The Role of Storm Resuspension in Contaminant Transport in Marine Environments

Patricia Wiberg
Department of Environmental Sciences
University of Virginia, P.O. Box 400123
Charlottesville, VA 22904-4123
phone: (804) 924-7546 fax: (804) 982-2137 email: pw3c@virginia.edu

Award #: N000149910030

LONG-TERM GOAL

My goal within the Harbor Processes program is to develop an integrated resuspension-sorption model for the marine environment and apply it to investigate the roles of resuspension, transport, and sorption in the redistribution and loss of sediment-associated contaminants during storm events.

OBJECTIVES

The objectives of this project for FY00 have been to 1) develop a shelf sediment resuspension model with dynamic flocculation; 2) to use the model to investigate the percentage of sediment in flocs under various flow conditions; 3) to calculate residence times of various classes of particles (particularly flocculation and disaggregated particles) in the water column during resuspension events and; 4) apply these results to understand the controls on desorption rates during resuspension events on the shelf.

APPROACH

My approach is to develop, test, and apply a physically based, coupled model of sediment suspension and sorption to investigate transport of sediment-associated contaminants in marine environments.

WORK COMPLETED

My student, Joel Carr, and I have developed a time-dependent resuspension model for fine-grained sediment that includes flocculation dynamics and cohesive bed effects. Joel Carr has devised a technique for tracking particle age in suspension, allowing us to determine the residence time of particles in each sediment size class and in flocs. We have run the model for a range of steady and unsteady flow conditions to understand the effect of model parameters, bed sediment conditions, and flow (waves and currents) on the population of flocs in the water column during resuspension events.

RESULTS

Time-dependent model for flocculation during resuspension

Sediment aggregates, whether formed by biological activity in the bed (e.g. fecal pellets) or flocculation of particles in the water column, are commonly present in sediment suspensions in marine environments. The presence of such aggregates forms the conceptual basis for sorption models based on radial diffusion through a porous sphere (e.g., Wu and Gschwend, 1986; Lick and Raupaka, 1996). Desorption rates predicted by these models vary strongly with particle size. In particular, desorption times are much longer for flocculated particles in suspension than for the single grains comprising the flocs when they are suspended in a disaggregated state. Thus it is important to know whether particles in suspension are incorporated into flocs or not, as well as the length of time that various particles, including flocs, remain in suspension. Of particular note is the fact that the residence time of particles in suspension is generally much shorter than the duration of a resuspension event because of cycling of particles between the water column and the bed.

The model we have developed is based on a formulation proposed by Paul Hill. It involves two coupled equations that partition suspended mass in each size class between a disaggregated and a flocculated state. Flocculation of disaggregated particles is determined by the concentration of mass in the disaggregated state, the estimated number of aggregates, and a flocculation rate based on the sum of shear induced scavenging of existing flocs and scavenging due to differential settling, as formulated by Hill and Nowell (1995). Disaggregation rate is not well known, and is treated as a model parameter. Effects of consolidation on erosion rates are included in the model by imposing a time-varying critical shear stress profile in the bed surface layers based on observations by Johansen et al. (1997). Sediment that is exchanged with the bed during transport conditions is maintained in an unconsolidated, high porosity layer at the bed surface with a relatively low critical shear stress (~0.08Pa). Predicted suspended sediment concentrations are in good agreement with field measurements of near-bed concentration at a site on the Eel shelf where floc settling-velocity distributions have also been measured (Sternberg et al, 1999).

The percentage of suspended particles incorporated into flocs varies with suspended sediment concentration, which, in turn, is a function of wave and current conditions (Figure 1). When waves and currents are small, little sediment is suspended and floc percentages are low. As wave and current conditions increase, suspended sediment concentrations increase and so do the floc percentages. The effect of increasingly consolidated (cohesive) beds is to limit the total volume of sediment in suspension and, consequently, suspended sediment concentrations.

Residence time of particles in suspension

Typical applications of shelf sediment transport models are concerned with the length of time that sediment is suspended but not the amount of time a particular sediment particle is in the water column. The latter becomes important, however, when considering sorption rates. Even under steady-state conditions, particles are exchanged between the water column and the bed -- the steady state is maintained by a balance between erosion and deposition rates. Sediment that is resuspended in a disaggregated form can be incorporated into flocs with high settling rates (~1 mm/s) compared to those of the individual constituent grains. As flocs settle down toward the bed, they can be disaggregated by high shears in the wave boundary layer or can deposit on the bed surface. Sediment deposited as flocs is then available to be reentrained either as individual grains or as a floc or floc fragment. Which of these is most likely depends on the shear stresses at the bed and the robustness of the floc. In marine environments, it is generally difficult to sample flocs formed in the water column because they rapidly disintegrate when disturbed. In this case we might expect that particles at the bed surface are largely entrained as single grains. In contrast, fecal pellets and other strongly bound aggregates are likely to be resuspended intact.

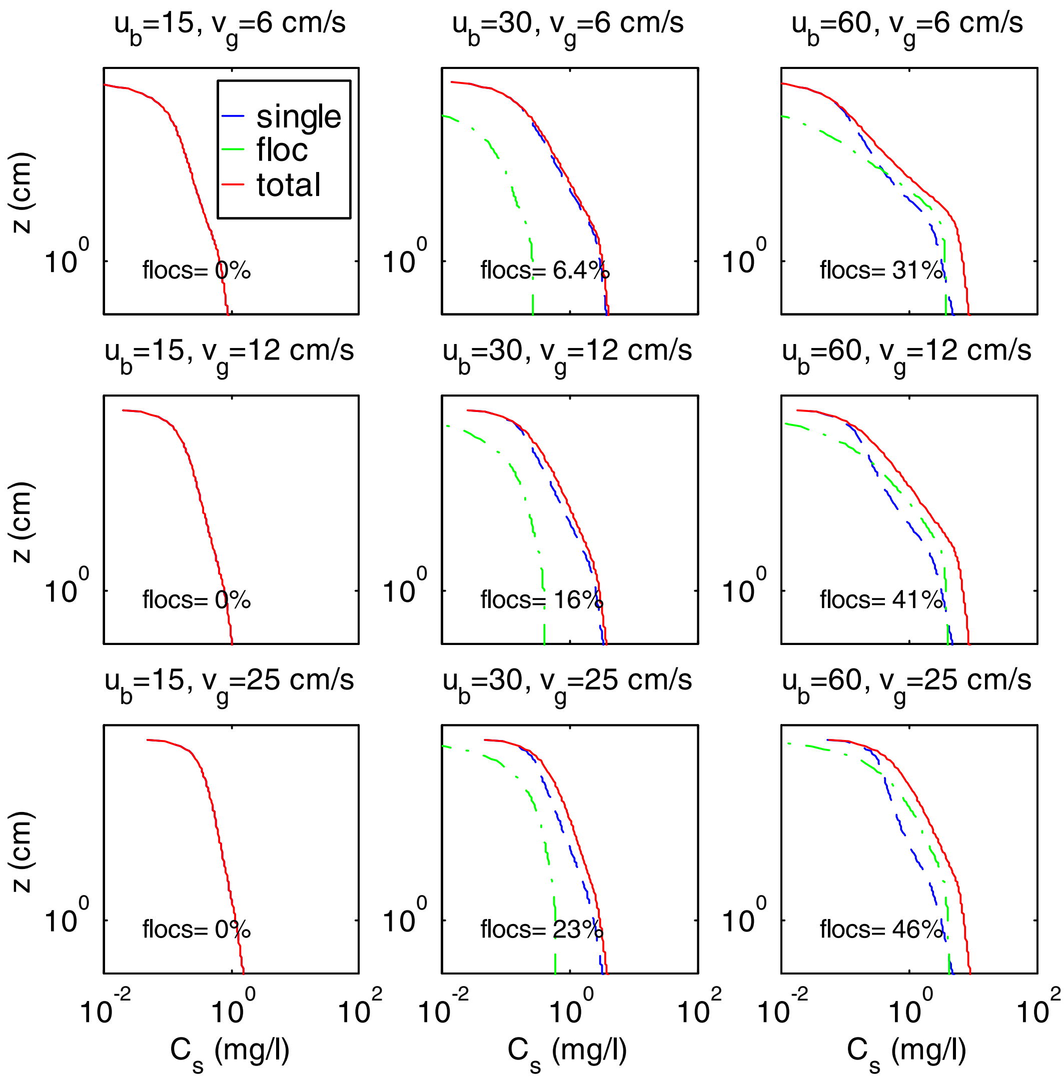

Figure 1. Calculated suspended sediment profiles, broken down by the contribution of single grains and flocs, for a range of wave (specified by near-bed wave orbital velocity, u_b) and current (specified by geostrophic velocity, v_g) conditions. The integrated floc percentage is indicated in each panel.

The formation of flocs in the water column significantly reduces the residence time of particles in the water column compared to a completely disaggregated suspension (Figure 2). Single grains that are incorporated into flocs following entrainment return to the seabed quickly thereafter owing to high floc settling rates. This rapid cycling of particles between the water column and the bed, and continual formation and breakup of flocs are likely to have a significant effect on sorption rates. In particular, sorption rates may depend critically on the total amount of time a particle spends suspended in a disaggregated state (the state favoring rapid desorption). The role of flocs in slowing sorption will be limited by cycles of floc formation and breakup that result in a floc population in which distinct particles are short-lived.

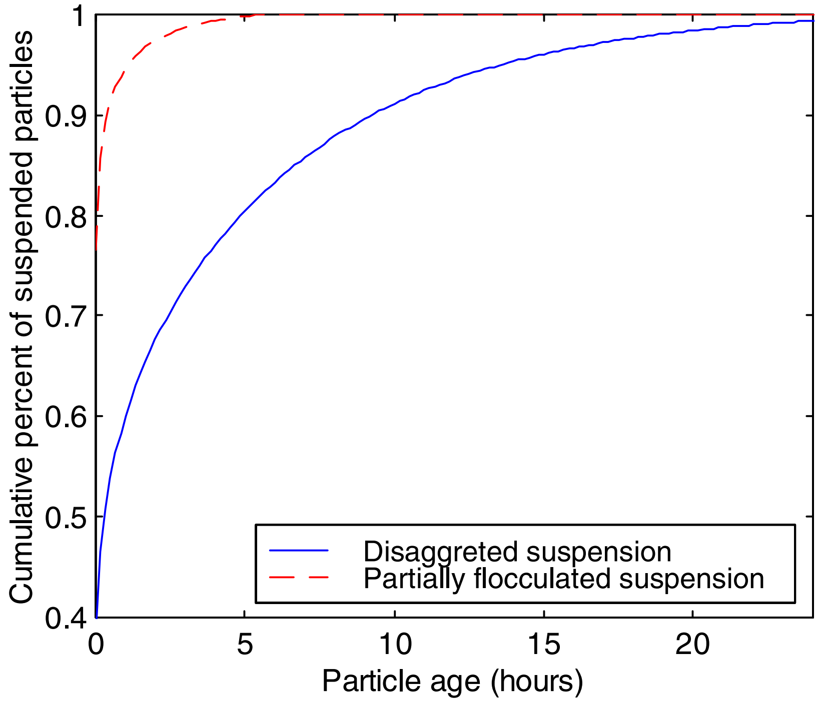

Figure 2. Cumulative distribution of the percentage of particles in suspension younger than the corresponding age. In a completely disaggregated suspension of 10μm particles, ~20% of suspended particles are >5 hrs old and ~10% are >10 hrs old. When flocculation is accounted for, the age distribution shifts toward younger particles (~90% < 1hr old), owing to rapid packaging and sinking of flocs.

IMPACT/APPLICATION

Our results suggest that floc dynamics play a critical role in controlling rates of sorption to and from fine-grained sediment resuspended from the seafloor of the continental shelf during storms. At the completion of this project next summer, we expect to be able to quantify this effect under a range of flow conditions.

RELATED PROJECTS

The shelf sediment transport model being used in this study was originally developed in the STRESS program and has been modified and tested during the STRATAFORM program. Related work in STRATAFORM includes adding time-dependent bed consolidation to the model, which is an important control on the concentrations of suspended sediment and investigating the depositional signature of flocculated suspensions.

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