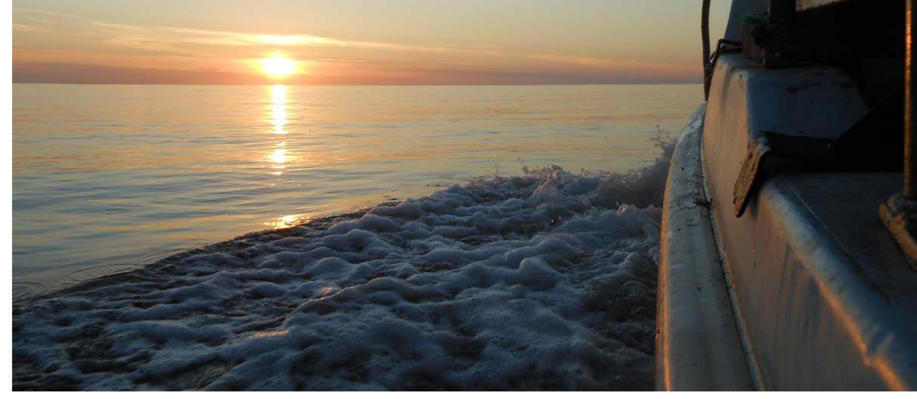
Distinguishing resuspension and advection signals in a hypertidal estuary



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Introduction

The Dee Estuary is a hypertidal coastal plain estuary, formed by the flooding of the river valley cut by the River Dee during the last major glaciation. One of three major estuaries emptying into Liverpool Bay along with the Ribble and Mersey it is located at the junction of north-east Wales and north-west England, on the eastern side of the Irish Sea.

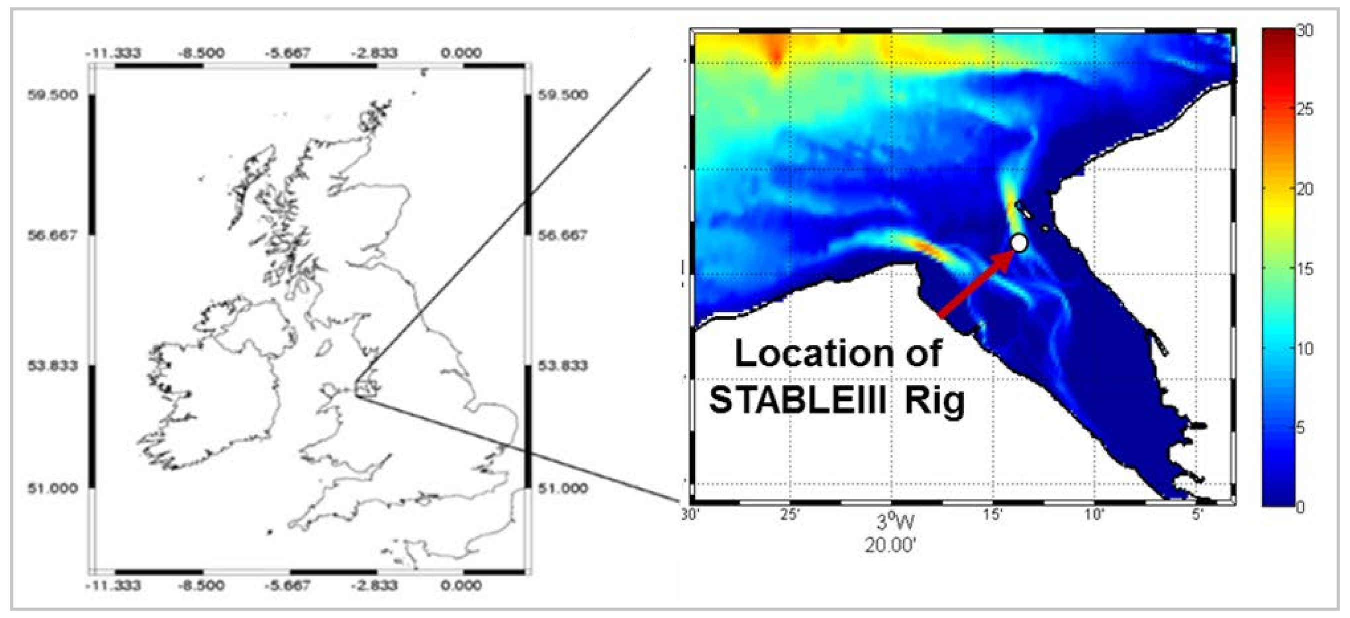
The estuary section of the Dee is 20 km long, and 8.5 km wide at the mouth. The sea bed is covered by a thick (up to 18 m) sediment layer, deposited after the last Ice Age, consisting of fine-grained sands, silt muds, and some gravel beds. Infilling has led to the gradual accretion of the sand and mudbanks, and an increase in saltmarsh area.

The estuary has a maximum spring tidal range in excess of 10 m, with an increase in tidal prism in excess of 80% occurring between mean low and mean high water during spring tides, causing tidal currents in excess of 1.2 ms^{-1}.

The 110 km (68 mi) length of the River Dee drains from a catchment area of ~1816 km^2 (701 sq mi). Average discharge during the year is 37 $m3s^{-1}$. This roughly equates to 0.4% of the tidal prism over an entire tidal cycle.

The main discharge channel bifurcates approximately 12 km after the canalised section into two main channels – the Welsh channel to the western side, and the Hilbre channel to the east – both of which extend into Liverpool Bay, and are approximately 1 km wide, 4 km long and 20 m deep.

The physical characteristics of the Dee make it an ideal location for studying turbulence-sediment interactions and flocculation: It has a large tidal prism, high tidal range, and abundant cohesive sediment. In addition, the freshwater input creates a horizontal density gradient that, through interaction with tidal forcing, creates both periodic stratification and a residual, gravity-driven circulation.

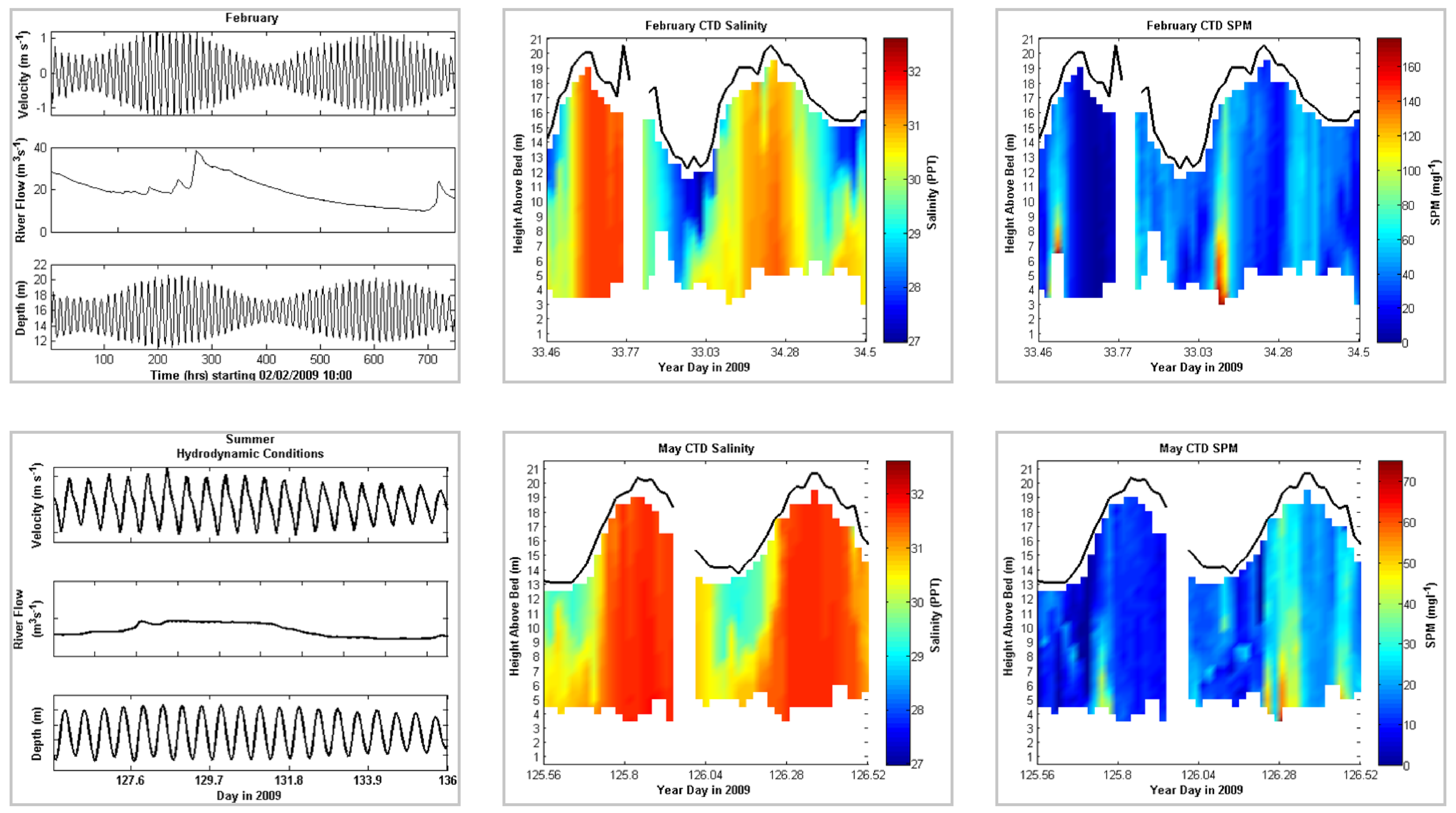


Data Collection

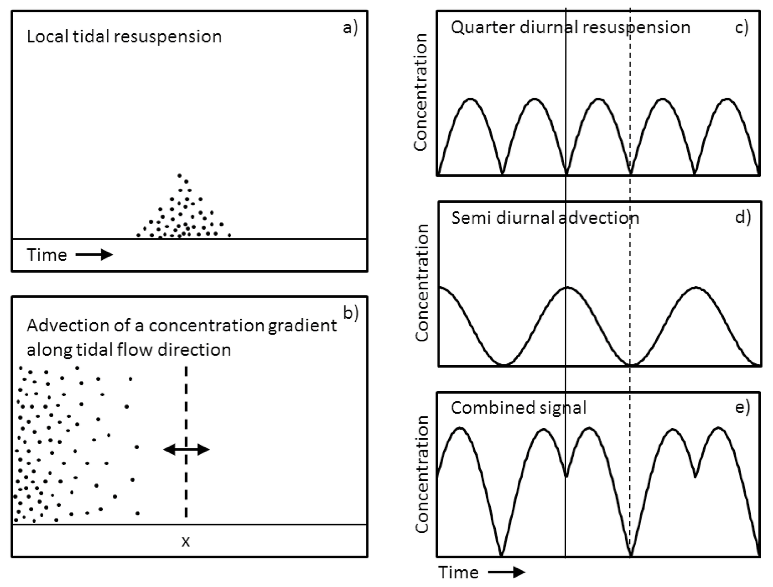
Data was collected over 2 month-long deployments of a benthic tripod (STABLEIII) in the Hilbre Channel during February-March and May-June 2009. CTD profiles were taken at half-hourly intervals at the beginning and end of each deployment. The CTD included a transmissometer, while mass concentrations were obtained through the gravimetric filtering of water samples. Only the first 2 weeks of the May-June data were available due to biofouling.

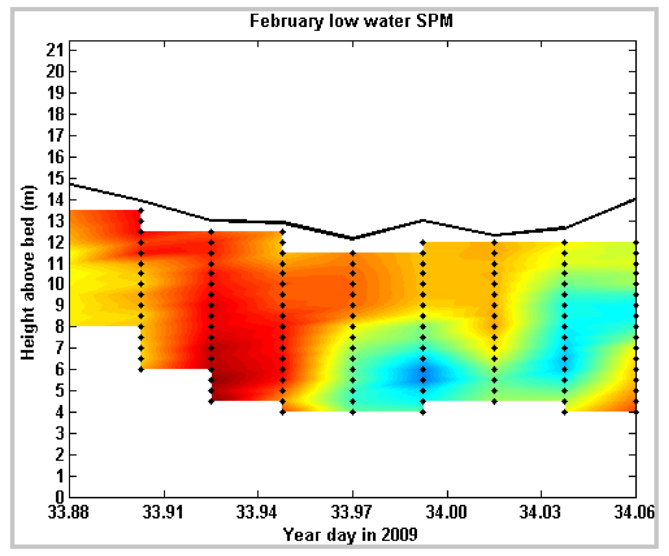
The salinity profiles show stratification at low water during both periods as higher river flow during February resulted in stronger stratification.

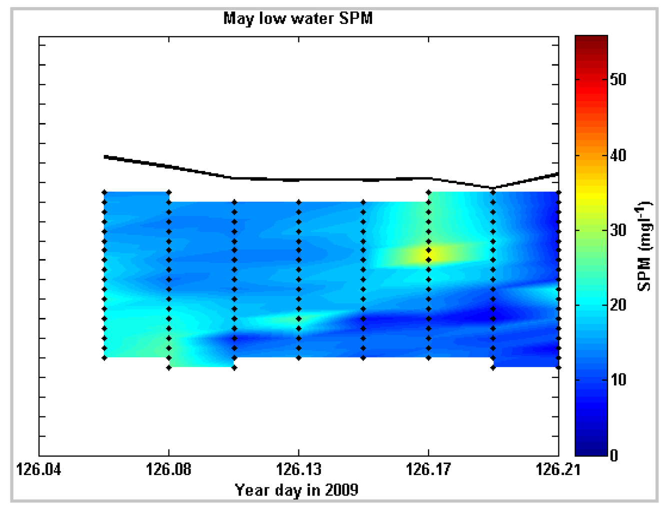
Fluorescence response from the CTD shows a markedly different signal between February and May.



Distinguishing Resuspension and Advection





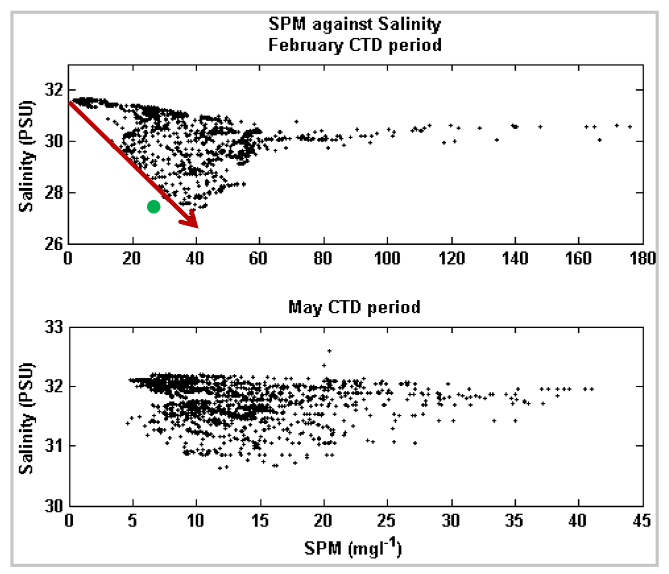


Distinguishing between resuspension and advection can be complex. Material that is resuspended within the area of study is regarded as resuspension, while that which is resuspended outside, but passes through, the area of interest, is regarded as advection.

In estuaries where SPM is composed of both resuspension and advection, SPM observations over time at any height above the bed are a combination of a resuspension component that is proportional to the current speed, and an advection component that forms a horizontal concentration gradient and is therefore proportional, at the point of measurement, to the tidal displacement. This is demonstrated in the figure in which local tidal resuspension **(a)** creates a quarter-diurnal in SPM concentration **(c)**, while the advection signal **(b)** creates a semi-diurnal peak in SPM concentration **(d)**. The combination of these signals **(e)** creates the characteristic twin peak signal. This is because the advection of a horizontal concentration gradient operates on a semi-diurnal timescale, with the concentration gradient either advecting into the estuary from offshore on the flood, or down the estuary during the ebb.

Conversely, resuspension of material tends to take place during both the flood and ebb tide (dependent upon the degree of tidal asymmetry), and therefore operates on a quarter-diurnal frequency. Distinguishing resuspension and advection using these principals is possible through the fitting of quarter-diurnal and semi-diurnal signals to an SPM time series. The phase of this signal is of key importance: the quarter-diurnal resuspension signal should be in phase with the current speeds, indicating resuspension, while the semi-diurnal signal should be out of phase with the current speeds, indicating that the semi-diurnal concentrations are not controlled by the current speeds. Where a semi-diurnal signal is in phase with one of the quarter-diurnal peaks, this indicates asymmetry in resuspension, with both peaks composed of a quarter-diurnal signal, but one peak having greater amplitude, resulting in a semi-diurnal component.

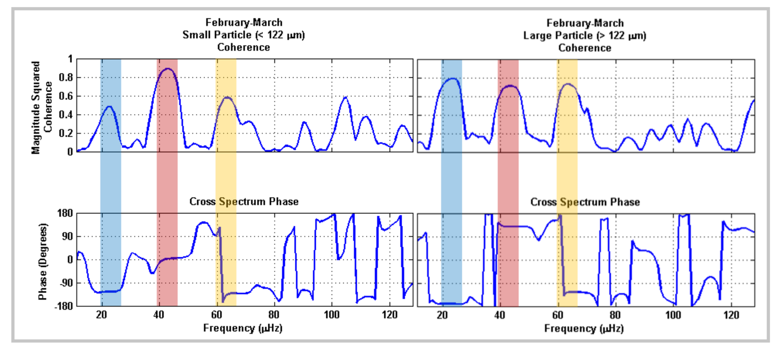
Salinity can also be used to show that a peak in concentration occurs during a period of lower or higher salinity indicating the presence of fresher water from the estuary.

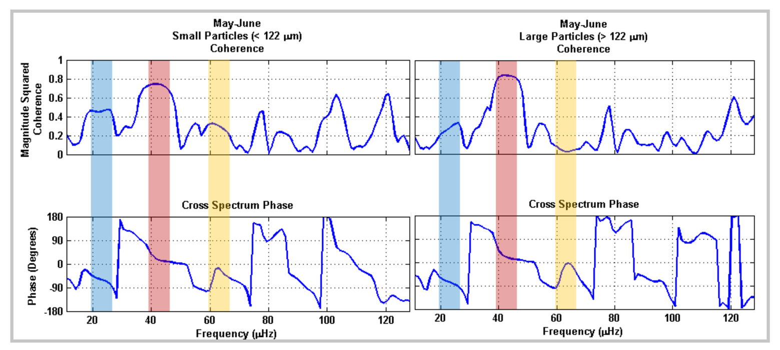


Plotting low water periods during February and May shows the difference in SPM concentration during these periods. Relating SPM to salinity shows the presence of a horizontal concentration gradient during February with a single anomalous point (highlighted in green) breaking this trend. This gradient is present during May, but is weaker and less clearly defined.

Phase and coherence were calculated relative to ADCP-derived current speeds. During February-March, small particles were predominantly quarter diurnal controlled with a phase of zero degrees relative to current speed, demonstrating a resuspension signal. The semi-diurnal component, with a phase of -130° indicates the advection of small particles with a peak during later ebb. The large particles displayed strongest coherence for a phase of 180° at the semi-diurnal frequency, indicating that these particles were the result of flocculation and / or advection at low water. The strong coherence also shown by the quarter-diurnal signal indicates flocculation / advection approximately 2 hours after peak current speeds at the start of high and low water.

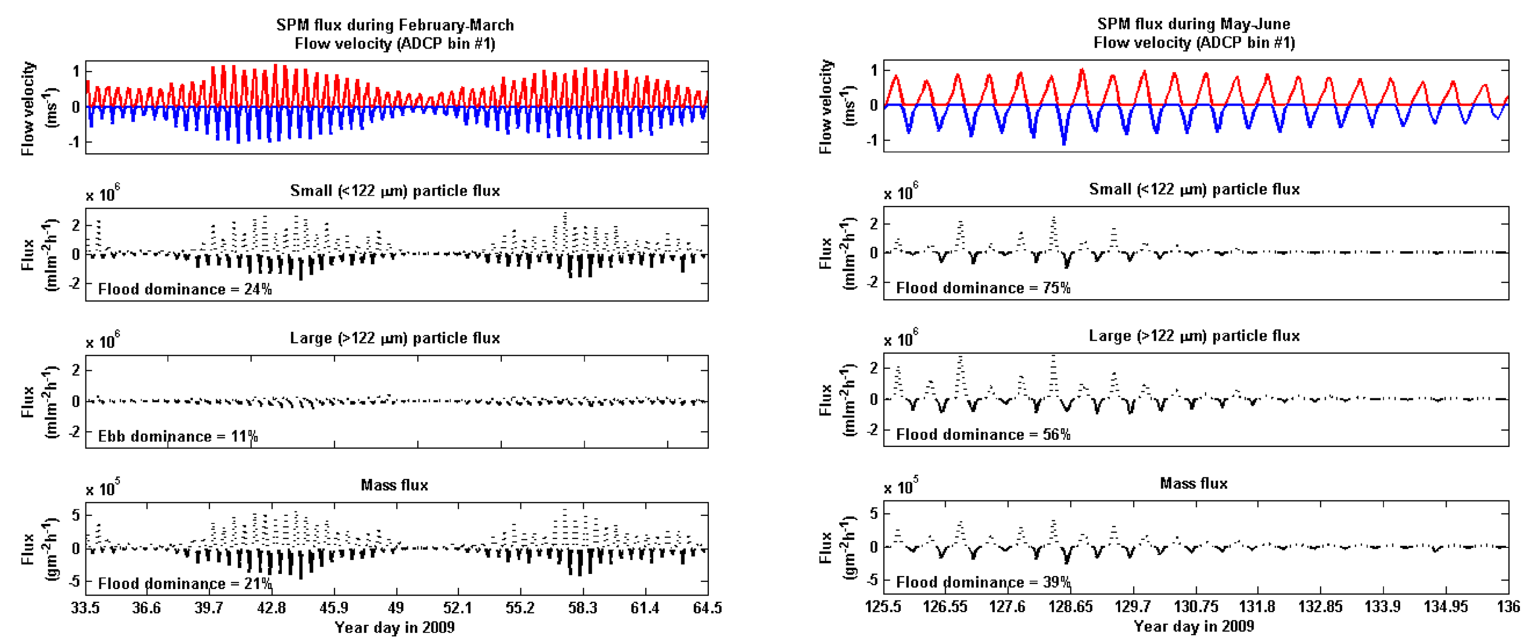
Small and large particles were both quarter-diunal dominant during May-June with a phase of <10° indicating that both were primarily the result of resuspension processes.





Impact on Sediment Flux

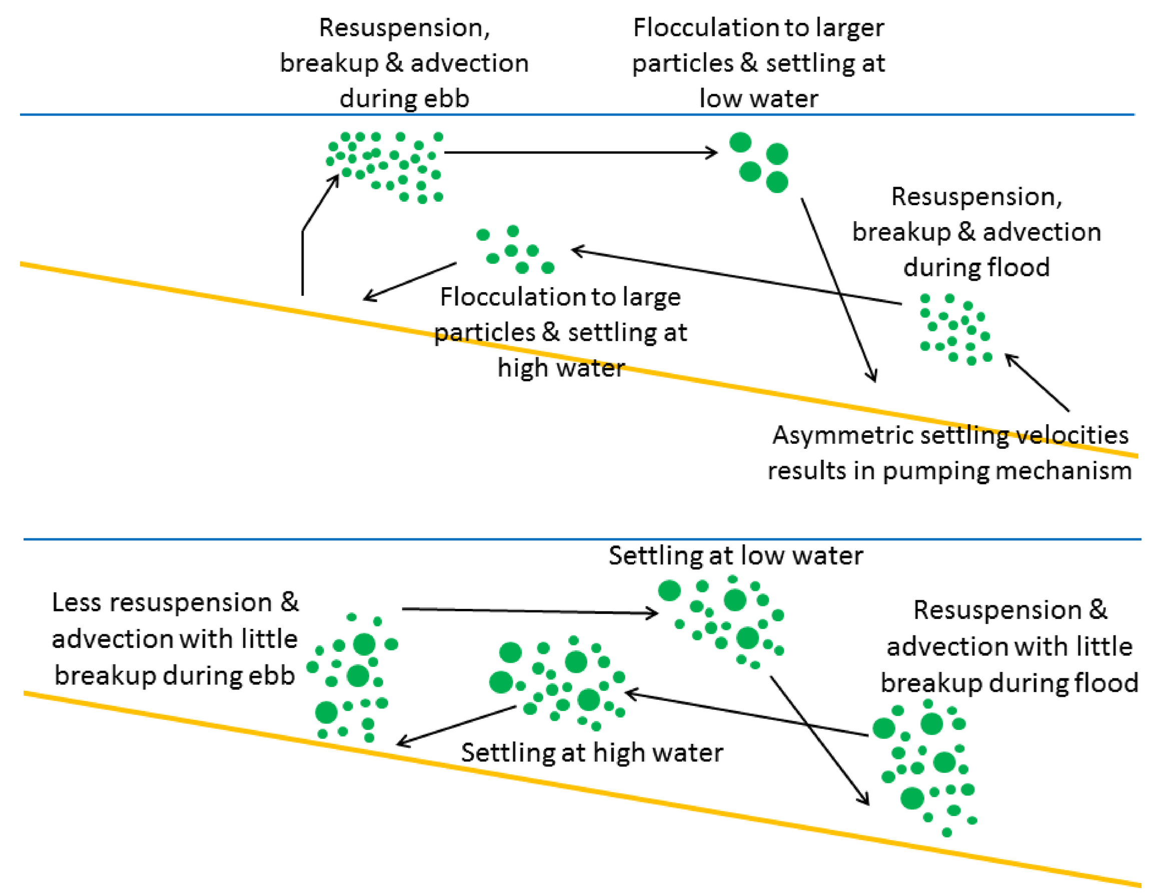
The large horizontal concentration gradient present during February-March, and subsequent ebb dominance of concentrations, results in a weak flood dominant sediment flux by both volume and mass. During May-June, both small and large particles and mass are strongly flood dominant, while during February-March, although small particles and overall flux remains flood dominant, large particle flux is ebb dominant.



Proposed Mechanism

During February-March, low biological abundance results in resuspension and a large horizontal concentration gradient. Weak flocs form during slack water, breaking up during flood and ebb. As low water lasts longer than high, larger flocs form resulting ebb dominant net transport of large particles however this is insufficient to change the net flux of the estuary and a small flood dominance of sediment flux is present.

During May-June, the horizontal concentration gradient is lower due to sediment binding by biological processes. Flocs are bound together by these processes, resulting in resuspension without break up. Sediment transport is therefore strongly flood-dominant due to velocity asymmetry resulting in a tidal pumping mechanism bringing material into the estuary.



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