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Calculations of Buoyancy and Particle Sizes in a Hyperpycnal Plume Turbidity Current

Simple turbidity current theory can be used as a first-order assessment of whether southern California hyperpycnal plumes are capable of transporting sand offshore and onto the continental shelf. First, a simple definition for river discharge buoyancy (g') is used:

$$g' = g \frac{\rho_o - \rho_r}{\rho_o} \qquad [1]$$

where g is the gravitational constant, ρ_r is the river discharge density, and ρ_o is the ocean water density. Discharge is hypopycnal when positively buoyant ($g' > 0$) and hyperpycnal when negatively buoyant ($g' < 0$).

The river discharge density (ρ_r) will be a function of the concentrations and densities of river water and suspended sediment (Mulder and Syvitski, 1995):

$$\rho_r = \rho_s C_{Vs} + \rho_w C_{Vw} \qquad [2]$$

where ρ_s and ρ_w are the densities of the solid sediment particles (~2650 kg/m^3) and the river water (~1000 kg/m^3), and C_{Vs} and C_{Vw} are the volumetric concentrations of sediment and water (m^3 m^{-3}), respectively, which sum to unity. Note that C_{Vs} can be calculated from the commonly reported mass concentration of suspended sediment (C_{ss}; kg/m^3, equivalent to g/L for fresh water) using:

$$C_{Vs} = \frac{C_{ss}}{\rho_s} \qquad [3]$$

Thus, for typical southern California seawater densities of 1025 kg/m^3 and fresh water without sediment (ρ_r = 1000 kg/m^3), the g' will be 0.24 m/s^2. The river buoyancy (g') will become zero at approximately 40 g/L of sediment. River discharges with sediment concentrations greater than 40 g/L will theoretically be hyperpycnal. The maximum suspended sediment concentration measured in the southern California rivers of 150 g/L would produce ρ_r of 1093 kg/m^3 and g' of -0.66 m/s^2.

Assuming steady-state conditions in one-dimension, hyperpycnal turbidity currents can be described by a modified Chezy relationship, which equates the downward buoyancy forcing with the friction along the bed and on the upper current interface (Komar, 1977). Using this simple model and assuming the frictional velocity (U^*) is equal to the settling velocity of the largest grain size in suspension ($w_{\max}$; assumed to be the 10th percentile grain size), Reynolds (1987) described the relationship between $w_{\max}$ and environmental variables to be:

$$w_{\max} = \sqrt{\frac{-g'\,h\sin\beta}{1+\alpha}} \qquad [4]$$

where g' is the buoyancy anomaly (equation 1), h is the hyperpycnal plume height, β is the bed slope, and α is the ratio of upper and lower boundary stresses (assumed to be 0.4). Equation 4 is similar to autosuspension equations (e.g., Pantin, 1979; Stacey and Bowen, 1988), except that autosuspension grain sizes are responsible for negative buoyancies, whereas equation 4 assumes that adequate fine sediment exists for autosuspension. Since the majority of southern California river sediment is clay and silt (modal grain sizes ~10-20 µm; Brownlie and Taylor, 1981; Mertes and Warrick, 2001), this autosuspension assumption is considered valid.

Thus, for a hyperpycnal river plume of 50 g/L, g' is -0.06 m s^{-2}. Since river flood stages range between 2−10 m (Warrick, 2002), a conservative value for h of 2 m is assumed. Slopes of the inner shelf (to the 30 m isobath) immediately off southern California rivers are approximately 0.15–0.5°, while the near inner shelf (to the 10 m isobath) are 0.6–0.8°. Using a conservative slope of 0.15°, w_{max} is computed to be 1.5 cm/s (fine sand). For a 100 g/L flood (g'= -0.36 m/s^2) and a 0.15° slope, w_{max} is estimated to be 3.7 cm/s (medium sand). For a higher slope (0.5°), medium to coarse sands are transported by the hyperpycnal turbidity currents. These *conservative* estimates of w_{max} predict that sand particles may be carried offshore during hyperpycnal river discharge.

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