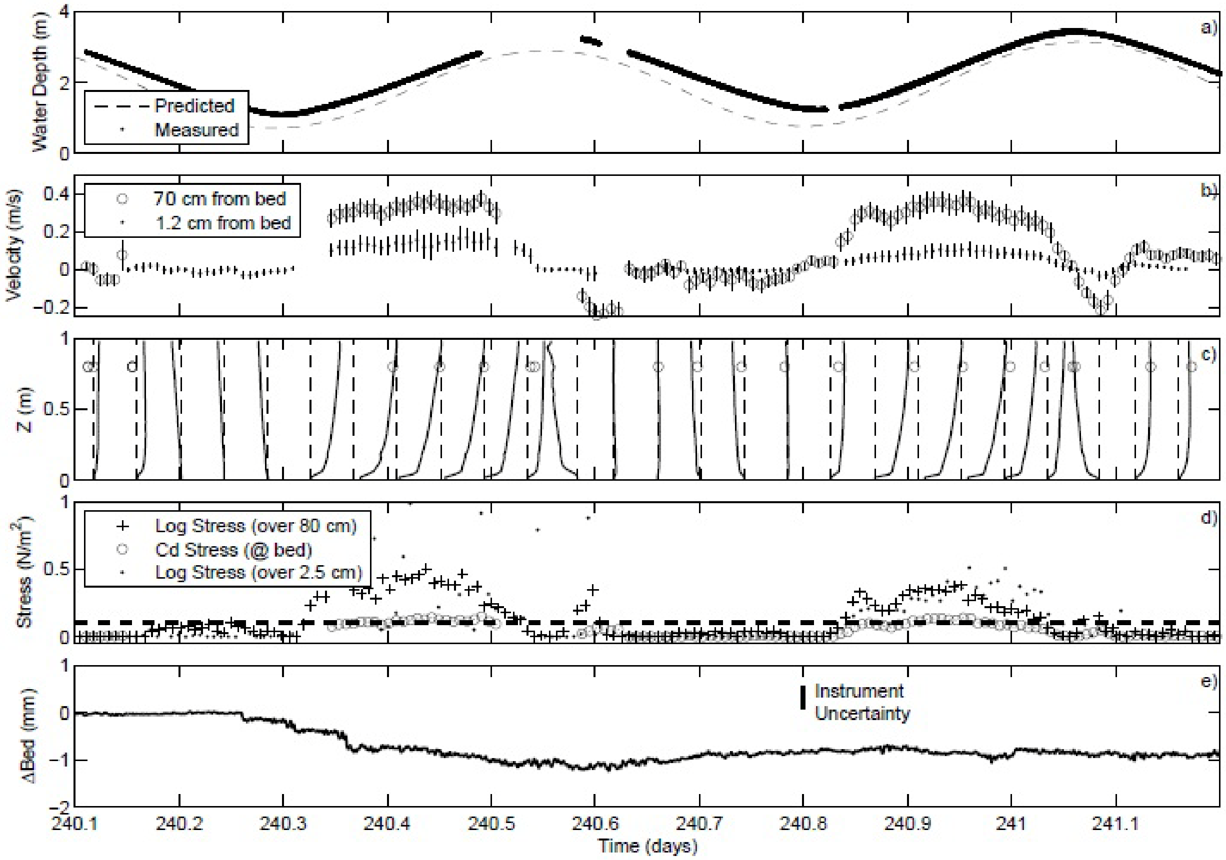

Figure 9. Storm condition data. a) Tidal level at Adam's Point. b) Temporally averaged velocity +/- one standard deviation for the Vector (hollow circle) and temporally and spatially averaged velocity +/- one standard deviation for the Vectrino II (black square). c) Velocity profiles over the closest 80 cm to the bed from Aquadopp HR compared to the velocity measured by the Vector at 70 cm above the bed (hollow circle). d) Bed stress estimated by three methods, from Log stress over 80 cm (Aquadopp HR), Cd stress (Vector), and log-stress over 2.5 cm (Vectrino II). e) Change in bed elevation over sampling period.

The erosion depths measured by the Vectrino II can be compared with those from the erosion chamber (Figure 10). The two methods compare well up to a shear stress of 0.3 N/m^2. This is very encouraging and gives considerable confidence that the erosion chamber is replicating erosion appropriately up to shear stresses of 0.3 N/m^2. This gives added confidence to the geochemical data from the erosion chamber as well. Beyond 0.3 N/m^2 however, the chamber and measured depths diverge significantly. Despite increasing shear stress the bed does not appear to have eroded beyond 1 mm. The erosion chamber predicts erosion down to depths of at least 2 mm. This discrepancy needs to be resolved to confidently use the erosion chamber results beyond 0.3 N/m^2. All other erosion chamber in use also predict increasing erosion depth with increasing shear stress, so the Eromes chamber is not predicting an unusual trend. There are a number of possible reasons why the two measurements diverge; sediments are notoriously heterogeneous environments and the Vectrino II may have been over a patch of sediment that had coarser particles that armored the bed. Alternatively at very high shear stresses fluid mud layers may have developed and influenced both the erosion depth measurement and the correct calculation of shear stress. Further work, especially more comparative deployments of the Vectrino II and erosion chamber are needed to resolve these differences.

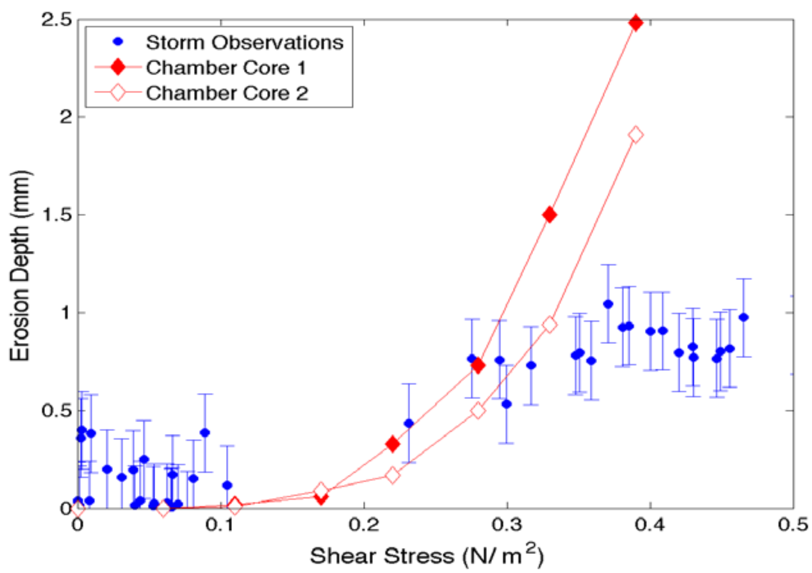

Figure 10. Comparison of erosion depths measured in-situ with the Vectrino II ADV and erosion depths calculated from erosion chamber data.

To calculate loads associated with sediment resupension the erosion chamber data needs to be coupled to records of shear stress. Due to the sensitivity of the instruments and the experimental nature of the first deployment, the instrument array could only be deployed for a number of days. Longer-term deployments are needs to generate a record that can be coupled with the erosion chamber data. In the absence of a longer record however, a back of the envelope calculation can be done to assess the importance of resupension. Figure 11 shows a compilation of the wind speeds that occurred during both the summer and storm deployment. From Figure 11 it can be seen that shear stresses greater than 0.1 N/m^2 (and therefore above the erosion threshold for the site) only occur if wind speeds are great than 2 m/s and the tide is flooding. From historical records of wind speeds, 70% of days from Spring – Fall have winds speeds in excess of 2 m/s. If we assume a flooding tide occurs 50% of the time, then that suggests, with a very coarse analysis, that resupension at the JEL site will occur on 35% of days. This suggest that on 35% of days particles enriched in trace metals are eroded into the water column, so this is likely important for trace metals transport within the Bay.

Estimating the nutrient load due to resupension is challenging due to the variable behavior of phosphate and nitrate. However for ammonium, the erosion chamber data is relatively consistent between sites and between seasons, so it is amenable to a ball-park estimate. On average for erosion events between 0.1 -0.3 N/m^2 the ammonium release is 0.2 $mmol/m^2$. If this release occurs on 35% of days from Spring –Fall and we assume the JEL site is representative of the shear stress experienced at muddy sites throughout the Bay (an unjustified assumption that requires hydrodynamic modeling or more velocity profile measurements to assess) then, the ammonium input due to resuspension in the Fall is about the same magnitude as the ammonium input from rivers in the Fall. This very coarse analysis suggest for ammonium, resupension is likely an important term in the nutrient budget.

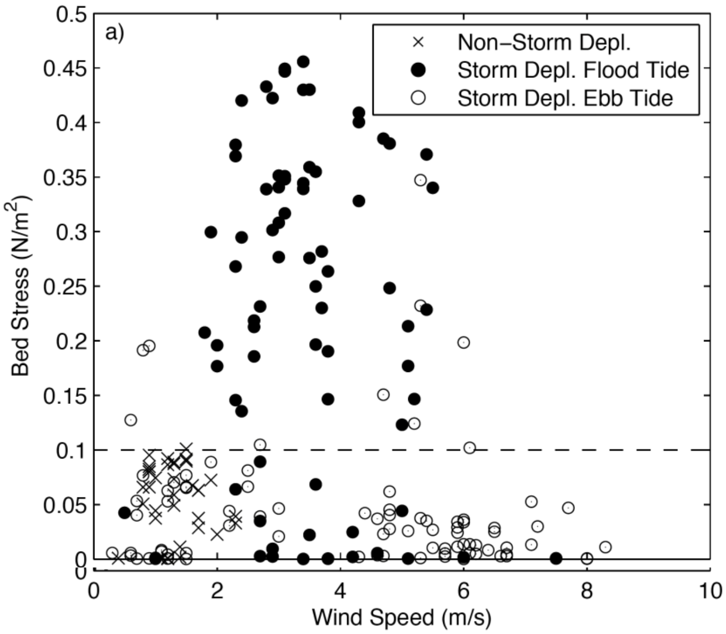

Figure 11. Plot of calculated shear stresses and the wind speed at which they occurred during both the summer deployment and the Tropical Storm Irene deployment.

Ongoing Work

Reporting of the results is the focus of the ongoing work.

Kalnejais and Foster presented this work to the NH DES on March 14 2013.

Two manuscripts will have been submitted for review. The first manuscript has been submitted to the Journal of Geophysical Research (Wengrove and Foster, 2014) on the results of the instrument array. A second manuscript on the coupled instrument observations and erosion chamber geochemical results is to be submitted this month to Estuarine Coastal and Shelf Science (Wengrove et al., 2014). A third manuscript is in preparation on the geochemical results and the sediment nutrient budget of the Great bay.

Accomplishments:

The porewater and erosion chamber data collected to-date suggests that the sediments are an important source of ammonium and silica to the Great Bay. This is a significant finding that has the potential to impact management of the nitrogen input from wastewater treatment plants and diffuse sources in the future. Reducing riverine and waste water treatment plant loads alone will not decrease the supply of nutrients to the Bay.

A significant accomplishment of this project is the combination of two very different datasets, *in situ* instrument measurements and erosion chamber experiments, to provide a much better understanding of the mechanisms operating in coastal waters. The high resolution temporal data on fluid velocites and stresses has verified chamber operation up to a shear stress of 0.3 N/m^2 . This is the first field verification of any erosion chamber so is significant as we now know our Eromes erosion chamber can provide reliable erosion simulation and thus have confidence in the geochemical measurements on the impacts of sediment erosion.

This project has supported two graduate students in two departments at UNH. Vincent Percuoco in the Earth Sciences department was advised by Kalnejais and Meagan Wengrove was in the Mechanical Engineering Department, advised by Foster. Both students have completed their Masters degrees. Wengrove is now on a Fulbright Scholarship working in the Netherlands and will return to UNH to start a PhD.

This project supported an undergraduate to work over the 2011 summer. Laurent Officer was supported with hourly wages to determine the nutrient fluxes due to the irrigation by benthic organisms. Laurent received the Best Earth Sciences Presentation award at the 2012 UNH Undergraduate Research Conference for his work and is about to start Medical School.

The successful deployment of the Vectrino II in a field environment and detection of the viscous sublayer is a significant accomplishment that will impact how coastal studies are conducted in the future. The viscous sublayer is important to the fluid dynamics of a water body because it is responsible for dissipating a large fraction of the energy out of the water column and it is an important control on benthic exchange as all solutes from the sediments need to diffuse through this layer to be introduced into the water column. As only the second recorded detection of the viscous boundary layer, there has been significant interest from the research community in also applying this technology to obtain direct measurements at their own field sites.

Six abstracts have been submitted on this work. The abstracts are:

Diane Foster; Meagan Wengrove, *Field Evaluation of Nortek Vectrino II Profiling Velocimeter in a Developing Tidal Boundary Layer*, Abstract OS33C-1684 presented at Fall 2011 Meeting, AGU, San Francisco, Calif., 5-9 Dec.

Meagan Wengrove; Diane Foster; Linda H. Kalnejais; Vincent Percuoco, *Field Observations of a Tidally Forced Developing Boundary Layer and the associated sediment resuspension and nutrient diffusion*, Abstract OS33C-1691 presented at Fall 2011 Meeting, AGU, San Francisco, Calif., 5-9 Dec.

Vincent Percuoco, Linda Kalnejais, Meagan Wengrove, Diane Foster, *The Role of Short Term Sediment Resuspension on the Release of Nutrients and Metals from Estuarine Sediments*, presented at Spring 2012 Ocean Sciences Meeting, Salt Lake City, Utah, 20-24 Feb.

Kalnejais, L.H., Percuoco, V., Wengrove, M.E., Foster, D.L., 2013 *Field and laboratory observations of the geochemical impact of sediment resuspension, Great Bay estuary, N.H.* presented at Spring ASLO meeting, New Orelans 18-22 Feb.

Kalnejais, L.H., Percuoco, V., Wengrove, M.E., Foster, D.L., 2013 *The Release of Particles, Metals and Nutrients due to Sediments Resuspension in the Great Bay, N.H.* To be presented at Northeast Geological Association of America Meeting, March

Wengrove, M.E., Foster, D.L., Kalnejais, L.H., Percuoco, V., and Lippmann, T.C., 2013. *Field Observations Bed Stress and Associated Sediment Geochemistry during Tropical Storm Irene*. To be presented at the 12th International Coastal Symposium (Plymouth, England).

Publications

Peer reviewed publications:

Wengrove and Foster, 2014, Field Observations of the Viscous Sublayer in a Tidally Forced Developing Boundary Layer, *Journal of Geophysical Review Letters*, in Review.

Wengrove, M.E., Foster, D.L., Kalnejais and Percuoco, V. Field observations of bed stress and associated sediment geochemistry during Tropical Storm Irene. *Estuarine, Coastal and Shelf Science* to be submitted March 2014

Percuoco, V. and Kalnejais, L.H Mechanisms of nutrient release from the sediments of the Great Bay, NH. To be submitted to Estuarine, Coastal and Shelf Science.

Theses/Dissertations:

Wengrove, M. 2012. Observations of a Developing Boundary Layer in a Tidally Forced Estuary. Master's thesis, University of New Hampshire. UNHMP-TH-SG-12-04 *Need PDF*

Percuoco, V. The mechanisms of metal and nutrient release from the sediments of the Great Bay. Master's thesis, University of New Hampshire. UNHMP-TH-SG-12-03

Officer, L. Seasonal Variation in Nutrient Release due to Benthic Irrigation in the Great Bay, NH. Undergraduate senior thesis, University of New Hampshire. UNHMP-TH-SG-12-18

Presentations to date, with published abstract citation if applicable:

Kalnejais,. L and Foster D. "Are the Sediments of the Great Bay Estuary a Source of Nutrients?" Talk at NH Department of Environmental Services, March 2013, Concord, NH.

Kalnejais, Linda. "The Calm and the Storm: Mechanisms of Metal Release from Coastal Sediments" Invited talk at University of Massachusetts, Dartmouth.

Kalnejais, Linda. "Human Impacts in Estuaries". Centers for Ocean Sciences Education Excellence (COSEE) Webinar presentation. Available at:
http://cosee.umaine.edu/coseeos/webinars/111710webinar.htm
Kalnejais, Linda. "The Oceans - chemistry, climate and the future". Presentation to the Durham Active Retirees Association.

Diane Foster; Meagan Wengrove, Field Evaluation of Nortek Vectrino II Profiling Velocimeter in a Developing Tidal Boundary Layer, Abstract OS33C-1684 presented at Fall 2011 Meeting, AGU, San Francisco, Calif., 5-9 Dec.

The Nortek Vectrino II is a newly developed acoustic Doppler profiling velocimeter. The three dimensional velocity profiles over a 3 cm range can resolve flow fields at a sampling rate of 100 Hz with a bin resolution of 1 mm. During June 2011, the Vectrino II was deployed in the Great Bay Estuary of New Hampshire, a tidal estuary in a long straight channel, where its capabilities were compared to a single point Nortek Vector ADV. In the first phase of the experiment, the Vectrino II was placed 13 cm from the flat muddy sand bed where it measured a relatively uniform velocity profile over the 3 cm range. Velocity magnitudes compared reasonably well to those of the Vector at 75 cm from the bed when fitting a boundary layer profile to the point measurements. Comparisons between the energy spectrum of the Vectrino II and Vector showed that the Vectrino II had a lower noise out to 5 Hz and reached the noise floor at roughly 8 Hz when the velocity of flow was 0.4 m/s or less. The vertical profiles allowed for estimates of the shear stress that are compared against estimates using Reynold stress and empirical drag law formulations. In the second phase of the experiment, the Vectrino II was moved such that the sampling region was within the water-bed boundary. Here, the Vectrino II read zero velocity measurements in the bed, and was able to resolve a velocity profile consistent with a developing boundary layer over the incoming half of a tidal cycle. Within 0.5 cm from the boundary, the Vectrino II can show intermittent evidence of beam interference by the bed. Within this very near bed region, histograms of the velocity, correlations, and amplitude allow for improved velocity estimates and suggest the presence of a viscous sublayer.

Meagan Wengrove; Diane Foster; Linda H. Kalnejais; Vincent Percuoco, Field Observations of a Tidally Forced Developing Boundary Layer and the associated sediment resuspension and Nutrient Diffusion, Abstract OS33C-1691 presented at Fall 2011 Meeting, AGU, San Francisco, Calif., 5-9 Dec.

Field observations of sediment suspension within a developing tidal boundary layer were collected with a newly developed Nortek Vectrino II Profiling Velocimeter acoustic backscatter probe; while nutrient release and sediment chemistry were sampled with pore water samples from sediment core sections. The velocimeter is capable of measuring a three dimensional velocity profile at 1 mm increments over a range of 3 cm. The observations were obtained in the Great Bay tidal Estuary of New Hampshire. The monitored area was a long straight channel with maximum depth of 20 m MLLW, tidal range of 3 m and depth of 1.5 m MLLW at the sampling location. During the incoming half tidal cycle, the tidal forcing produces a fairly unidirectional flow over the flat sandy mud sediment bed. Three methods for estimating the bed stress were evaluated and compared against laboratory observations with a sediment core erosion chamber. When wind conditions are low to moderate and there are low hydrologic influences, the roughly 30 cm/s near the bed flows resulted in peak shields parameters near the threshold for motion of 0.07 to 0.16 for a dimensionless grain size of 1.96. During periods of larger wind and/or higher hydrologic conditions, the threshold is exceeded and there is evidence to suggest a local response in the sediment chemistry. During the developing phase of the tidal boundary layer, the observations provide evidence for a viscous sublayer in the lowest 0.5 cm of the water column before moving into turbulent boundary layer flow. Observations of the stress placed upon the bed in relation to the nutrient chemistry of the sediment column provide an image of the types of loads and stresses the Great Bay Estuary receives during various hydraulic and weather related forcing conditions.

Vincent Percuoco, Linda Kalnejais, Meagan Wengrove, Diane Foster, The Role of Short Term Sediment Resuspension on the Release of Nutrients and Metals from Estuarine Sediments, to be presented at Spring 2012 Ocean Sciencees Meeting, Salt Lake City, Utah, 20-24 Feb.

The role of sediment resuspension on the release of trace metals and nutrients from estuarine sediments is currently under investigation in the Great Bay Estuary, New Hampshire.
Resuspension was simulated using a laboratory erosion chamber on cores collected from multiple sites with varying sediment characteristics. Turbidity and suspended solid measurements revealed that the critical shear stress for erosion ranged from 0.15 to 0.2 N/m^2. Field measurements using an acoustic backscatter probe during the recent tropical storm Irene verified particle movement at the shear stress 0.15 N/m^2. In most experiments, release of manganese, ammonium, nitrate-nitrite and silica occurred above the critical shear stress. There was no significant release of iron and phosphate, except at the critical shear stress, suggesting that rapid oxidation and adsorption removes some dissolved species during erosion

events. Continuing work will investigate the release of dissolved trace metals including silver, chromium, cobalt, zinc and copper. In addition, the metal and phosphate concentration in eroded particles will be determined to examine the role of particles on sequestration or release of nutrients and metals during resuspension events.

Kalnejais, L.H., Percuoco, V., Wengrove, M.E., Foster, D.L., 2013 *Field and laboratory observations of the geochemical impact of sediment resuspension, Great Bay estuary, N.H.* presented at Spring ASLO meeting, New Orelans 18-22 Feb.

Nutrient and metal release due to resuspension of cohesive sediments has been investigated in the Great Bay, NH. Erosion was simulated with an EROMES laboratory-based erosion chamber and the release of solutes and particles as a function of imposed shear stress was determined for a variety of sites and seasons. Resuspension leads to an enhanced release of ammonium, silica and particulate metals, but not phosphate or nitrate. To verify the accuracy of the erosion chamber, and to observe resuspension in the field, a comprehensive array of instruments was deployed. The instruments included two velocimeters, a current profiler and a sonar. Deployments were undertaken over a summer tidal cycle and during Tropical Storm Irene. The observed critical shear stress was 0.10 N/m2 and agreed with erosion chamber estimates. During Tropical Storm Irene the sediment was eroded by 1 mm. Erosion chamber data applied to this event estimate an erosion depth of 2 mm. Continuing work is aimed at combining erosion chamber and field observations to improve estimates of nutrient release from Great Bay sediments over a wide range of flow conditions.

Kalnejais, L.H., Percuoco, V., Wengrove, M.E., Foster, D.L., 2013 *The Release of Particles, Metals and Nutrients due to Sediments Resuspension in the Great Bay, N.H.* To be presented at Northeast Geological Association of America Meeting, March

The fine-grained sediments in coastal areas close to population centers are often large stores of organic carbon and contaminants that have built up over centuries. These sediments however, do not necessarily permanently store this material, and determining the mechanisms that drive release of contaminants from sediments is important for understanding the controls on coastal water quality. To understand the release of particles, nutrients and trace metals from the sediments in the Great Bay, NH we have investigated release due to both diffusion and sediment resuspension with a combination of field and laboratory techniques. Resuspension was simulated with an EROMES laboratory-based erosion chamber and the release of solutes and particles as a function of imposed shear stress was determined for a variety of sites and seasons. Resuspension leads to an enhanced release of ammonium, silica and particulate metals, but not phosphate or nitrate. To verify the accuracy of the erosion chamber, and to observe resuspension in the field, a comprehensive array of instruments was deployed at one site. The instruments included two velocimeters, a current profiler and a sonar. Deployments were undertaken over a summer tidal cycle and during Tropical Storm Irene so that observations spanned a large range of shear stresses. The observed critical shear stress for erosion was 0.10 N/m^2 and agreed well with erosion chamber estimates. This value was not exceeded during the summer tidal cycle deployment, but during Tropical Storm Irene shear stresses reached up to 0.45 N/m^2 and the sediment was eroded by 1 mm. Continuing work is aimed at combining erosion chamber and field observations to improve estimates of nutrient, metal and particle release from Great Bay sediments over a wide range of flow conditions so that the impact of sediment release can be quantified for both the conditions today and for future conditions when more extreme events are predicted.

Wengrove, M.E., Foster, D.L., Kalnejais, L.H., Percuoco, V., and Lippmann, T.C., 2013. *Field Observations Bed Stress and Associated Sediment Geochemistry during Tropical Storm Irene*. To be presented at the 12th International Coastal Symposium (Plymouth, England).

Field observations of boundary layer development within a tidally forced estuary reveal evidence of an observable viscous sublayer. This investigation reveals what may be only the second known observation of the viscous sublayer in a marine environment within the past 30 years, and what could be the first known observation of the viscous sublayer within a shallow marine environment. This effort coupled near-bed observations of fluid dynamics and nutrient geochemistry during two deployments within the summer of 2011 that represent a typical flood tide and a storm condition within the Great Bay Estuary of New Hampshire. Beyond quantifying the role of the benthic boundary layer in nutrient dynamics, these observations are useful in providing insight into very near boundary stress estimates leading to incipient motion in estuarine and coastal environments.

Measurements were taken within a long straight channel where during flood tide the flow field over the flat sandy mud bed is primarily unidirectional with a tidal range of 2 m and depth of 1.5 m MLLW at the sampling location. The first deployment observed boundary layer development during typical tidal forcing conditions where the threshold of sediment motion was not reached (0.10 N/m^2). The second deployment monitored the tidal boundary layer response to Tropical Storm Irene where excess shear stress was induced.

Near bed velocity measurements were collected with a newly developed Nortek Vectrino II Profiling Velocimeter acoustic backscatter probe. The velocimeter is capable of measuring a three dimensional velocity profile at 1 mm increments over a range of 3 cm. Bed stress estimations and bed elevation observations suggest that during normal tidal forcing, the estuary is in local morphological equilibrium. The shape of the mean velocity profile is consistent with the characteristic velocity profile shape when the viscous sublayer is present in the Caldwell and Chriss (1979) observations and also with the non-dimensional wall-unit profile with further support provided by higher order moments of skewness and kurtosis. Finally, within the viscous sublayer and buffer layer during the non-storm condition there is a significant stress contribution from the viscous stress, while during storm conditions the viscous stress does not appreciably contribute to the total stress estimate. Each of these parameters produces independent evidence that the typical flood tidal boundary layer supports an observable sublayer in the lowest 0.5 cm of the water column, where viscous effects dominate.

Students Supported (**see next page**)

Students Supported

Student Name	Where is he/she now?	Institution/ Department	Duration of support	Type of support (stipend, travel, supplies, etc.)	Type of degree: Undergrad Master's PhD	Year degree awarded	Title of thesis/dissertation if supported by N.H. Sea Grant
Vincent Percuoco		UNH Department of Earth Science	2 years at 50% support	Stipend and summer salary	Masters	2012	The mechanisms of metal and nutrient release from the sediments of the Great Bay
Meagan Wengrove		UNH Department of Mechanical Engineering	2 years at 50% support	Stipend and summer salary	Masters	2012	Observations of a Developing Boundary Layer in a Tidally Forced Estuary
Sophia Burke		UNH Department of Natural Resources	summer 2010	hourly	undergrad		
Laurent Officer		UNH Department of Earth Science	Summer 2011	hourly	undergrad	2012	Senior thesis: Seasonal Variation in Nutrient Release due to Benthic Irrigation in the Great Bay, NH