Multiple scales of controls on sediment transport in intertidal flats: tidal stage, storms, and seasons

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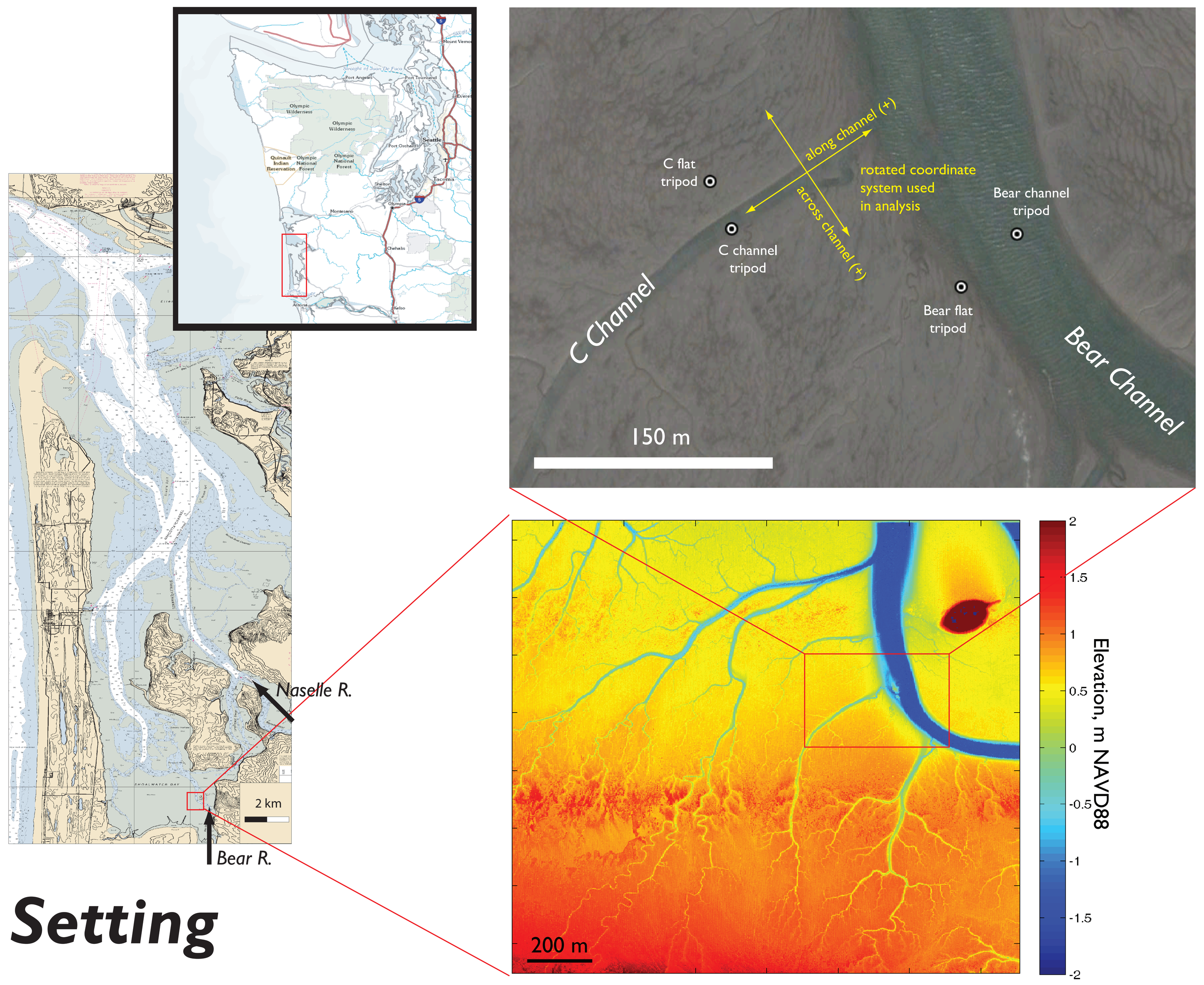
Introduction

The muddy flats of southern Willapa Bay, Washington, are tidally dominated and receive relatively little direct freshwater influence. We use data from paired instruments in a representative channel and adjoining flat to better understand sediment dynamics in each morphological setting and to investigate whether sediment fluxes are balanced between environments.

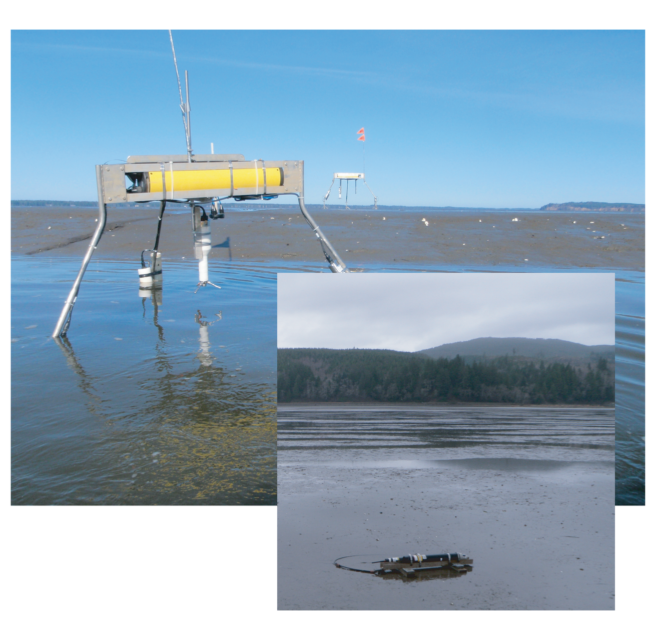
In this poster we investigate 30 days of data collected during December 2009 and January 2010. The deployment expeienced both calm and windy periods, as well as rainfall.



Setting

- Muddy tidal flats incised by channels of multiple orders:
  Primary Bear channel (~4 m depth at bankfull, 50 m width) is always inundated & connected to northern Willapa Bay & Pacific Ocean
  Secondary "C" channel (1 m depth at bankfull, 15 m width) is alternately inundated & exposed depending on tidal state
- Waves are relatively fetch-limited except from the north, however, strong, fetch-limited easterly winds can generate 0.5-1 m waves
- Mesotidal, mixed-semidiurnal tides (2 - 4 m range)
- Bear River (0.2 - 8 m^3/s; multi-year 5^{th}-95^{th} percentile range), mouth 4 km from site; Naselle River (1 - 43 m^3/s), mouth 10 km from site

Methods



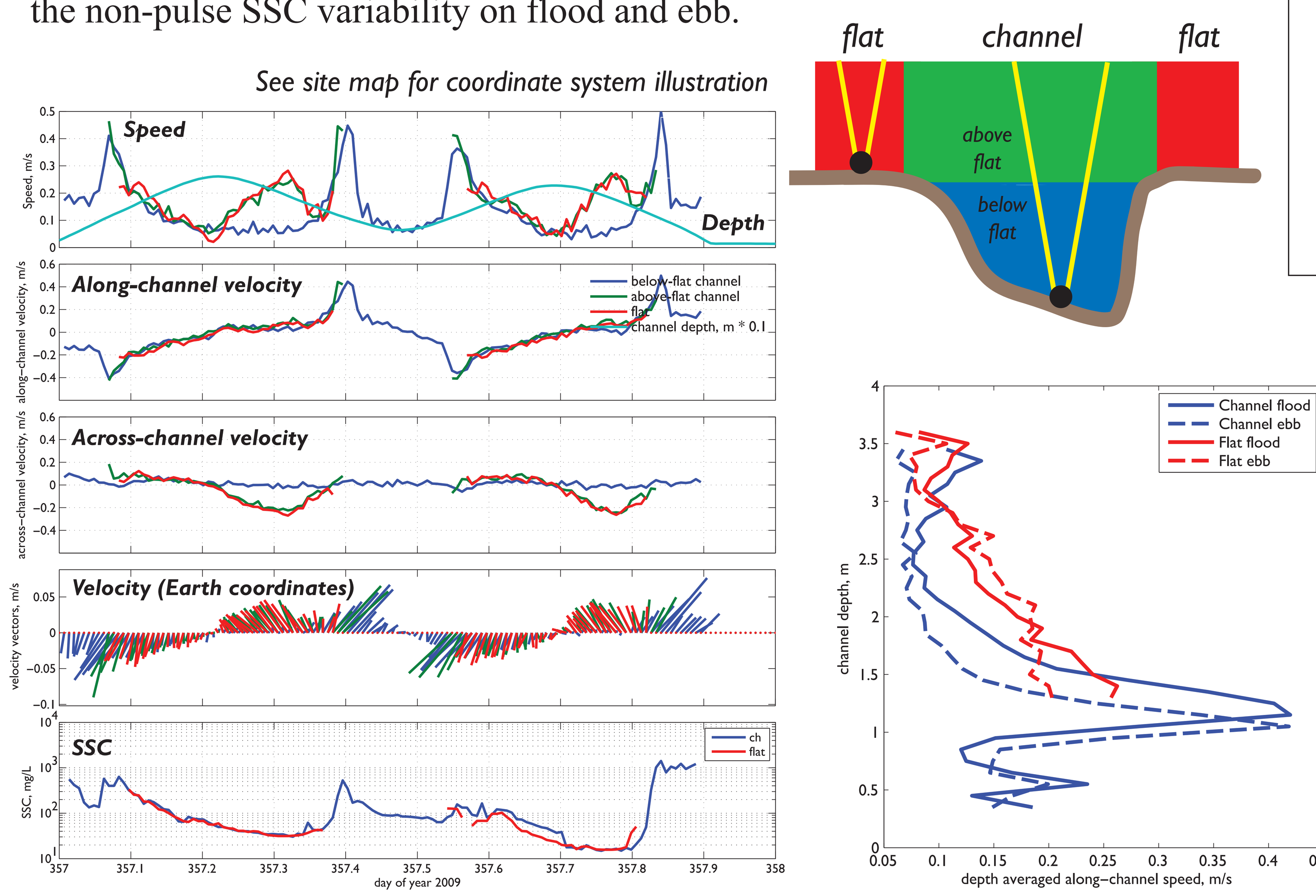
Paired instrumented tripods deployed in study channel and adjacent flat were equipped with:
- SonTek 5 MHz ADV: point velocity
- Optical backscatter (OBS): point suspended-sediment concentration
- Sea-Bird CTD
- Nortek Aquadopp Profiler: velocity profile throughout water column in 10-cm bins
- Physical suspended-sediment samples
- Instruments collect data every 10 minutes to capture rapid changes in flow and sediment transport.

Baseline channel-flat dynamics

When water is below flat level (see figure below), flow in the channel is relatively slow and confined by channel geometry. As water level rises, a pulse of along-channel velocity is seen during floods when water is just above flat level. Flows during the later part of the flood are similar in magnitude and direction in both channel and flat.

On the ebb, flows on the flat (red) and above-flat channel (green) are dominated by large-scale tidal forcing, with significant cross-channel flow. Flows in the channel below the flat (blue) are minimal. As water level approaches flat level, the presence of the channel once again becomes imporant as along-channel speeds increase. A pulse of along-channel velocity is observed within the channel when water drops to flat level.

Periods of elevated SSC are associated with pulses on both flood and ebb. Flood SSC is greater and more diffuse than the ebb; ebb SSC is generally low except for during pulses. Settling lag/scour lag effects likely are responsible for the non-pulse SSC variability on flood and ebb.

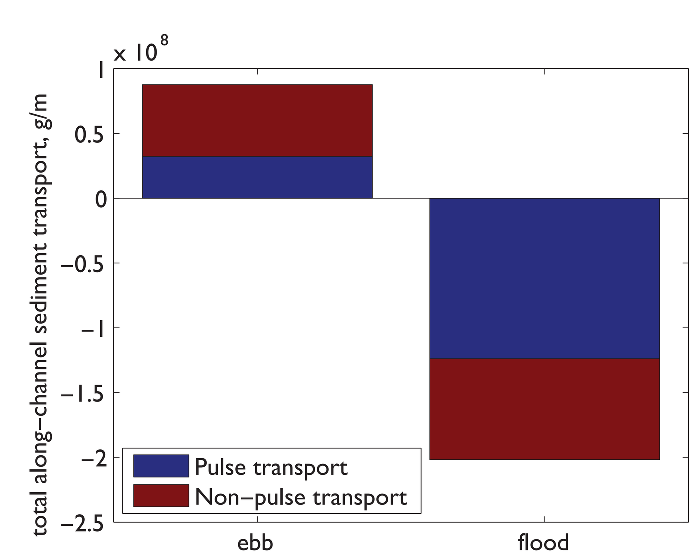


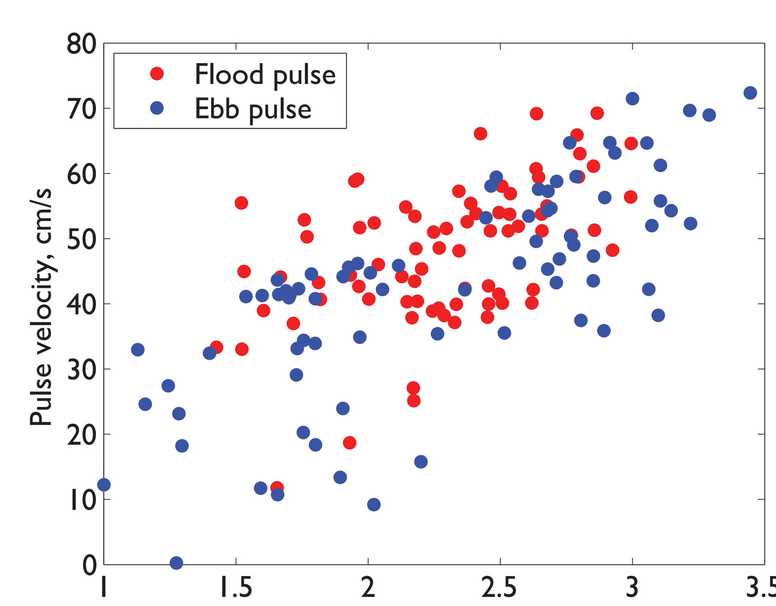
Importance of the tidal pulse

The tidal pulse is an essential feature of both water and sediment transport in Willapa Bay. Pulse intensity is a function of tidal range; larger tidal ranges produce greater velocity pulses and associated increased bottom stress.

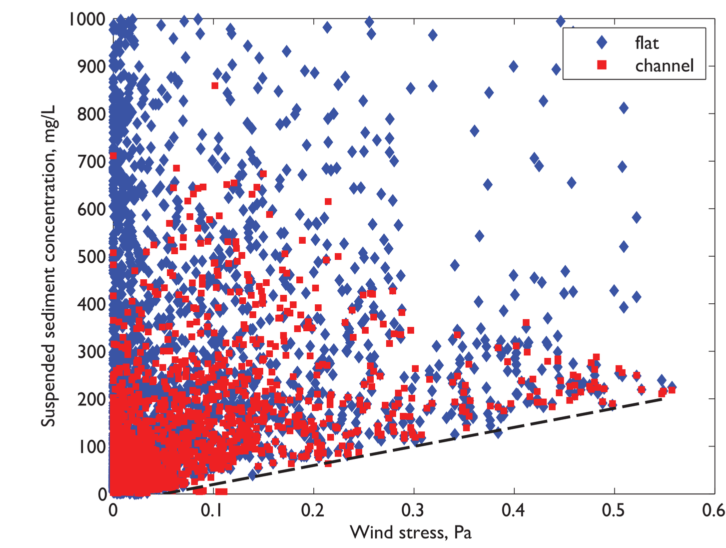
Flood-pulse sediment flux accounts for 63% of total upstream transport but just 18% of upstream flow time

Ebb-pulse sediment flux accounts for 38% of total upstream transport but just 18% of downstream flow time





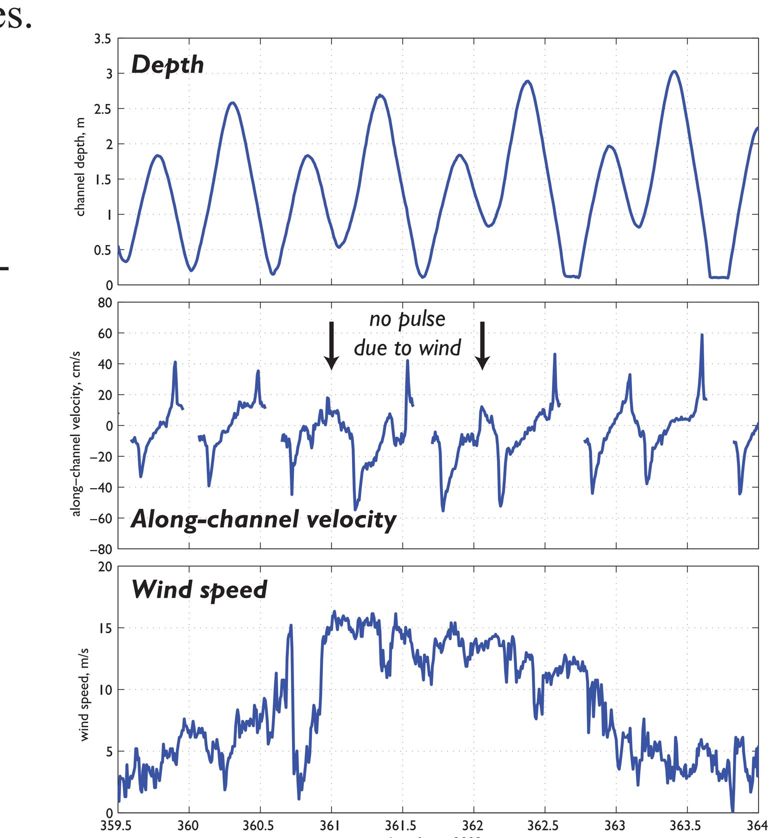
Rain on flats & wind

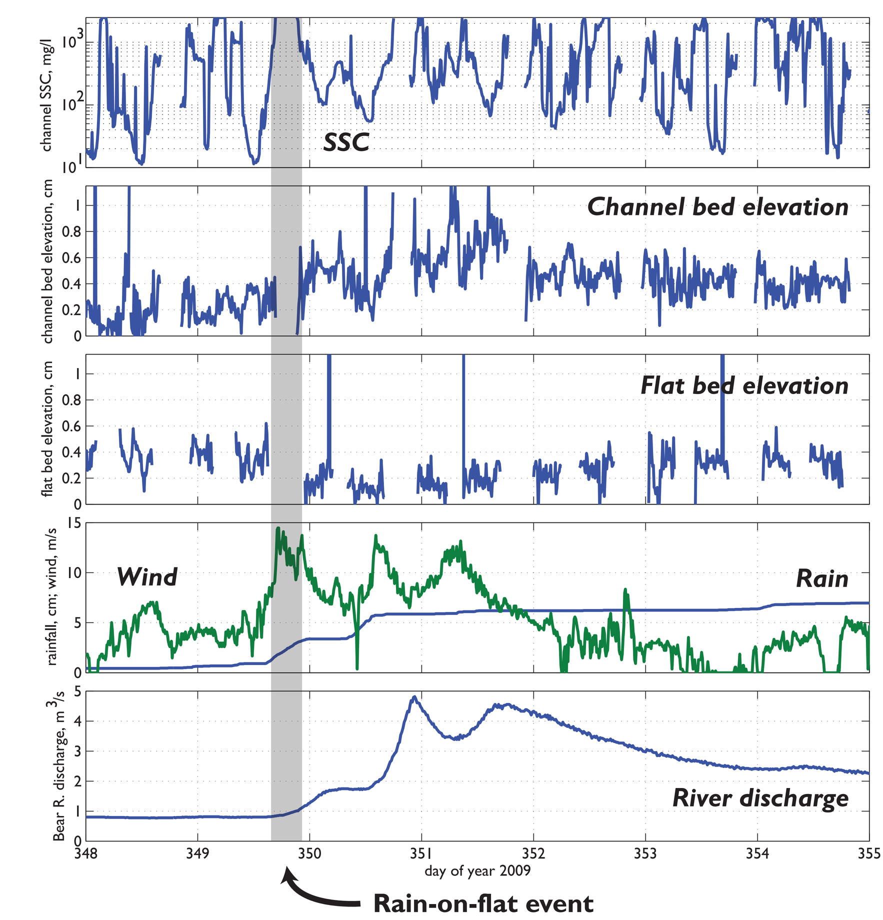


Wind stress is an effective indicator for minimum (i.e., background) SSC in both secondary channels and flats. Background SSC increases linearly with wind stress (left figure), indicating that wind, and by proxy, wind-generated waves, keeps sediment in suspension that otherwise would have settled out of the water column.

This relationship (dashed line) is valid primarily for concentrations above approximately 50 mg/L, indicating that baseline SSC below this range is a function more of the sedimentological and hydrodynamic conditions of the system and not external stresses.

Wind can also erase the ebb-tide pulse, particularly on lesser ebbs (figure at right). As a result, the channel becomes strongly flood-dominated during windy periods. This effect arises from the wind over-powering the local bathymetric gradient during low-water periods and reducing export of water via channels.

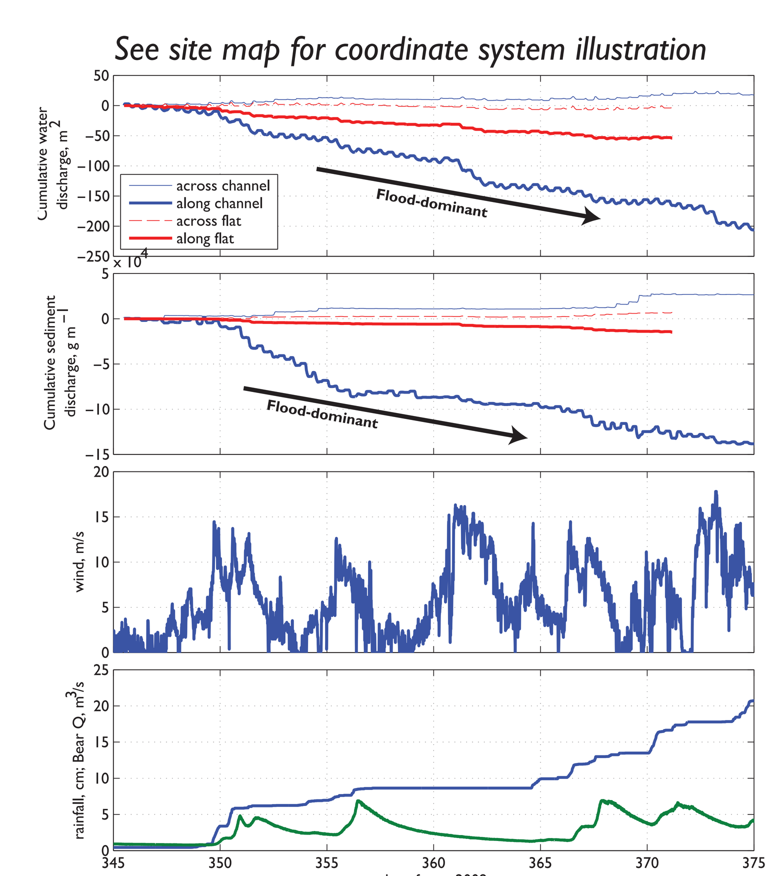




Rain falling directly on flats can erode flat sediment and deliver it to channels. In the figure at left, 2 cm of rain falls on exposed flats (grey box) during one tidal cycle. Elevated background SSC, a combination of both the wind and eroded sediment, is seen after the event. Channel bed elevation increased by approximately 8 mm during the two tidal cycles after the rain-on-flats event. Flat bed elevation decreased during this same time period. Dry storms do not produce similar bed-level changes.

Water & sediment budget

Both the secondary (C) and primary (Bear) channels are flood dominated in terms of their water and sediment discharges. No matter the weather conditions, river discharge, or season, channels import more water and sediment to the inner flat complex on floods than they export on ebbs. While the duration of ebbs is greater than floods, the intensity of flood velocities and greater SSC throughout the flood force the system to flood dominance.



Summary

The most important velocity and SSC signals (tidal pulses) in secondary channels are controlled by channel-flat morphology. Water and sediment discharge are flood-dominated, and these quantities must exit the flats via another flowpath. External forcing mechanisms, including wind and rain, modify the importance of the pulse and increase the flood dominance of the system.