Lecture10-Bedload_Suspended_load

November 13, 2025

1 Lecture10 - Bedload and suspended load sediment transport

Learning Objectives: bedload transport, suspended load transport, suspended sediment concentration vs. total suspended solids, shear stress impacting bed load transport (Shields parameter), turbulent diffusive forces impacting suspended load transport (Rouse number)

Before class:

- Please fill out the When2Meet poll to move the final exam to Friday, December 5, 2025: https://www.when2meet.com/?33427311-MBnmm

After class:

- Read about Erosion on the East coast and think about how a softer shoreline can be a natural approach to reduce erosion and flooding.
- Watch video on Why River Move and think about the concepts of bed load vs suspended load transport.

Reference:

- classnote taken from CEE262G Sediment Transport Physics and Modeling by Oliver Fringer, Stanford University
- B.S. 6.4 - 6.6
- optional: Julien Ch. 9, 10

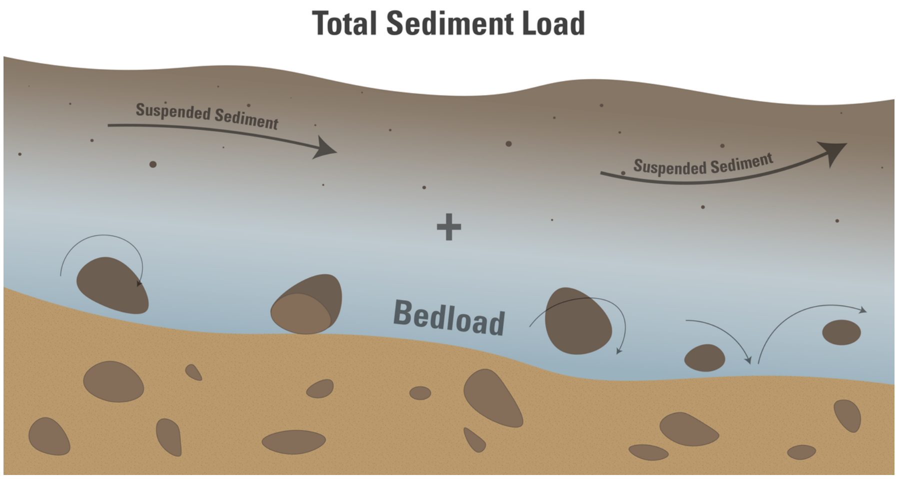
1.1 1. Bed-load vs. suspended-load

1.1.1 1). Definition

[Airborn picture by Larissa Graham during high river discharge conditions after tropical storm Irene.]

- **Bed load transport**: the transport of sediment particles in a thin layer close to the bed. The particles are in more or less continuous contact with the bed. Bed load transport at low shear stresses is shown in Fig. 6.6a. At higher shear stresses, an entire layer of sediment is moving on a plane bed (Fig. 6.6b). This is called sheet flow and is often considered bed load, since grain-grain interactions play a role.
- **Suspended load transport**: the transport of particles suspended in the water without any contact with the bed. The particles are supported by turbulent diffusive forces. Figure 6.6c shows this transport mode.

The sum of bed load and suspended load is called **total load**.



source: https://www.usgs.gov/media/images/total-sediment-load

Discussion: Watch four video on Bedload Transport on the Kootenai River near Bonners Ferry, ID and discuss 1) what behaviors of sediment motion do you observe? 2) What may contribute to the different motions?

Concentration by mass, typically in mg L^{-1} :

$$C = C_m = \frac{\text{Mass of dry sediment}}{\text{Volume of sediment-water mixture}} = \frac{m_s}{V_s + V_w}$$

$$= \frac{\rho_s V_s}{V_t}$$

Concentration by volume, typically in mL L^{-1} (ppt):

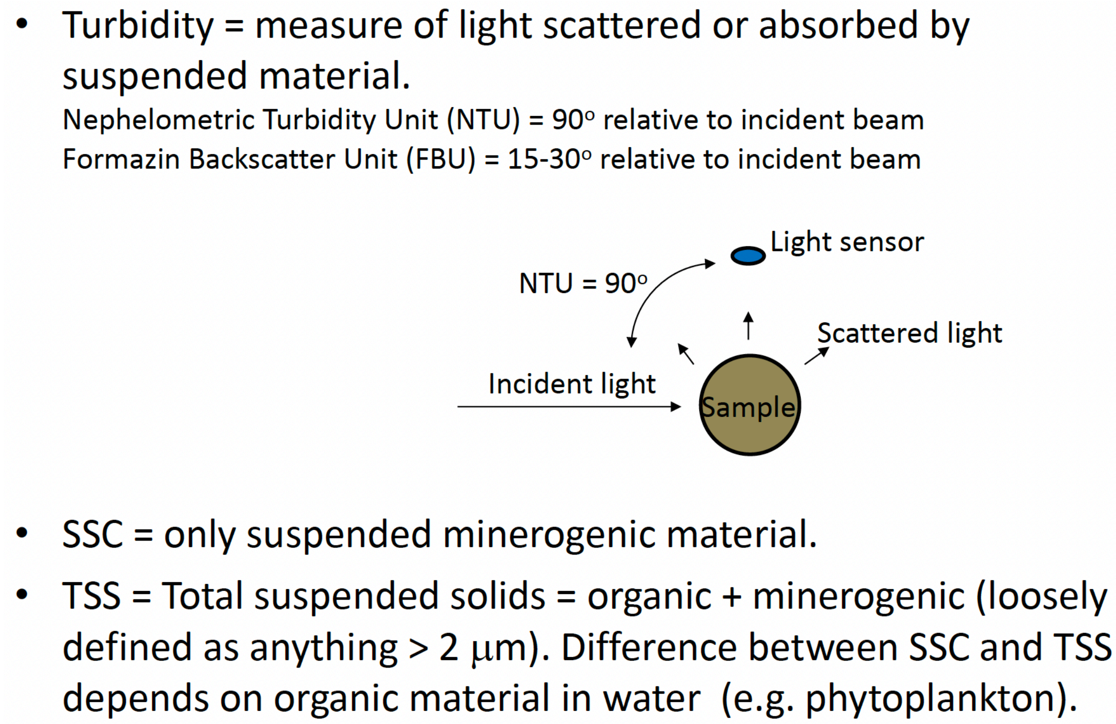
$$C_v = \frac{\text{Volume of dry sediment}}{\text{Volume of sediment-water mixture}} = \frac{V_s}{V_t} = \frac{C}{\rho}$$

eg: $C_m = 100$ mg L^{-1}, assume quartz with $\rho_s = 2650$ kg

$$C_v = \frac{C_m}{\rho_s} = \frac{100 \text{ mg L}^{-1}}{2650 \text{ mg L}^{-1}} = 0.037 \text{ L L}^{-1} = 37 \text{ mL L}^{-}$$

a. Suspended Sediment Concentration (SSC)

b. Total Suspended Solids (TSS) vs Turbidity vs Suspended Sediment Concentration (SSC)



1.1.2 2). Relation to shear stress (Shields parameter)

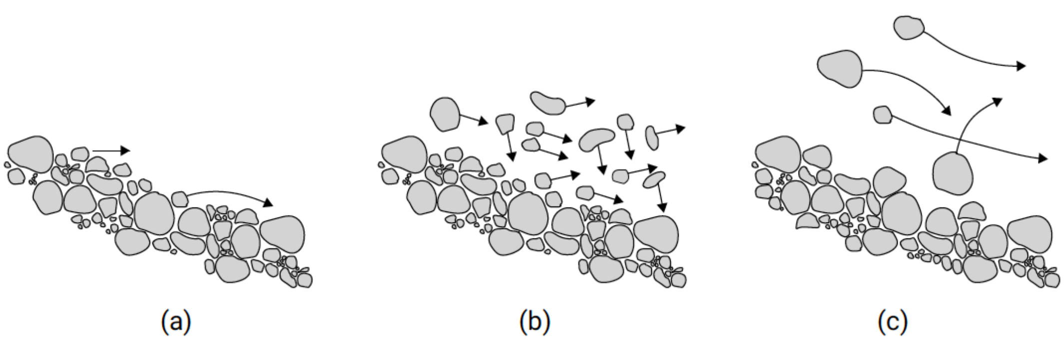


Figure 6.6: Different modes of sediment transport:(a) bed load at small shear stresses; (b) sheet flow (often considered as bed load at higher shear stresses); (c) suspended load.

a. Bed load transport at low shear stresses **As soon as the bed shear stress exceeds a critical value** (Shields parameter between 0.03 and 0.06), sediment particles start **rolling or sliding** over the bed. If the bed shear stress increases further, the sediment particles move across the bed by making small **jumps**, which are called **saltations**. As long as the jump lengths of the saltations are limited to, say, a few times the particle diameter, this type of motion is considered part of the bed load transport. Close to initiation of motion, the bed remains flat, but for somewhat larger bed shear stresses the bed load occurs primarily via the migration of small-scale bed forms. When the jumps become larger, the particles lose contact with the bottom and become suspended.

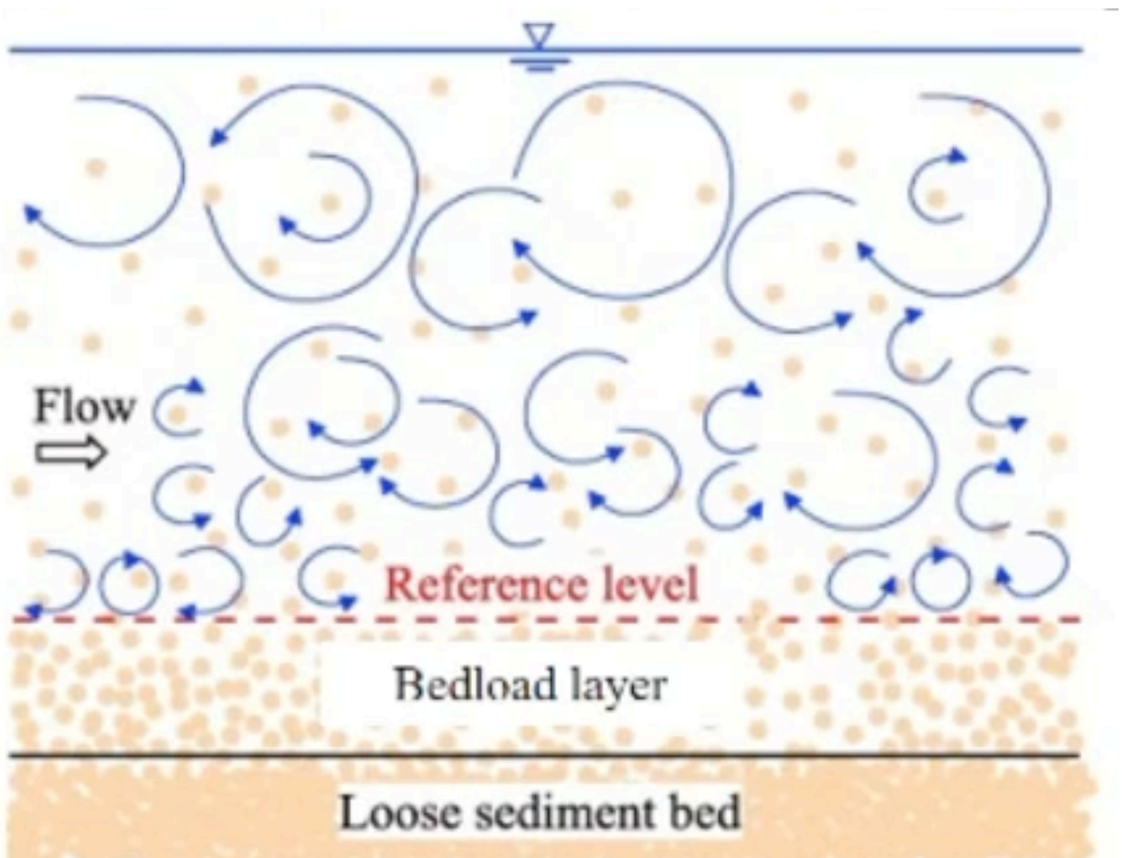
See videos about bedload transport at very low shear stress here and slightly higher shear stress here.

b. Sheet flow transport **At higher shear stresses** (Shields parameters higher than about 0.8–1.0), the particles closer to the bed start **moving in multiple layers**, instead of rolling and jumping in a single layer. **Intergranular forces and grain-water interactions are important**. Sheet flow transport can be considered bed load transport at high shear stresses.

See videos about sheet flow here and here.

c. Suspended load transport Above the bed load layer or sheet flow layer, sediment may be in suspension. Particles in suspension do not immediately return to the bed under the influence of their settling velocity, but are kept in suspension by **fluid turbulence**. Suspended particles present in a certain vertical plane can be assumed to **move horizontally** across the plane with the water particles and thus at the same speed as the water particles. The particles are suspended in the flow at relatively low concentrations, so that **intergranular forces are not important**.

1.1.3 3). Bedload and suspended sediment transport modeling



source: https://www.youtube.com/watch?v=E7XCxHZT43s

- **Bed load transport**
  - is almost exclusively determined by the **bed shear stress** acting on the sediment particles that roll, slide and jump along the bed.
  - Hence, bed load formulas are often expressed in terms of bed shear stress due to currents and waves, often supplemented with a criterion that describes initiation of motion.

  - In practical applications, bed load transport formulas are assumed to predict sheet flow transport rates when used for large Shields parameters.
- **Suspended load transport**
  - takes place above the bed load layer.
  - The suspended sediment flux at a certain height above the bed is often modelled as the product of the sediment concentration C and the horizontal velocity u of the water that is transporting the sediment.
  - The suspended sediment transport can be computed by integrating the suspended sediment flux uC from the top of the bed load layer to the water level.
  - In order to compute the sediment concentration C, it is generally assumed that **turbulent diffusive forces** are responsible for transporting the sediment upwards in the water column, against the downward movement with the fall velocity.

a. Bed load transport modeling Recall from last class, the **Shields parameter** θ: $> \theta = \frac{\tau_b}{(\rho_s - \rho_0) g d_s}$, $>$ is a measure of the forcing on the sediment grains (drag and lift) relative to the resisting force.

Many approaches for bed load transport are based on - 1). the shear stress on the grains and - 2). the size of grains.

In such formulas, the sediment transport is a function of a Shields parameter θ (true shear stress divided by resisting force). **Large Shields number corresponds to large bedload transport.**

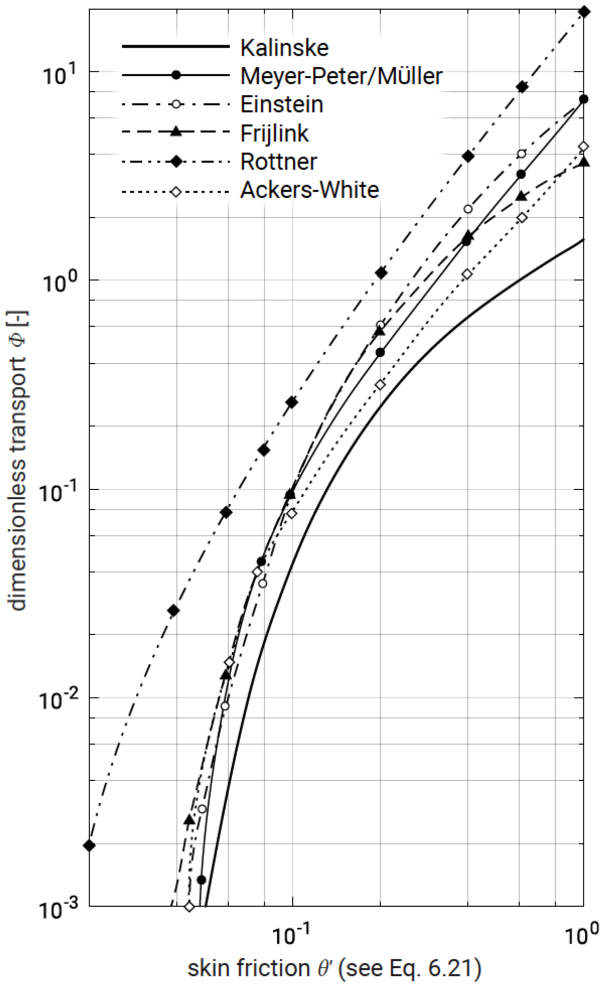


Figure 6.11: Comparison of various bed-load transport formulas developed for rivers. On the y-axis is the dimensionless transport Φ in the case of steady flow (cf. Eq. 6.19), on the x-axis a Shields parameter based on skin friction (cf. Eq. 6.21). Note that $\Delta = (\rho_s - \rho)/\rho$ and the subscript 0 to the shear stress refers to the bed shear stress. Adapted from Breusers (1983).

In Fig. 6.11 a comparison is made between various bed load transport formulas developed for rivers. Although the formulas seem quite different at first glance, Fig. 6.11 demonstrates that they all represent dimensionless transport as a function of a **Shields parameter**. Further note that the predicted transport rates for a certain value of the Shields parameter vary by up to an order of magnitude. This is (unfortunately) quite common for sediment transport predictions and underlines the fact that calibration of the transport formulas for the locations and conditions under consideration is crucial.

Watch video on Modeling Bedload Transport - Forecasting of Port Sedimentation in a 6-Year Period. The model uses the Shields parameter-based bedload transport formula.

b. Suspended load transport modeling When the actual bed shear stress is (much) larger than the critical bed shear stress, the particles will be lifted from the bed. If this lift is beyond a certain level, then the turbulent upward forces may be larger than the submerged weight of the particles. In that case, the particles go into suspension, which means that they lose contact with the bottom for some time.

In order to obtain the sediment concentration, a mass balance equation for the sediment needs to be solved. > $\frac{\partial C}{\partial t}+\frac{\partial (Cu)}{\partial x}+\frac{\partial [(w-w_s)C]}{\partial z} = \frac{\partial}{\partial x}(\nu_{s,x}\frac{\partial C}{\partial x})+\frac{\partial}{\partial z}(\nu_{s,z}\frac{\partial C}{\partial z})$, > where C is the mass concentration of sediment and $\nu_{s,x}$ and $\nu_{s,z}$ are the sediment diffusivity coefficients in x and z direction, respectively, in unit of m^2/s.

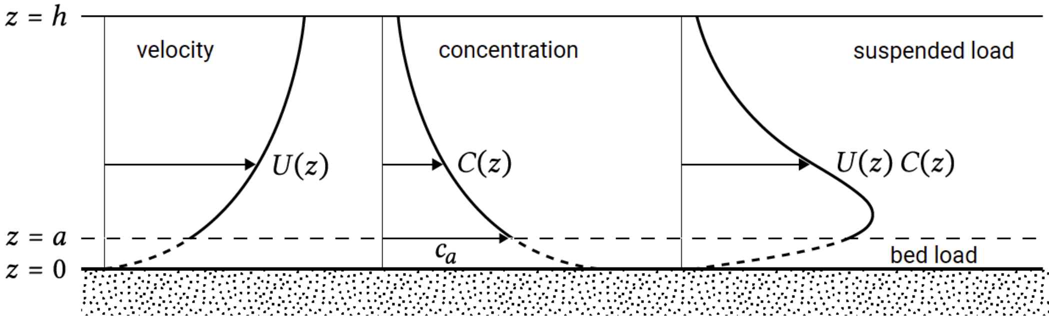
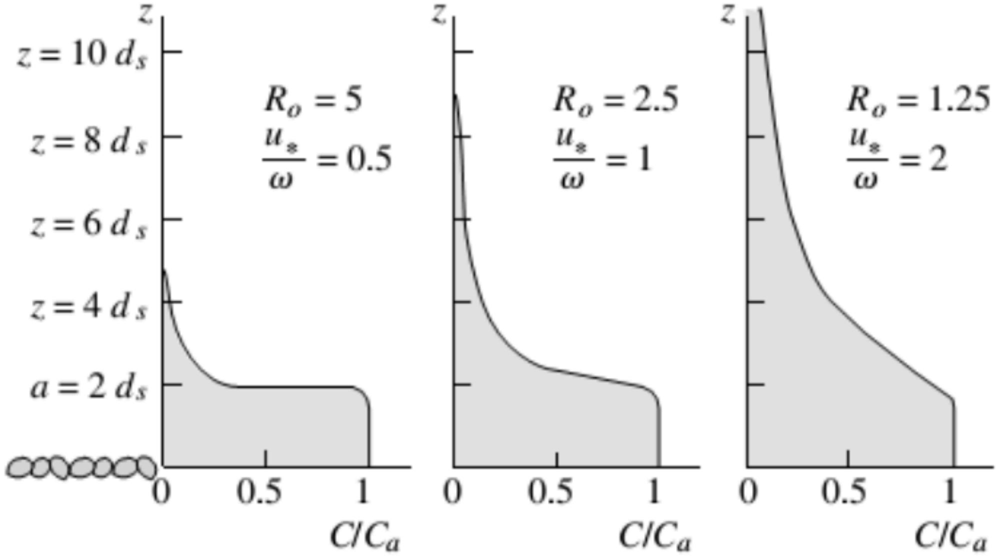


Figure 6.10: Bed load transport takes place in a thin bed load layer close to the bed (between $z = 0$ and $z = a$). The suspended load transport takes place in the upper layer. Note that the z-coordinate is still vertically upward but now the bed is $z = 0$ and the mean water level at $z = h$.

- The above equation suggests: change in sediment concentration + net import of sediment by the horizontal fluid velocity + net upward transport of sediment by the combined effect of vertical fluid velocity and fall velocity = net downward transport of sediment due to fluid turbulence
- Turbulent exchange makes sure that a sediment-laden fluid parcel goes **upward** to a level with a lower sediment concentration.
- The vertical distribution of suspended sediment concentration depends on the Rouse number (falling velocity divided by lifting velocity by turbulence) and the suspended sediment concentration level right above the bed (**"the erosion": $z = a$, $C(z) = C_a$**): >$Ro = \frac{w_s}{\kappa u_*}$, > where κ is the Von Karman constant = 0.4, u_* is the shear velocity, w_s is the fall/settling velocity of the sediment.
- The suspended sediment further drifts along with the background current/wave.



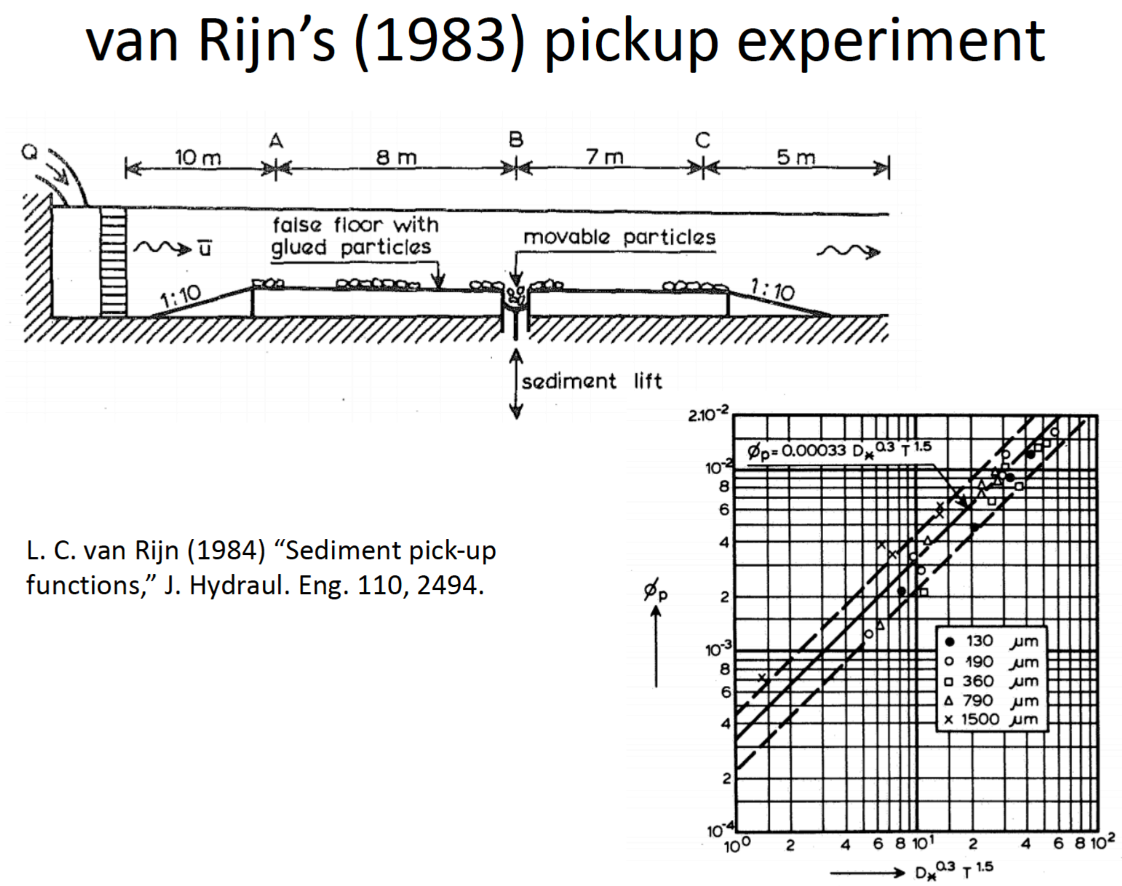
source: Julien Figure 10.8

Discussion: Watch video on River flows into a lake/ocean - how sediments are deposited and discuss 1) From the equation, what factors control the magnitude of the Rouse number? 2) From the figure above, does a large Rouse number correspond to bedload dominance or suspended-load dominance? 3) Are the conclusions above consistent with what you see in the video?

c. Erosion - bedload to suspended load Now let's summarize what we have learned so far:

- Shields number (near-bed stress vs. resistance force - function of sediment specific density and size) to determine if the sediments would move (recall the Shields curve in Lecture09).
- Shields number to determine bedload transport (large Shields number -> large bedload transport).
- Rouse number (fall speed vs. lifting speed by turbulence) and the **erosion** (suspended sediment concentration right above the bed) to infer the suspended sediment concentration as a function of depth above the bed (large Rouse number -> high concentration at depths well above the bed).

In order to determine the **erosion**, van Rijn (1983) conducted a series of lab experiments that connected erosion (y-axis in the figure below) with the product of bed shear stress and particle diameter (x-axis in the figure below).



1.1.4 4). Sediment Resuspension and Transport by Internal Solitary Waves (Boegman and Stastna, 2018)

Watch videos on modeled internal wave motions and wave-induced nepheloid layer

> Nepheloid layer: from the Greek "nephos," or "cloud," a layer of water in the deeper portion of the water column containing significant suspended sediment

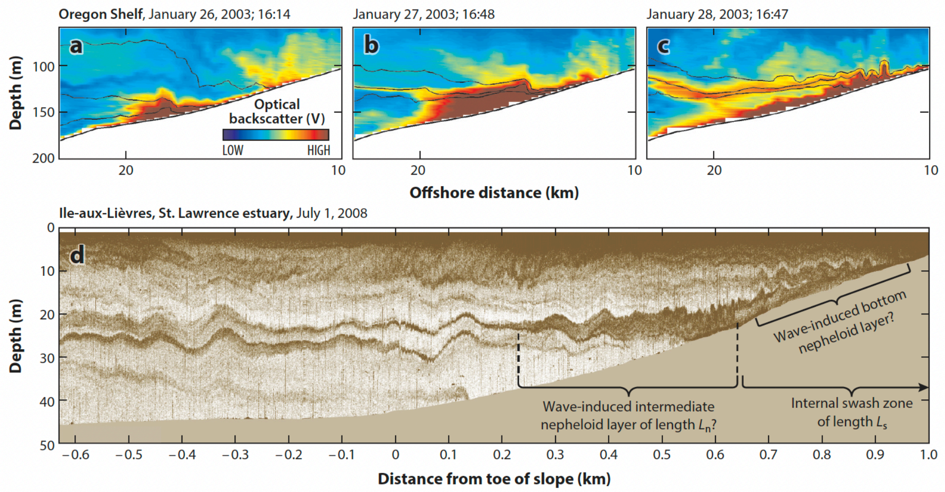
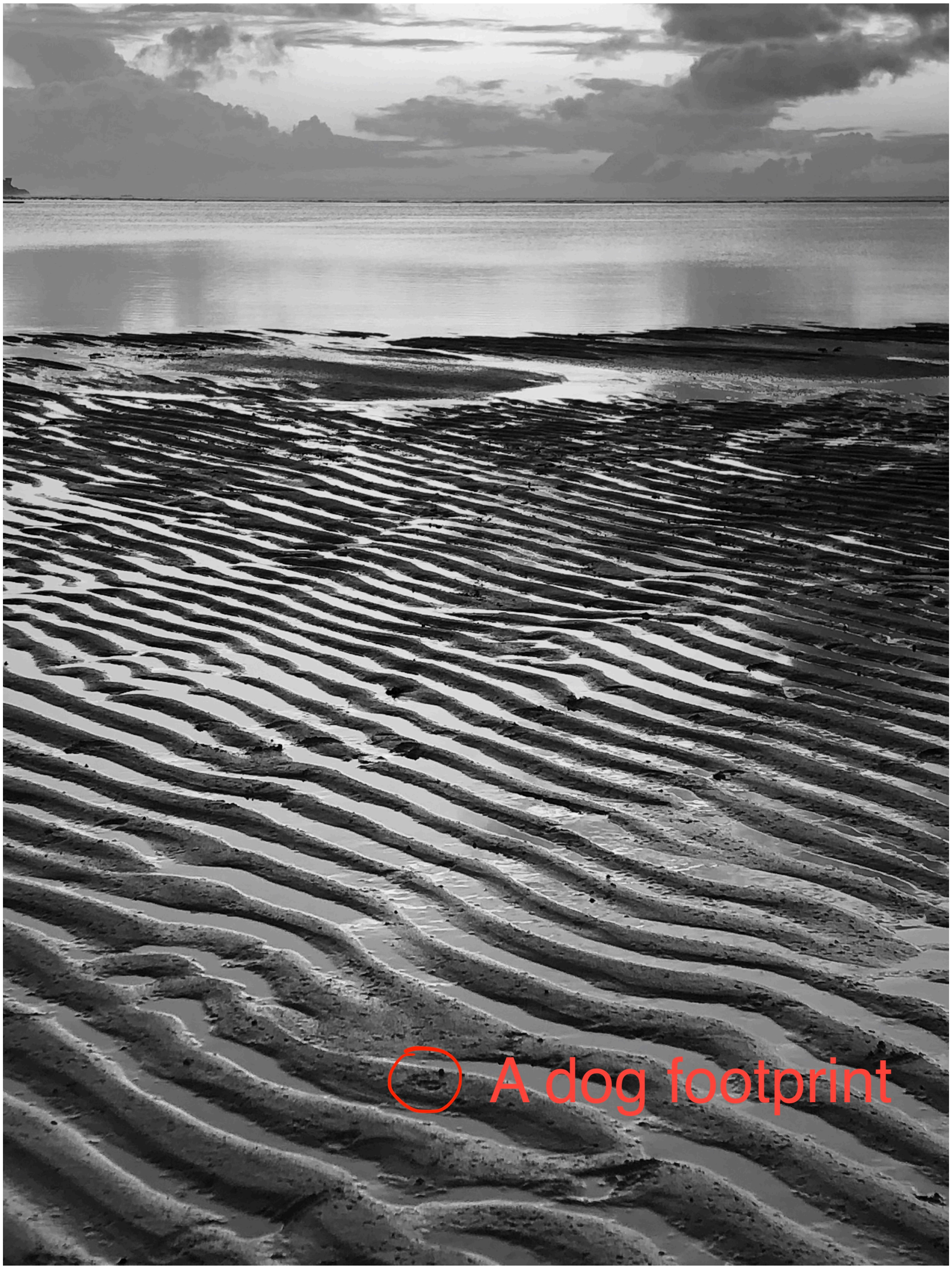


Figure 3

Shoaling internal solitary wave (ISW) fronts and resultant nepheloid layers. (*a–c*) Cross-shelf structure of shoaling fronts and ISW packets on three successive days in January 2003 on the Oregon shelf. Isopycnals (*black lines*) are spaced at 0.5 kg/m, and the background color denotes optical backscatter. The upper 50 m of the water column has been omitted. (*d*) Echogram suggesting sediment transport by shoaling ISWs along the flank of Ile-aux-Lièvres, an island in the St. Lawrence River estuary. Both the bottom and intermediate nepheloid layers are indicated as well as the remnant of a shoaling ISW (see **Figure 4**). Panels *a–c* adapted from Moum et al. (2007), with permission from the American Meteorological Society, and panel *d* adapted from Bourgault et al. (2014), with permission from Elsevier.

1.2 2. Bedform formation and migration

The combination of bedform transport, erosion, and suspended sediment transport due to currents or waves causes the formation of different bedforms (“ripples” vs. “dunes”), which can migrate over time.

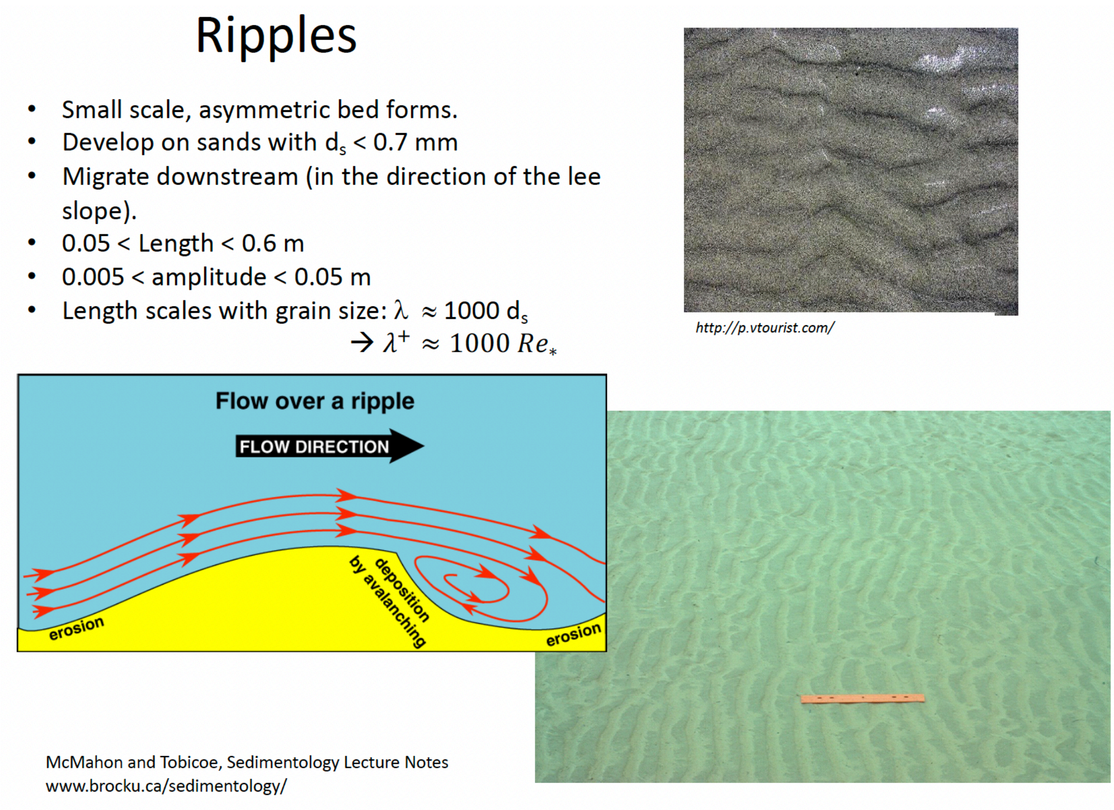


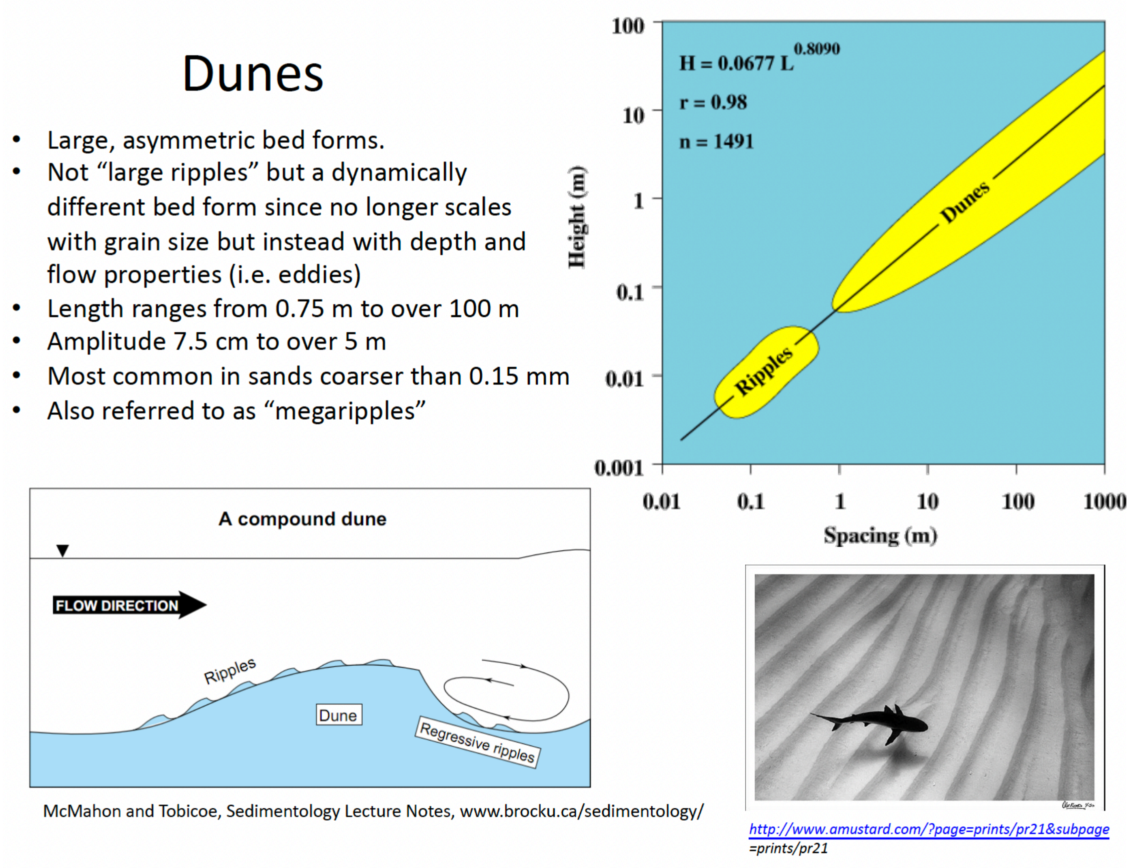
[ripples at a beach in Guam, 2022, by Shuwen Tan]

[dunes at Limantour Beach, CA, by Oliver Fringer]

[A lone Caribbean reef shark (Carcharhinus perezi) cruises over sand dunes. Walkers Cay, Northern Bahama Islands, Republic of Bahamas. by Alex Mustard]

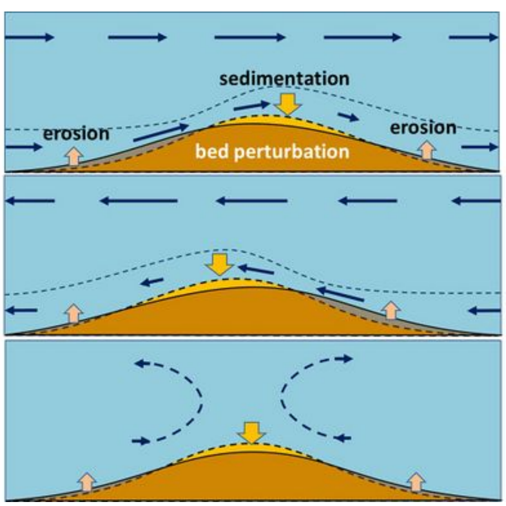
1.2.1 1). Ripples and dunes





1.2.2 2). Bedform formation

Ripple formation by waves, by Oliver Fringer.



1.2.3 3). Bedform migration

1.3 Reference

Boegman, L., & Stastna, M. (2019). Sediment resuspension and transport by internal solitary waves. Annual review of fluid mechanics, 51(1), 129-154.

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