Observations of Tidal Boundary Layers: Working Towards Resolving Estuarine Nutrient Fluxes

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MOTIVATION

The Great Bay is one of the 28 "**estuaries of national significance**" established under the Environmental Protection Agency's National Estuarine Program and has been showing signs of eutrophication. The New Hampshire Department of Environmental Services has reported significant loss of eel grass coverage, loss of oyster bed populations, and increase in microalgae concentration. The health of the Great Bay is of major concern, and in order to protect our local resources, we must better understand the physical mechanisms that drive them.

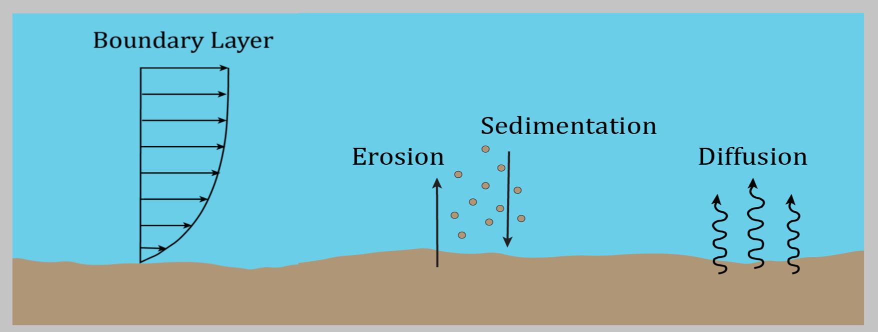


Figure 1: A classic representation of a boundary layer, or vertical velocity gradient above an interface, along with depictions of suspension and diffusion events that can result from the shear stresses acting on the fluid-sediment interface.

Figure 2: Great Bay Estuary, field location of interest.

FIELD SITE & METHODS

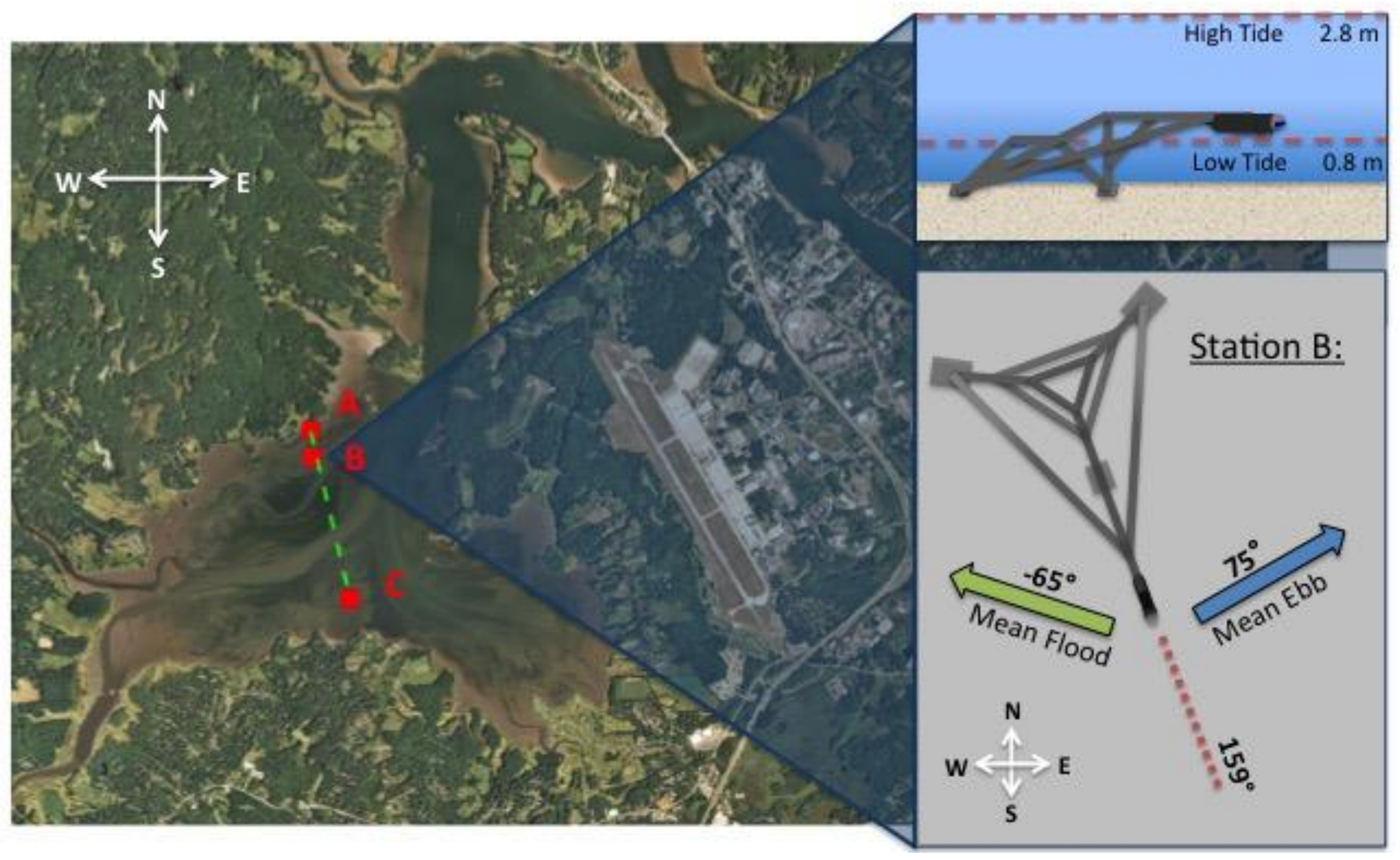


Figure 3: Field sites along 3 km transect of Great Bay, labeled A-C, along with inset of frame configuration and orientation.

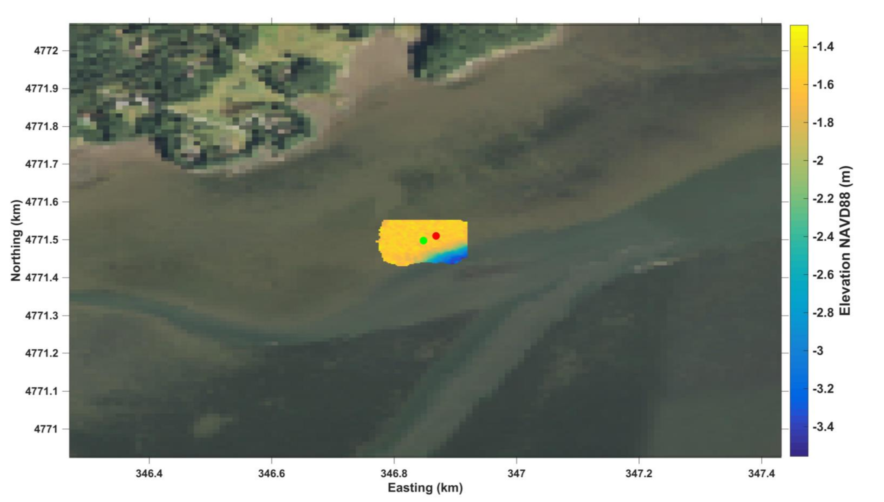


Figure 4: Multibeam survey bathymetry collected at area surrounding Station B plotted on top of GIS image of the Great Bay. Red and green dots represent frame location, as the frame was deployed in a slightly different location in 2017 as in 2016.

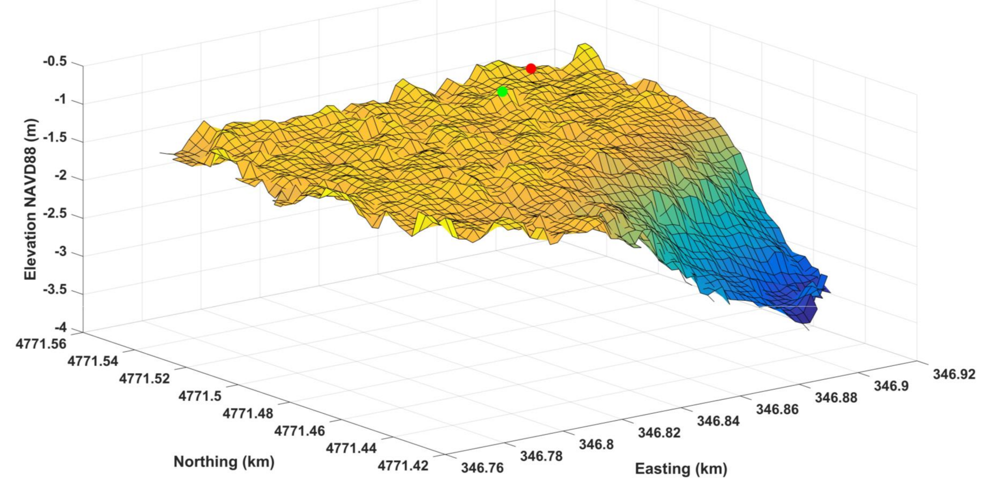


Figure 5: 3D visualization of multibeam survey bathymetry collected at area surrounding Station B. Bathymetry reveals low-sloping hummocks and no distinct or repeatable bedform pattern.

Deployments were conducted at three sites along a 3 km transect of the Great Bay, focusing on shallow mudflats. An instrument package was mounted on a tripod frame with cantilever arm that was oriented approximately cross-channel at 159 degrees from true north. Mean flood tides moved past the instrument at 75 degrees, and mean ebb tides moved past at -65 degrees, thus minimizing frame interference.

The instrument package includes a downward-looking Nortek Aquadopp Acoustic Doppler Current Profiler (ADCP), a Nortek Vector Acoustic Doppler Velocimeter (ADV), and an SBE 16plus SeaCAT Conductivity, Temperature, Depth (CTD) sensor outfitted with two auxiliary optical turbidity sensors. Sensors were counted at depths of 10 cm and 34 cm from the bed. In addition, a YSI CastAway CTD was used to obtain salinity and temperature measurements through the water column over a complete tidal cycle. Casts were made every 5 minutes over the course of a 12.5 hr tidal cycle. Acoustic backscatter return was collected by the Nortek Aquadopp ADCP and was used to provide another measure of uncalibrated particulate concentration in the water column. This suite of instruments provide a high resolution record of the small-scale hydrodynamics and water column characteristics over the sample period, which ranged from 1 to 28 days.

In addition to hydrodynamic measurements, sediment grab samples and cores were collected. Grain size analysis, sediment composition, and porewater analysis were done on sediment samples in order to characterize sediment properties and determine nutrient concentrations present in the bed.

Bathymetric surveys were collected using CBASS (Coastal Bathymetry Survey System) which is a waverunner equipped with differential GPS, a 192 kHz multibeam sonar, a POS MV V5 IMU for survey corrections due to vessel motion, and an internal navigation system (system constructed by Lippmann).

EXPERIMENTAL RESULTS

Current velocity data shows a highly repeatable flow pattern over a 5 day deployment, with sustained periods of maximum velocity during the flood and ebb tides, as shown in Figure 4 highlighted in yellow. Plotting the average velocity profile of the highlighted flood and ebb event on a semilog scale, as shown in Figure 5, we see a distinct linear trend in the lower and upper portions of the water column during the ebb event, and a linear trend in the upper portion of the water column during the flood event. The linear portions are indicative of a boundary layer profile, which seams to suggest a dual-log layer system.

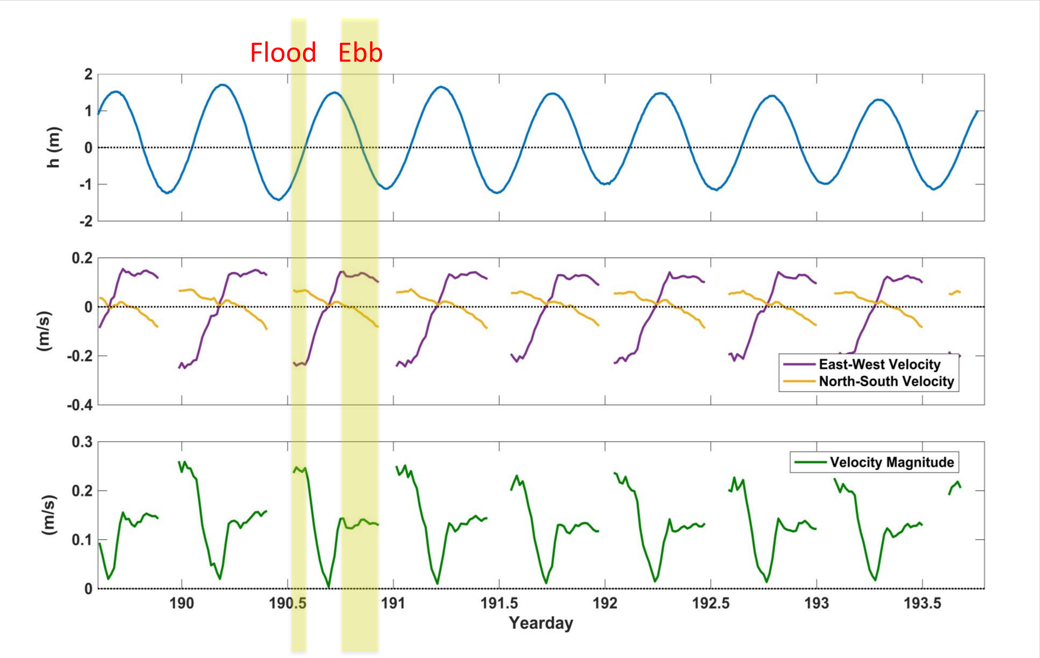


Figure 4: For a 5 day deployment at station B, top panel: tidal signal, middle panel: East-West and North-South velocity components, bottom panel: velocity magnitude. Repeatable patterns of periods of sustained velocity during the ebb and flood are observed and highlighted in yellow.

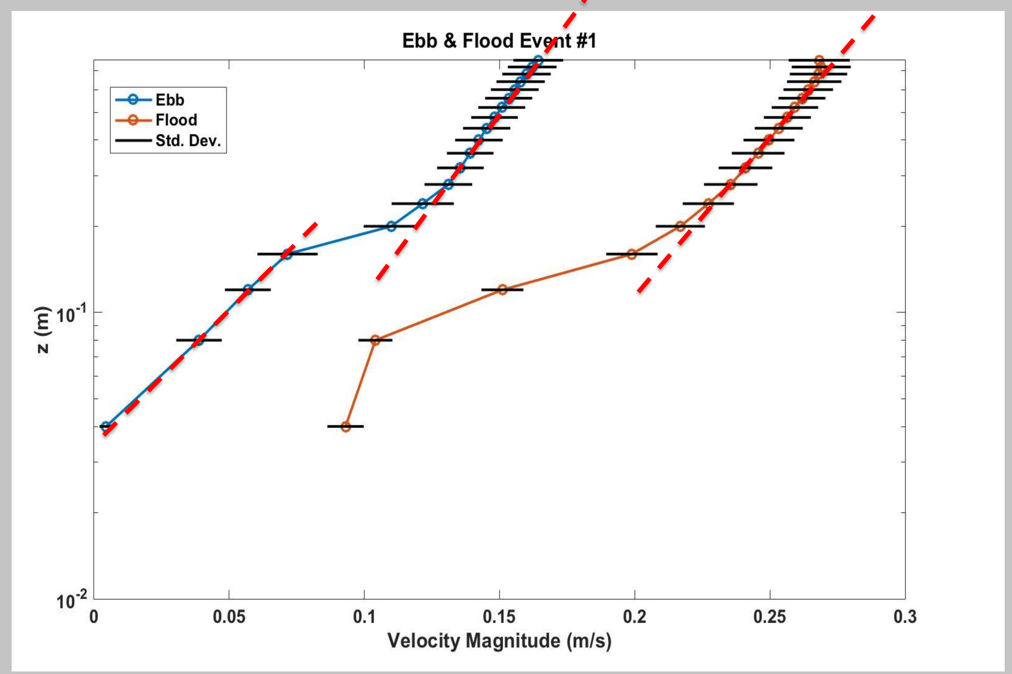


Figure 5: Average velocity profile on a semilog axis for the periods of sustained velocity highlighted in Figure 4.

Using indicator functions to estimate the shear velocity and thereby shear stress at the bed, we find that the threshold of incipient motion for the sediment found at the site is exceeded, with a greater shear stress estimated in the lower log layer during the ebb event. This is shown in Figure 6. In figure 7, we take a closer look at the vertical structure of the flow field. Here we see that the flow direction on the flood tide is fairly consistent through the water column at approximately -80 to -90 degrees relative to true north. However, as the tidal cycle moves through high tide and into the ebb tide, we see that the lower portion of the water column is moving in a direction nearly 180 degrees out of phase with the upper portion. This period of directional independence between the two layers is sustained over a period of several hours, and the depth of the interface between them appears to be approximately in agreement with the interface between the two log layers, shown in Figure 5.

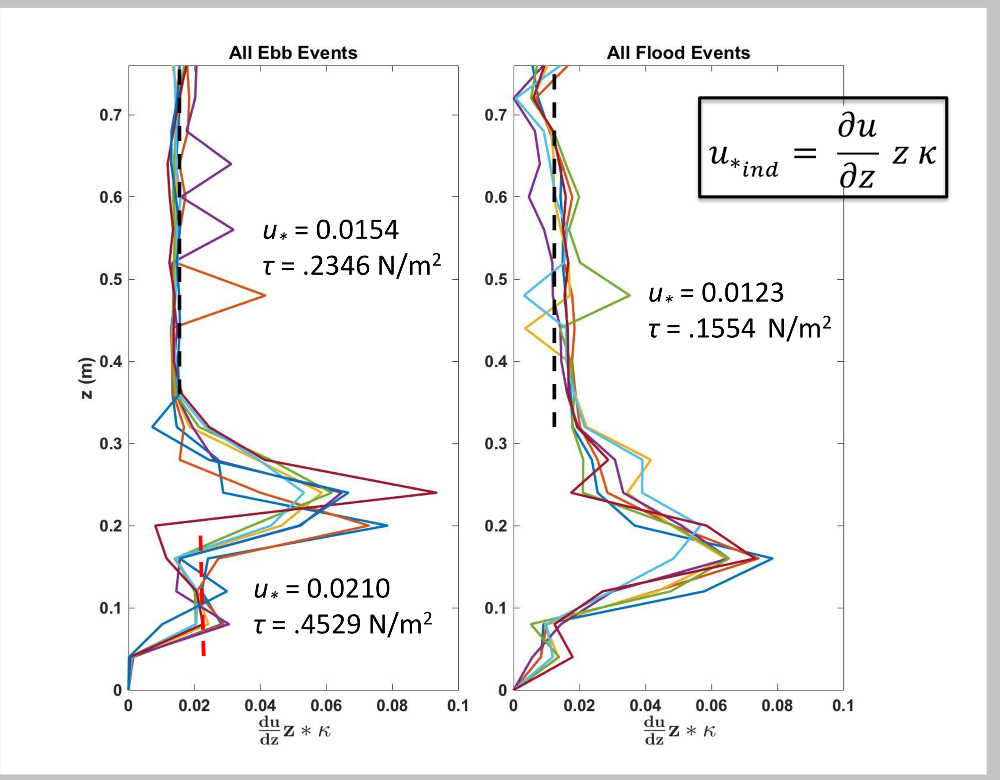


Figure 6: Indicator function plots for all ebb and flood events over the 5-day deployment. Averages over vertically linear portions of the plot provide estimates of shear velocity, u_*.

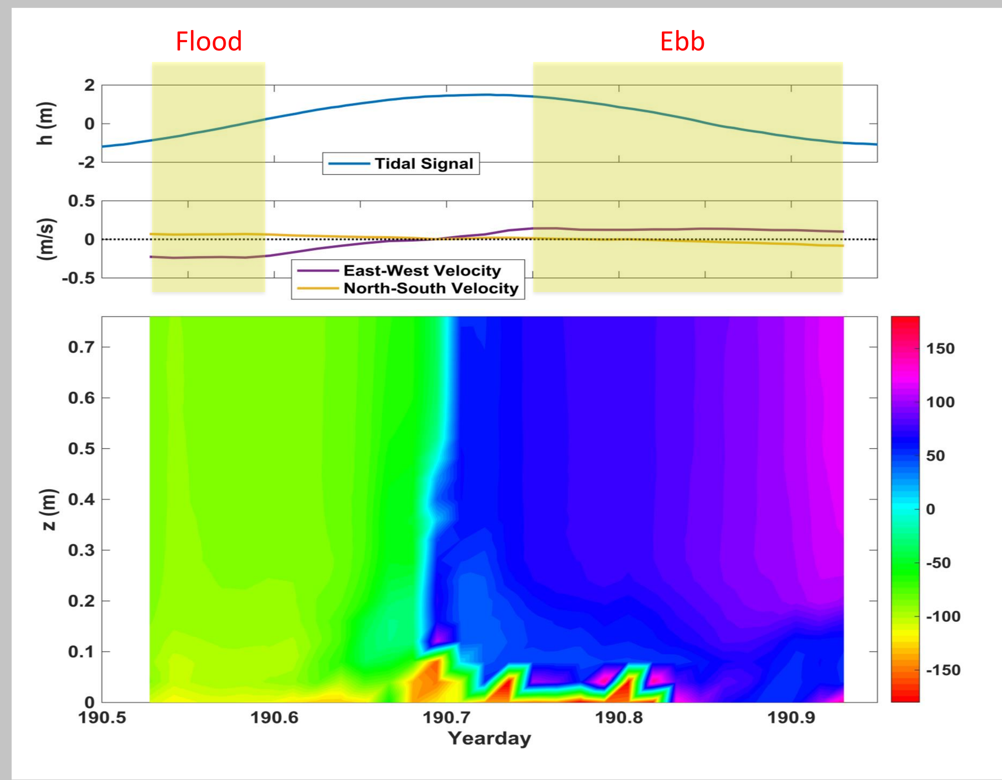


Figure 7: Over a single tidal cycle with periods of sustained velocity highlighted in yellow, top panel: tidal signal, middle panel: East-West and North-South velocity components, bottom panel: direction of mean flow through the ~80 cm sample range, where 0 m represents the bed.

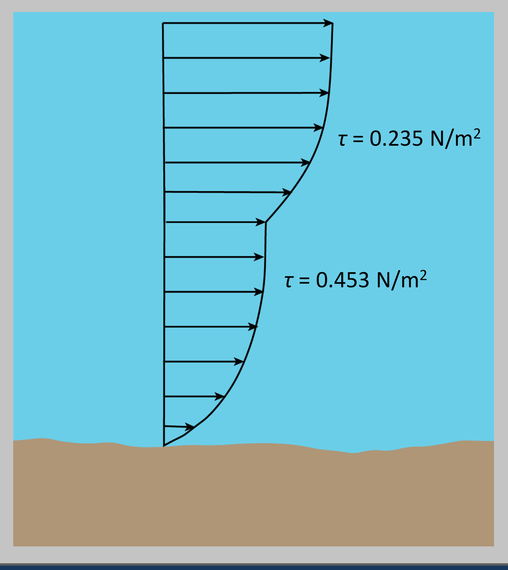
CTD surveys collected at Station B revealed a well-mixed water column with no evidence of stratification due to a gradient in temperature or density. Optical turbidity sensors mounted at 10 cm and 34 cm above the bed indicate no significant gradient in qualitative turbidity concentration.

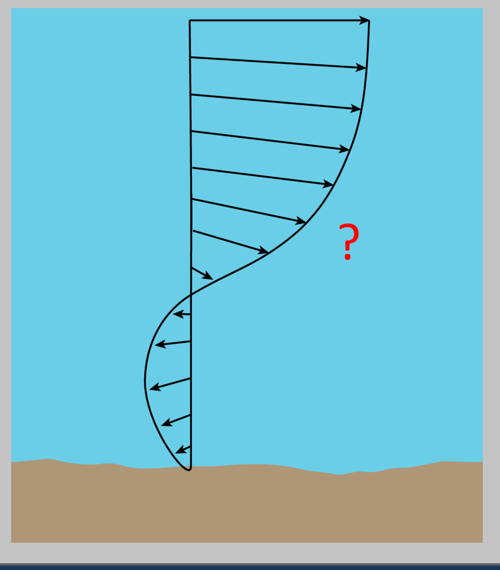
CONCLUSIONS

Results show:

- Observations of a tidal boundary layer along transect
- Evidence for secondary near-bed log layer
- Transition region shows strong rotational structure

Given the unique hydrodynamics observed, the common practice of using a simple logarithmic boundary layer model may not be appropriate in this case. The dual-layer flow field and rotational structure could have significant impact in estimations of shear stress and nutrient release.





REFERENCES

[1] PREP (2013). State of our Estuaries 2013. Piscataqua Region Estuaries Partnership, UNH. [2] DES. 2011. Nitrogen, Phosphorus, and Suspended Solids Concentrations in Tributaries to the Great Bay Estuary Watershed in 2011, Department of Environmental Services, State of New Hampshire. [3] M. Wengrove, *et al. Limnol Oceanogr, sub judice* (2013). [4] V. Percuoco *et al., ECSS,* (2013)

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