N.H. Sea Grant Research Project Progress Report

Today's date: February 2012

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: 2/1/10

Principal investigator: Linda Kalnejais

Affiliation: UNH

Associate investigator(s) and affiliation(s):
Professor 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 release 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:

Investigations have continued to understand the mechanisms which lead to the release of nutrients and metals from the sediments of the Great Bay. Quantification of the flux of these species from the sediments is currently underway using a unique combination of geochemical measurements and physical field observations that will provide the best estimates of sediment flux available for a water body to date.

Geochemical Results

The geochemical conditions in the sediments of the Great Bay have now been investigated at four sites. Two additional sites were added this year, a site adjacent to the Jackson Estuary Lab (JEL site) and a site in the Great Bay near the Squamscott River (SQM site). These sites were added so that our sediment sampling covers the dominant sediment types in the Great Bay. The JEL site was sampled seasonally to give a measurement of the variability of the fluxes over the year. For each geochemical sampling event the Kalnejais group collected high-resolution porewater profiles so that the chemical conditions in the sediments were determined and a diffusive flux of solutes could be calculated from the porewater data. The calculated diffusive flux of nutrients from the sediments is provided in Table 1 and it can be seen that the sediments are a source of ammonium and silica to the estuary, while phosphate and nitrate fluxes are low and largely determined by the thickness of the oxic layer in the sediments. The diffusive flux estimates will be improved by incorporation of the acoustic Doppler velocimeter (ADV) measurements of the boundary layer thickness, once that data has been fully analyzed (see below).

Flux (μmol/m^2/day)	**SQM**	**Spring JEL**	**Fall JEL**
Ammonium	6.1 ± 2.8	1.4 ± 0.4	1.5 ± 0.8
Phosphate	0.3 ± 0.1	0.4 ± 0.1	0.1 ± 0.1
Nitrate	-0.1 ± 0.1	0.2 ± 0.5	0.1± 0.01
Silica	4.6 ± 2.3	4.0 ± 1.7	5.0 ± 1.4

Table 1: Fluxes (µmole/m^2 day) of nutrients predicted by Fick's First Law using pore water concentration gradients. Fluxes are averages of two sectioned cores, error is the standard deviation.

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 1).

The data provided by the erosion experiment provides a critical shear stress, the shear stress at which erosion first begins and the erosion rate of sediment. The critical shear stress for erosion ranged from 0.14 - 0.18 N/m^2, which is similar to other New England estuarine cohesive sediments. The critical shear stress did not change from June to August at JEL even though water content increased. After a shear stress change the erosion rate decreased exponentially (Figure 1), similar to the findings of Piedra-Cueva and Mory (2001). In situ shear stresses were measured at JEL during Tropical Storm Irene (see below for more information) using an Acoustic Doppler Velocimeter. Particle movement was observed at 0.14 N/m^2, comparing well with the erosion chamber estimates.

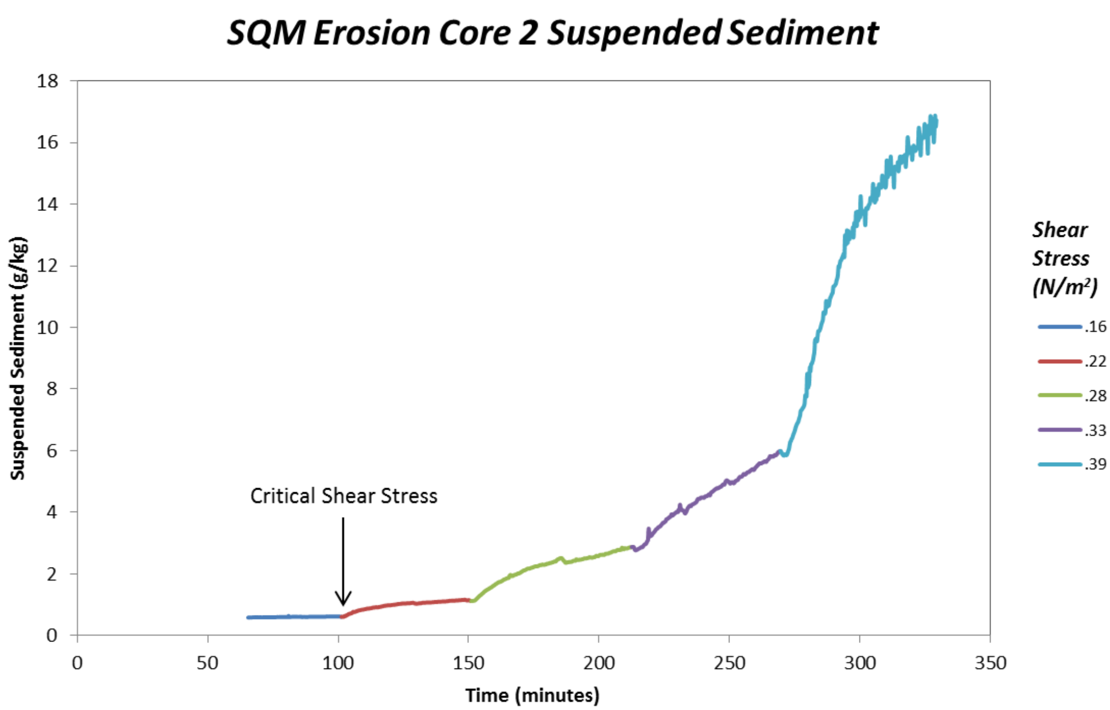

Figure 1 . Plot of the suspended sediment during the SQM erosion experiment recorded by the Hydrolab turbidity sensor.

Water samples were collected throughout the erosion experiments and analyzed for nutrients and metals in the dissolved and particulate phases (Figure 2). 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 did not show a net release due to resuspension. This is likely due to removal in the water column due to particle scavenging.

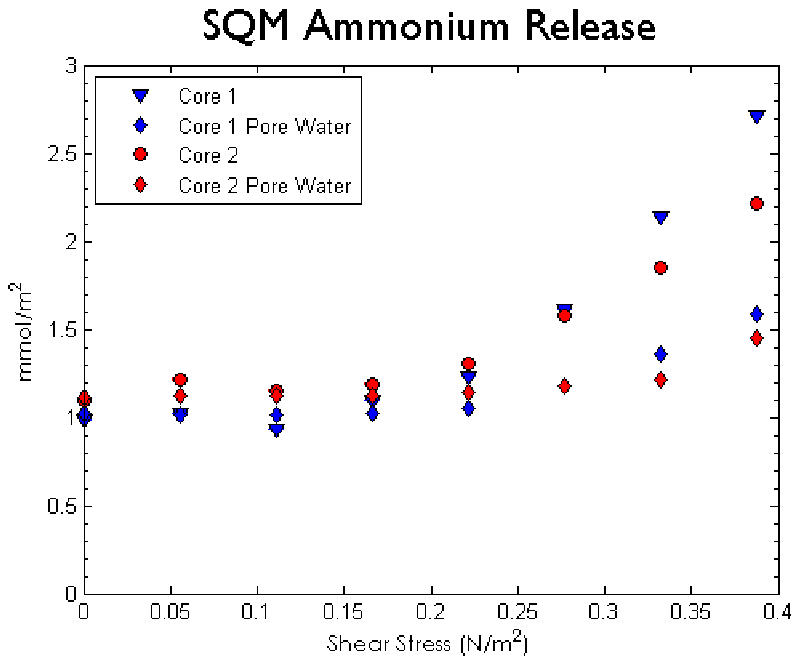

Figure 2. Nutrients released at each shear stress. Data labeled as "Pore Water" is the flux predicted from advection of the interstitial pore water from the eroded layer.

The data from the erosion chamber can be converted to a flux as shown in Figure 3. Comparison of the values from Figure 3 with the diffusive fluxes in Table 1 suggest that sediment resuspension can lead to fluxes of ammonium up to 4 orders of magnitude greater than diffusive fluxes! Silica fluxes show the same behavior. Chemical analysis is ongoing on the water samples collected for trace metals, so that diffusive and resuspension fluxes can be determined for these contaminant species also. Integration of this data with the physical observations of shear stress will be undertaken shortly to convert these resuspension fluxes into total nutrient loads from storms.

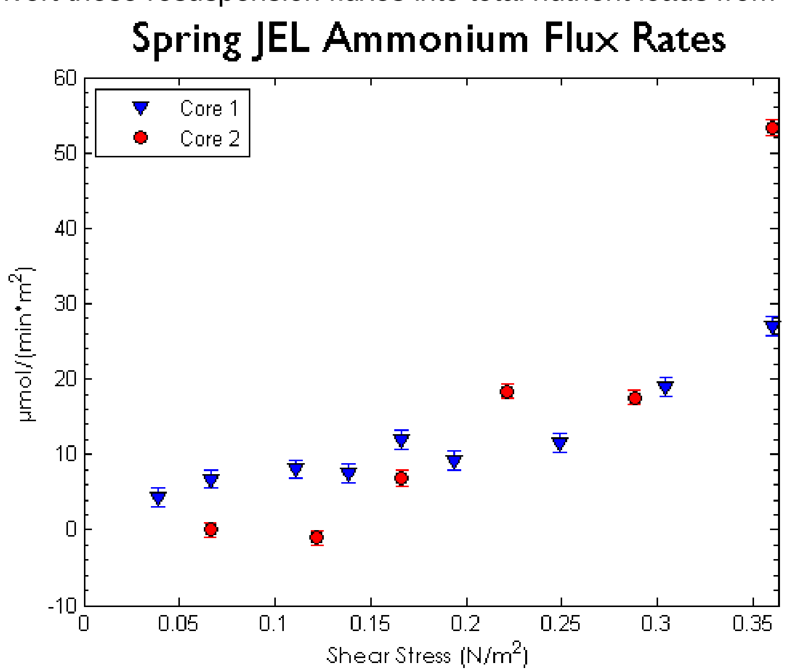

Figure 3. Fluxes of ammonium in the Spring JEL erosion experiments.

Analysis of the particulates collected during the erosion experiments is currently underway. Preliminary results for the SQM erosion experiment are shown in Figure 4 and 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. This 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. The impact to this finding on the fate of trace metals in sediments is still ongoing.

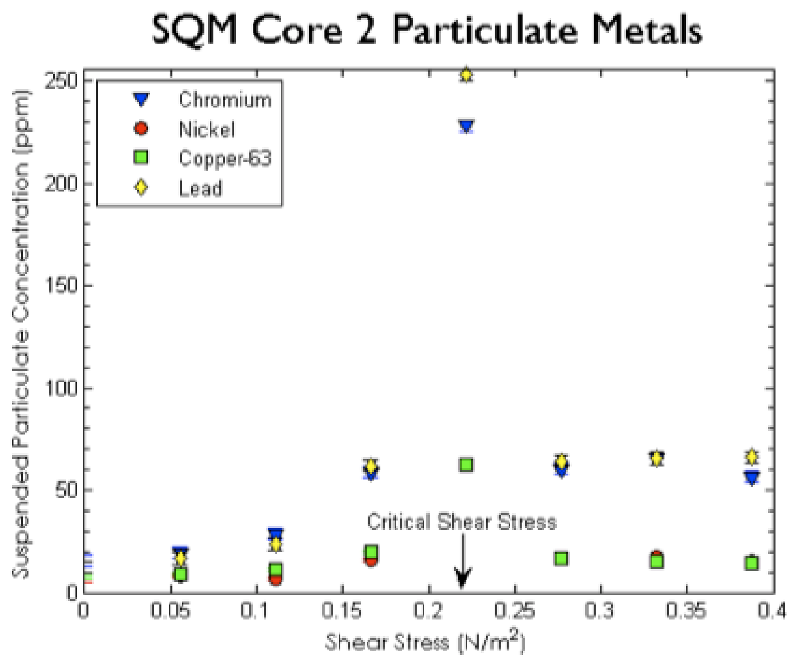

Figure 3. Plot of the chromium, nickel, copper and lead concentrations in the sediment particulates suspended in the SQM Core 2 erosion experiment.

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 4. 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. A third deployment was completed during the King Tides in late October.

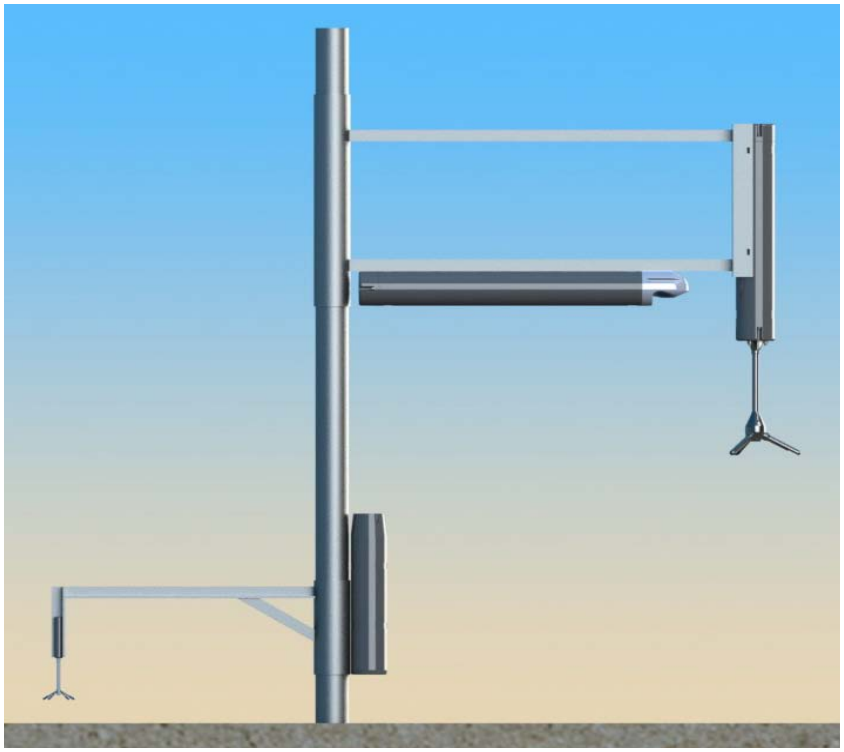

Figure 4: Instrumentation deployment method and relative locations in relation to sediment bed. Vectrino II (left) is 6 cm from bed, Vector (far right) is 0.8 m from bed, Aquadopp HR (horizontal, alignment to right) is 1 m from bed.

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 5 and 6. 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 Figures 5 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.

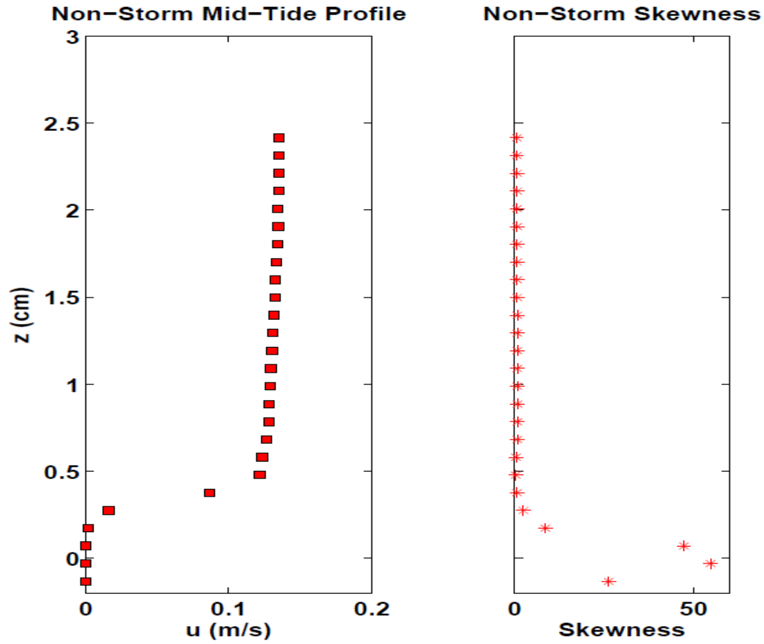

Figure 5: Along-shore, linear velocity profile for non-storm condition (left) and skewness of velocity profile as approaching the bed (right). A high skewness indicates the presence of the viscous sublayer.

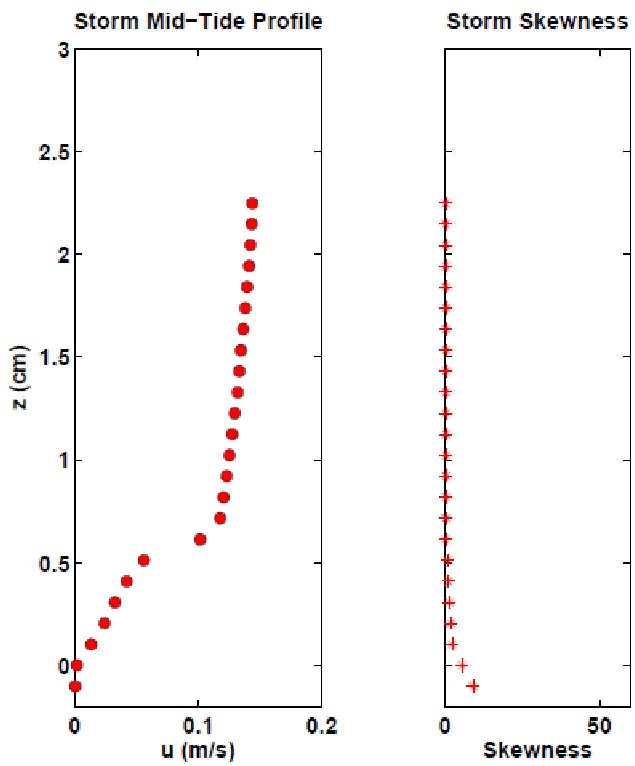

Figure 6: Along-shore, linear velocity profile for storm condition (left) and skewness of velocity profile as approaching the bed (right). A high skewness indicates the presence of the viscous sublayer

A goal of the field deployment was to measure the in situ shear stresses to compare with the erosion chamber results. The shear stress can be estimated from the velocity profiles using multiple methods. The results for the non-storm deployment are shown in Figure 7. For one of the deployment days there still exists considerable variability between the different estimates. One explanation is there were low frequency motions that were not removed and work is continuing to develop further methods to calculate shear stress from this very new and unique dataset.

Ongoing Work

The project's current focus is to complete the chemical and physical analyses and draw all of the information together to provide a detailed description of the fluxes of metals and nutrients from the sediments in the Great Bay. In order to accomplish this, the remaining work needs to be done:

- Trace metal analysis of the erosion experiments samples will be completed.
- Suspended particles were sampled during Tropical Storm Irene, the composition of these particles will be analyzed.
- Data analysis of the King tide deployment.
- Re-caluculation of the diffusive fluxes using the viscous sublayer layer results from the field deployments.
- Calculation of total nutrient fluxes during Tropical Storm Irene by integration of the chemical and physical data

Following the completion of these tasks, the results will be written up into two Masters theses that will be defended before the end of summer 2012. At least three publications to scientific journals will be prepared based on this work. Once final calculations have been complete (targeted for April 2012), presentations on this work will be scheduled with the New Hampshire Department of Environmental Services to ensure that resource managers are aware of the findings.

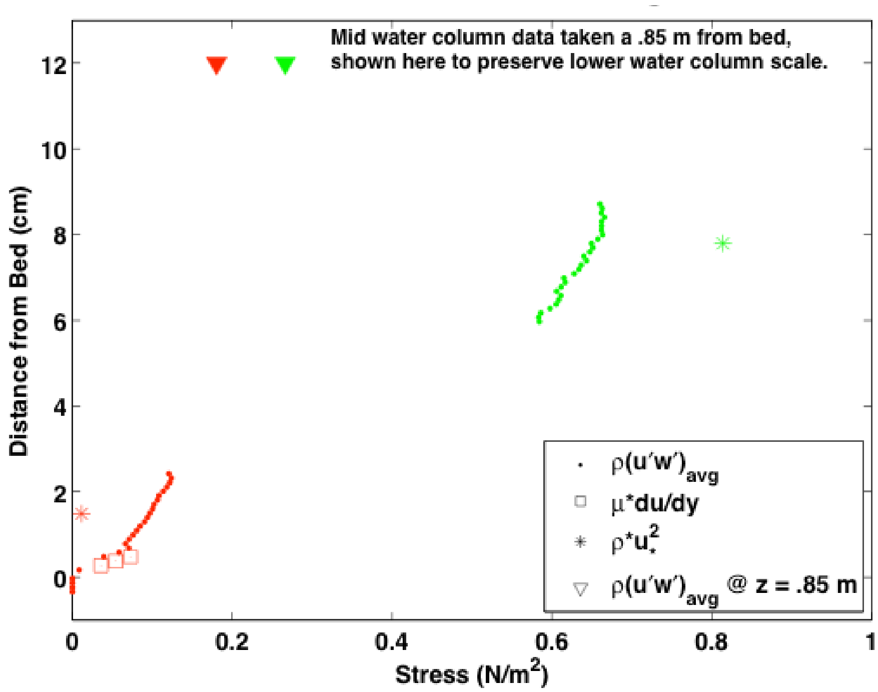

Figure 7: Vertical profiles of the estimates of the shear stress. Green is data from day 167, red is data from day 171, both during the non-storm deployment in Jun 2011.

Impacts to date:
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. As we complete this work over the next few months we will further quantify the nutrient fluxes and provide a mechanistic understanding of the fluxes to ensure we can provide the most accurate assessment of the role of sediments to policy makers.

This project has supported two graduate students in two departments at UNH. Vincent Percuoco is an Earth Sciences department and advised by Kalnejais and Meagan Wengrove is in the Mechamical Engineering Depratment, advised by Foster. Both students will defend their theses by the end of the summer 2012.

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 is now writing this work up as part of his senior thesis in the Earth Sciences Department.

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.

Accomplishments:
Three abstracts have been submitted on this work. Two were presented at the Fall AGU meeting and the third abstract is to be presented this week at the Spring ASLO meeting. 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 , to be presented at Spring 2012 Ocean Sciencees Meeting, Salt Lake City, Utah, 20-24 Feb.

A significant accomplishment of this project once it is completed later this year will be the combination of two very different datasets to provide a much better understanding of the mechanisms operating in coastal waters. The high resolution temporal data on fluid velocites and stresses combined with geochemical measurements of eroded particles and solutes will be a unique study that will provide unprecedented information on the impact of physical processes on chemical fluxes in coastal waters.

Problems encountered:
This project was started 3 months later than intended due to the difficulties in finding suitably skilled graduate students to work on this project. The students best suited for this project were unable to start early in the summer, so our first field campaign was in September 2010 after both students had arrived at UNH for the start of the fall semester. Intensive sampling was conducted in 2011, but due to the late start, sample analysis is still ongoing.

The Vectrino ADV instrument was suffering from a sporadic electrical fault and some data was lost during the early deployments. Foster and graduate student Wengrove have resolved this issue and are are now collecting exciting data (see Figure 5-7).

The ICP-MS instrument that was to be used for the trace metal analysis was malfunctioning for a number of months in 2011. The problem has now been resolved and the first metal results have been obtained (see Figure 3). Chemical analysis is continuing to complete the metal analysis for this project.

Publications to date:
In preparation

Presentations to date, with published abstract citation if applicable:

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.

Students Supported

Student Name	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 if supported by N.H. Sea Grant	Where is he/she now?
Vincent Percuoco	UNH Department of Earth Science	2 years at 50% support	stipend	Masters	planned for 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	Masters	planned for 2012	Erosion in the Great Bay, New Hampshire	
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	