MS698–3: Sediment transport processes in coastal environments
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Lecture 9: Suspended Sediment Transport II

- Types of suspended load equations.
- Sensitivity to Rouse parameter.
- Sensitivity to τ_{cr}.
- Sensitivity to sediment availability.

Class business

- This Thursday: Voulgaris and Collins paper.
- Homeworks; grades under 95%: can correct problems and return for 1/2 credit.
- Rescheduling next Thursday.
- Guest lecturer, April 10, Dave Fugate.

Materials used

- Rijn, Leo C. van; **Principles of sediment transport in rivers, estuaries, and coastal seas**, Section 3: Fluvial and sediment properties. Aqua Publications, 1993.
- Raudkivi, A.J.; **Loose Boundary Hydraulics**, Chapter 2: Sediment Properties. Third Edition; Pergamon Press, Oxford, 538pp.

Types of suspended load equations

Relationships for suspended sediment concentrations can be divided into three types; *diffusion models, energy models,* and *stochastic models*. In the last lecture we discussed a diffusion model, where downward settling of sediment was countered by upward diffusion against the vertical gradient in concentration. These use a conservation of mass argument. Energetics models proceed on the assumption that the suspended particles extract energy from the flow, and that transport rates can be estimated through assumptions about the energy created within the flow. They tend to follow the approach of Bagnold. We'll talk more about energetics models when we cover the paper by Elgar et al.

Another distinction is whether the transport or suspended sediment concentrations can be estimated analytically or numerically. The simplified eddy viscosities that led to the concentration profiles derived in the notes from lecture 8 lend themselves to analytical solution. Several assumptions were needed for these, however, including steady, uniform conditions, constant settling velocity, near-bed location (for linear eddy viscosity), or whole-water depth (for parabolic eddy viscosity and Rouse Profile). Also embedded in the solutions were the assumption that settling velocity does not change with time or location, that concentrations are low ($c_s << 1$), that grain $-$ grain interactions can be neglected, and that the eddy viscosity depends on shear velocity (u_*) and a length scale. This does not allow changes in turbulent mixing due to other effects - notably it neglects stratification by either temperature, salinity, or suspended sediments to dampen or enhance turbulent mixing.

The inclusion of any of these usually results in a problem that can not be solved analytically. Numerical models provide a way through finite difference and finite element methods to solve concentration profiles for an arbitrary eddy viscosity. This is how the model by Wiberg and Smith (1983); Wiberg et al. (1994) (and I think McLean, 1992) proceed- by solving the suspended sediment concentration profile using finite differences. In contrast, the methods of Glenn/Grant/Madsen/Styles rely on finding analytical solutions that include effects of stratification and non-steady boundary layers.

Sensitivity of suspended profiles

Though it is an approximation, the Rouse profile provides a useful conceptualization of suspended sediment sediment concentrations near the bed.

$$\frac{c_s}{c_a} = \left[\frac{z\,(h - z_a)}{z_a\,(h - z)}\right]^{-P/\alpha}. \tag{1}$$

where P is the *Rouse Parameter* ($P = w_s/\kappa u_*$), c_a is the *reference concentration* at some height z_a, h is water depth, u_* is shear velocity, w_s is settling velocity, κ is von Karman's constant, and c_s is suspended sediment concentration at the height z. The parameter, α relates the eddy viscosity for momentum (K_m) to the eddy diffusivity for sediment ($K_s = \alpha K_m$); for a parabolic eddy viscosity as is assumed in deriving the Rouse profile, $K_m = \kappa u_* z\,(1 - z/h)$.

The higher the Rouse parameter, the steeper will be the suspended sediment profile ($\partial c_s/\partial z$), whereas for low Rouse parameter suspensions- sediment is distributed fairly uniformly through the flow. van Rijn summarizes as:

$P > 5$	near bed suspensions; $h/10$
$5 > P > 2$	suspension through bottom half of boundary layer;
$2 > P > 1$	suspension throughout boundary layer;
$1 > P$	uniform suspension throughout boundary layer;

The Rouse parameter determines the shape of the suspended sediment profile.

Shape is not everything - however. The reference concentration c_a determines the *magnitude* of sediment in suspension. The suspended sediment concentration c_s increases linearly with increases in c_a. Suspended sediment calculations are therefore very sensitive to the method used to determine c_a and z_a.

Smith and McLean (1977) proposed

$$c_a = \frac{c_b \gamma_0 S}{1 + \gamma_0 S}, \tag{2}$$

where γ_0 is a constant ($\gamma_0 = 0.001 - -0.005$ can be found in the literature). They use a reference height, z_a equal to the saltation height above the bed. The reference concentration depends on the concentration of sediment on the bed c_b and on the excess shear stress, $S = (\tau_{b,sf} - \tau_{cr})/\tau_{cr}$. Equation 2 differs from some formulations in that, as S increases, $c_a \to c_b$. In general, all other things equal, coarser sediment will have lower reference concentrations than fine-grained sediment. The formulation does bring a dependence on critical shear stress into suspended sediment problems.

Multiple Grain Size Distributions

Thus far we really have not treated the problem of how to predict suspended sediment concentrations on sediment beds that contain a range of grain sizes. At low concentrations it is valid to assume that sediments do not interact. In such situations, the continuous distribution of sediment sizes can be partitioned into a finite number of size classes. Relationships like equations 1 and 2 can be solved independently for each grain size. The Rouse parameter for each size class will depend on that sediment's settling velocity, $P_j = w_{s,j}/\kappa u_*$, where $w_{s,j}$ is the settling velocity of size class j. The reference concentration needs to take into account the concentration of each grain size on the bed and the critical shear stress of that size class, $c_{b,j} = c_b f_j$; where f_j is the volumetric fraction of size class j.

Fine grained portions of the size distribution would therefore be spread more uniformly throughout the boundary layer, because they'd have lower Rouse parameters. The actual contribution of each size class toward total suspended load would also depend on the availability of that size for suspension.

References

McLean, S. R. (1992). On the calculations of suspended load for non-cohesive sediments. *Journal of Geophysical Research*, 97(C4):5759–5770.

Smith, J. D. and McLean, S. R. (1977). Spatially averaged flow over a wavy surface. *Journal of Geophysical Research*, 82(12):1735–1746.

Wiberg, P. L., Drake, D. E., and Cacchione, D. A. (1994). Sediment resuspension and bed armoring during high bottom stress events on the northern California continental shelf: measurements and predictions. *Continental Shelf Research*, 14(10/11):1191–1219.

Wiberg, P. L. and Smith, J. D. (1983). A comparison of field data and theoretical models for wave-current interactions at the bed on the continental shelf. *Continental Shelf Research*, 2:147–162.