RSM-U Reservoir Sedimentation Workshop

Mechanics of Reservoir Sedimentation – Delta Progression, Formation, Processes, and Products

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Discussion Overview

- Topic: Mechanics of Reservoir Sedimentation – Delta Progression, Formation, Processes, and Products
- Duration: Approximately 20 minutes
- Key Points:
  - ►Introduction and Overview
  - ►Sediment Characteristics and Reservoir Processes
  - ►Cohesive Sediment Mechanics
  - ►Recap and Summary

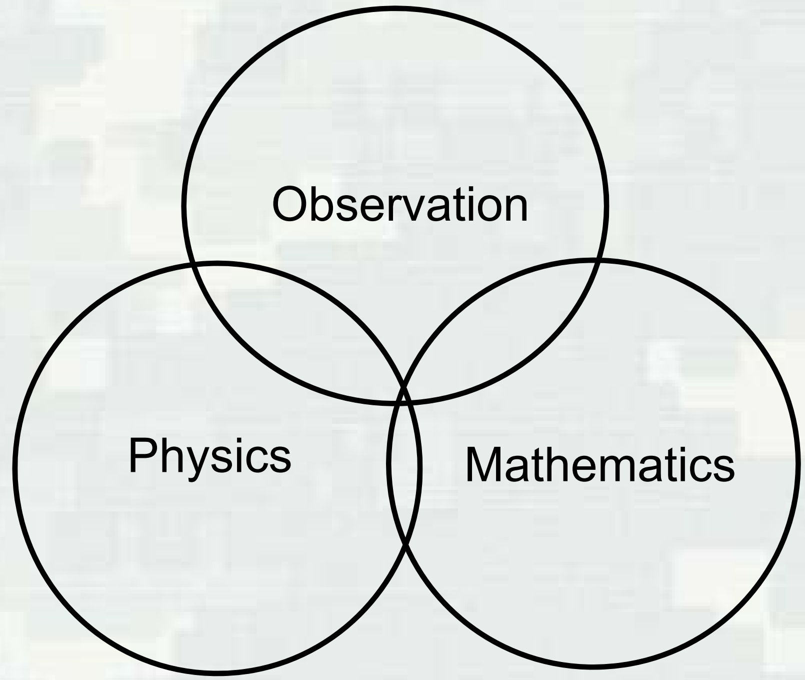
Learning Objectives

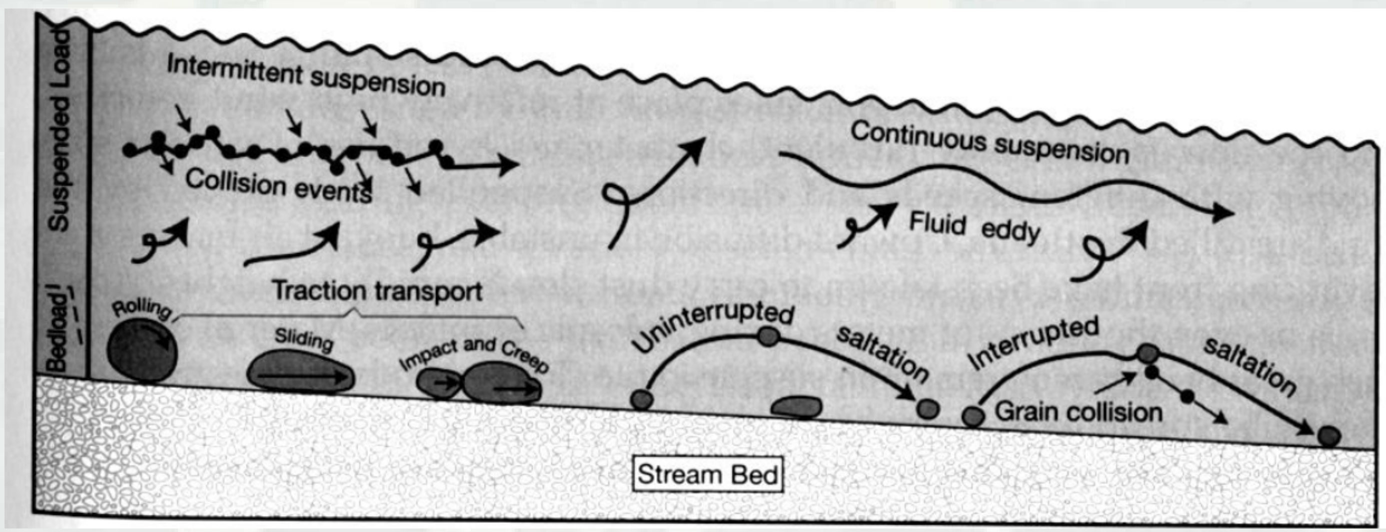
- Students will have a basic conceptual understanding of sediment properties, reservoir geometry and hydraulics
- Students will have basic knowledge the differences between non-cohesive and cohesive sediments
- Students will be introduced to concepts associated with sediment transport mechanics commonly encountered in reservoir delta formation

Introduction

Introduction

- Sediment Classification
  - Cohesive (clay and silts)
  - Non-Cohesive (sand and gravel)
- Sediment Transport Modes
  - Wash Load
  - Suspended Load
  - Bedload





Sediment Characteristics and Reservoir Processes

- The physical properties of fluids and solids are usually expressed in terms of the following fundamental units:
  - Mass (M)
  - Length (L)
  - Time (t)
  - Temperature (Tº)

2.1 Dimensions and units 5

Table 2.1. *Geometric, kinematic, dynamic, and dimensionless variables*

Variable	Symbol	Fundamental dimensions	SI Units
Geometric variables (L)			
length	L, x, h, d_s	L	m
area	A	L^2	m^2
volume	$\forall$	L^3	m^3
Kinematic variables (L, T)			
velocity	V, v_x, u, u_*	LT^{-1}	m/s
acceleration	a, a_x, g	LT^{-2}	m/s^2
kinematic viscosity	v	L^2T^{-1}	m^2/s
unit discharge	q	L^2T^{-1}	m^2/s
discharge	Q	L^3T^{-1}	m^3/s
Dynamic variables (M, L, T)			
mass	m	M	1 kg
force	$F = ma, mg$	MLT^{-2}	1 kg m/s^2 = 1 Newton
pressure	$p = F/A$	$ML^{-1}T^{-2}$	1 N/m^2 = 1 Pascal
shear stress	$\tau, \tau_{xy}, \tau_o, \tau_c$	$ML^{-1}T^{-2}$	1 N/m^2 = 1 Pascal
work or energy	$E = F \bullet d$	ML^2T^{-2}	1 Nm = 1 Joule
power	$P = E/t$	ML^2T^{-3}	1 Nm/s = 1 Watt
mass density	ρ, ρ_s	ML^{-3}	kg/m^3
specific weight	$\gamma, \gamma_s = \rho_s g$	$ML^{-2}T^{-2}$	N/m^3
dynamic viscosity	$\mu = \rho v$	$ML^{-1}T^{-1}$	1kg/ms = 1Ns/m^2 = 1 Pas
Dimensionless variables (–)			
slope	S_o, S_f	–	–
specific gravity	$G = \gamma_s/\gamma$	–	–
Reynolds number	$\mathrm{Re} = Vh/v$	–	–
grain shear Reynolds number	$\mathrm{Re}_* = u_* d_s/v$	–	–
Froude number	$\mathrm{Fr} = V/\sqrt{gh}$	–	–
Shields parameter	$\tau_* = \tau/(\gamma_s - \gamma)d_s$	–	–
concentration	C_v, C_w, C	–	–

Note: Figure 2.1 from Julien 2010

Sediment Characteristics and Reservoir Processes

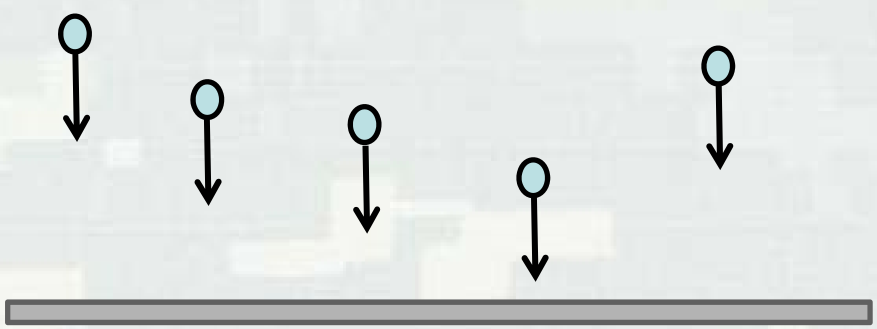
Descriptive Term	Size	Familiar Example
Boulder	8 inches or more	Man's head or larger
Cobble	3 to 8 inches	Grapefruit or orange
Coarse Gravel	3/4 to 3 inches	Walnut or grape
Fine Gravel	1/4 to 3/4 inches	Pea
Coarse Sand	2 mm to 1/4 inches	Rock salt
Medium Sand	0.4 mm to 2 mm	Sugar or table salt
Fine Sand	0.4 mm to 0.075 mm	Powder sugar

Note: Particles about 0.075 mm in diameter can just be discerned with the naked eye at a distance of about 10 inches.

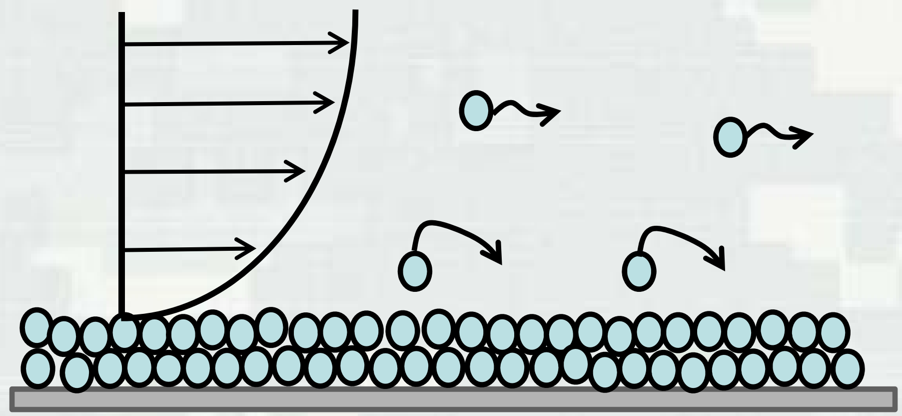
Sediment Characteristics and Reservoir Processes

- A primary consideration in sedimentation engineering is the interaction between the flow and sediment grains

Settling of a grain through the water column



Lateral transport of sediment



- Reservoir sedimentation is a function of the river regime, flood frequencies and magnitude, reservoir geometry and operation, flocculation potential, sediment consolidation, density currents, and possible LULC over the life expectancy of the reservoir.

Sediment Characteristics and Reservoir Processes

- As natural rivers enter reservoirs, the water depth increases and flow velocity decreases. Resulting in a loss of energy (or transport capacity) and sediment deposition.
- The pattern of deposition generally begins with a delta formation in the reservoir headwater area.
- Density currents (and other cohesive sediment transport) may transport finer sediment particles closer to the dam.

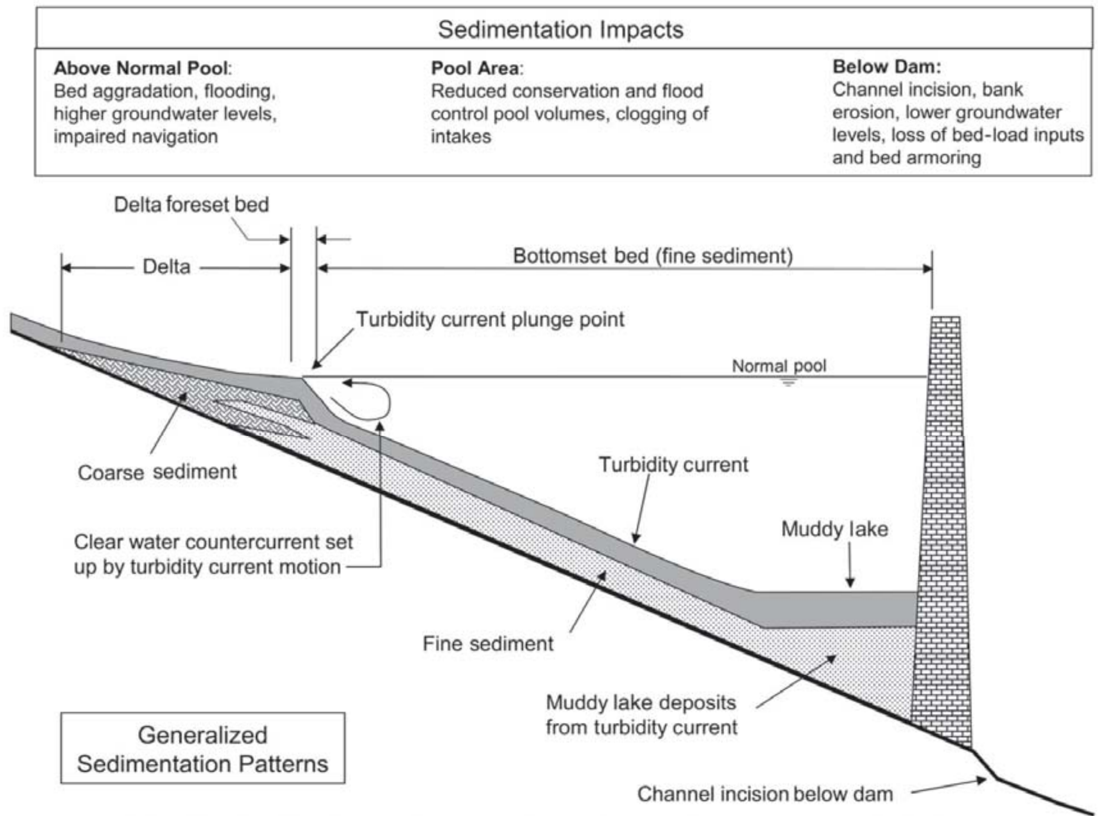


Fig. 12-4. Deposition patterns in reservoirs and classes of sediment-related impacts imposed by the dam.

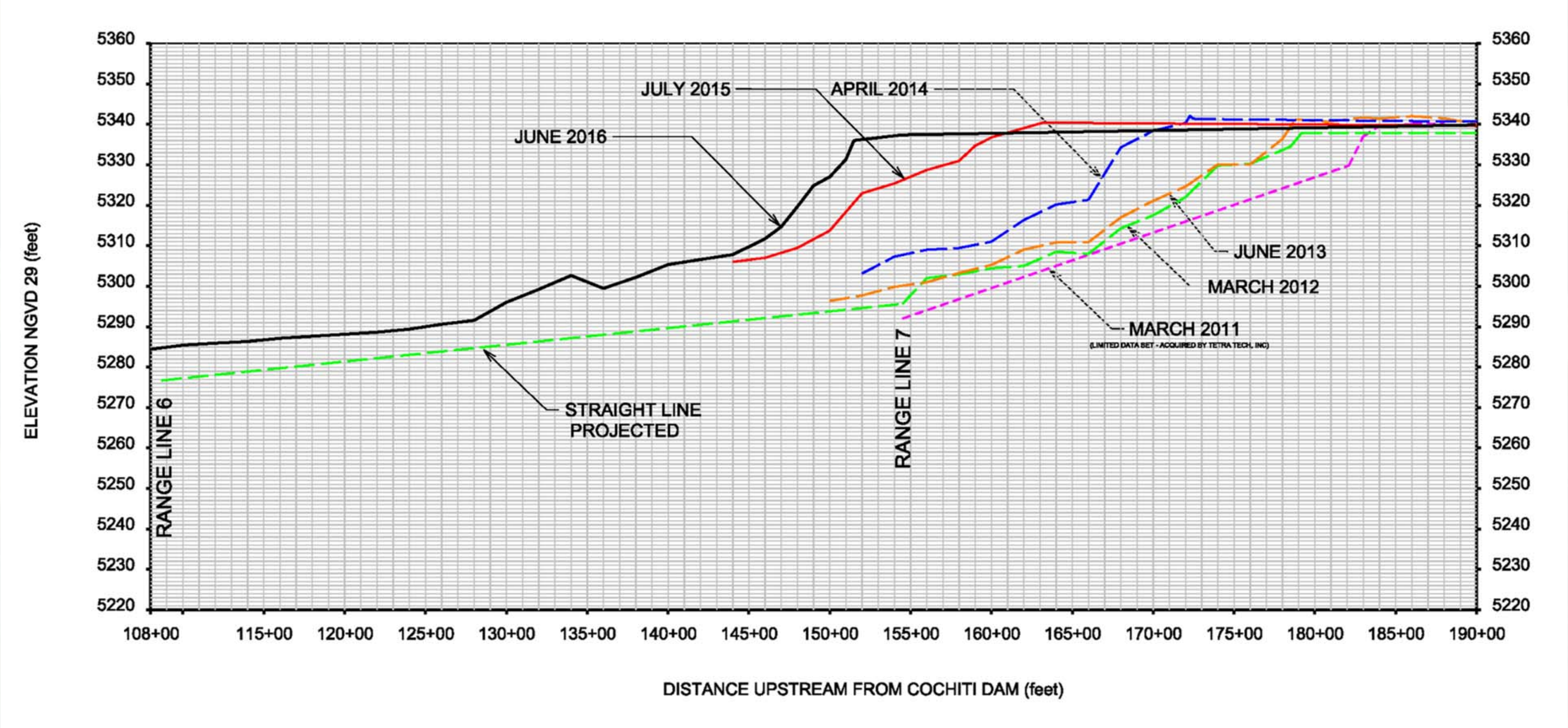
From: Morris et al., 2004

Sediment Characteristics and Reservoir Processes

- The coarse fraction of the inflowing sediment load creates a delta deposit where the main river or side tributaries enter the reservoir
- Depending on the incoming sediment grain size, delta deposits can range from silt to cobbles.
- The delta is commonly divided into the topslope and foreslope deposits, and the downstream limit of the delta is characterized by a rather abrupt reduction in sediment grains size.
- Deltaic deposits not only extend into the reservoir, but due to backwater effects they also extend upstream. Mathematical modeling is the recommended method for predicting delta depositional patterns.

Sediment Characteristics and Reservoir Processes

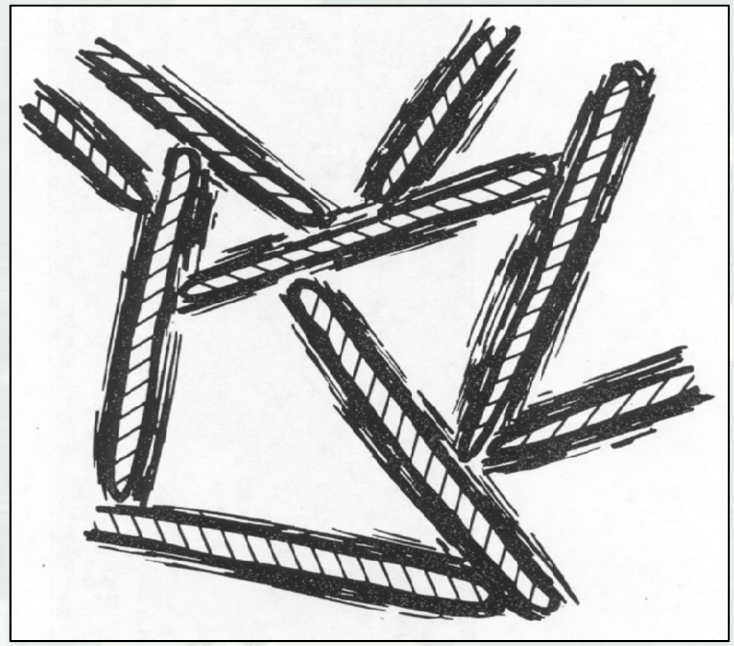
USACE-SPA Cochiti Reservoir Delta Progradation



Sediment Characteristics and Reservoir Processes

- Non-Cohesive

- Cohesive

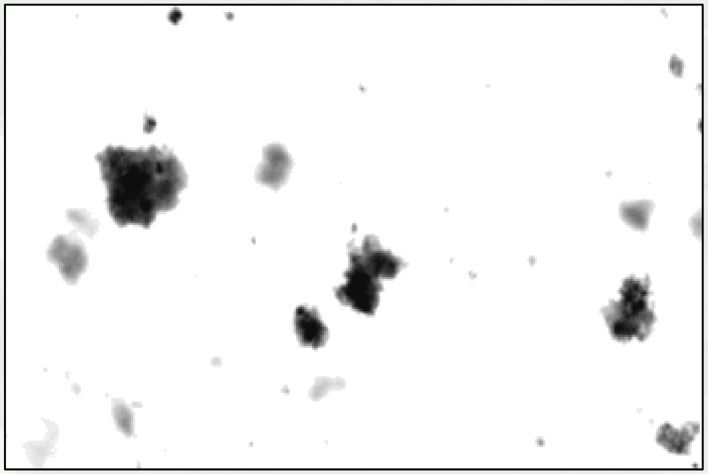


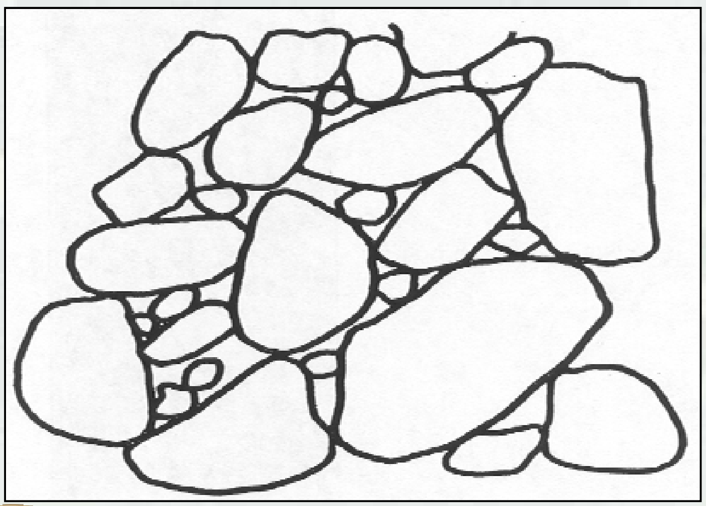
Its important to distinguish between non-cohesive and cohesive sediment, both in transport and deposition.

Sediment Characteristics and Reservoir Processes

- Non-Cohesive
  - Grains are significantly larger than their clay counterparts (at least 16x larger in diameter and 4000x in volume.
  - Most sand found on beaches is quartz sand, which is simpler to describe and chemically inert.
  - Used as scour protection around structures and bank stabilization – referred to as rip rap and consist of large stones and/or gravel.
- Cohesive
  - Generally associated with sticky and muddy sediments.
  - As encountered in low energy natural environments, cohesive sediments generally consists of a mixture of clay and silt (this combination is generically referred to as mud), fine sand organic material, and water.
  - Non-linear processes flocculation, consolidation, density current, and fluid mud

Cohesive Sediment Mechanics





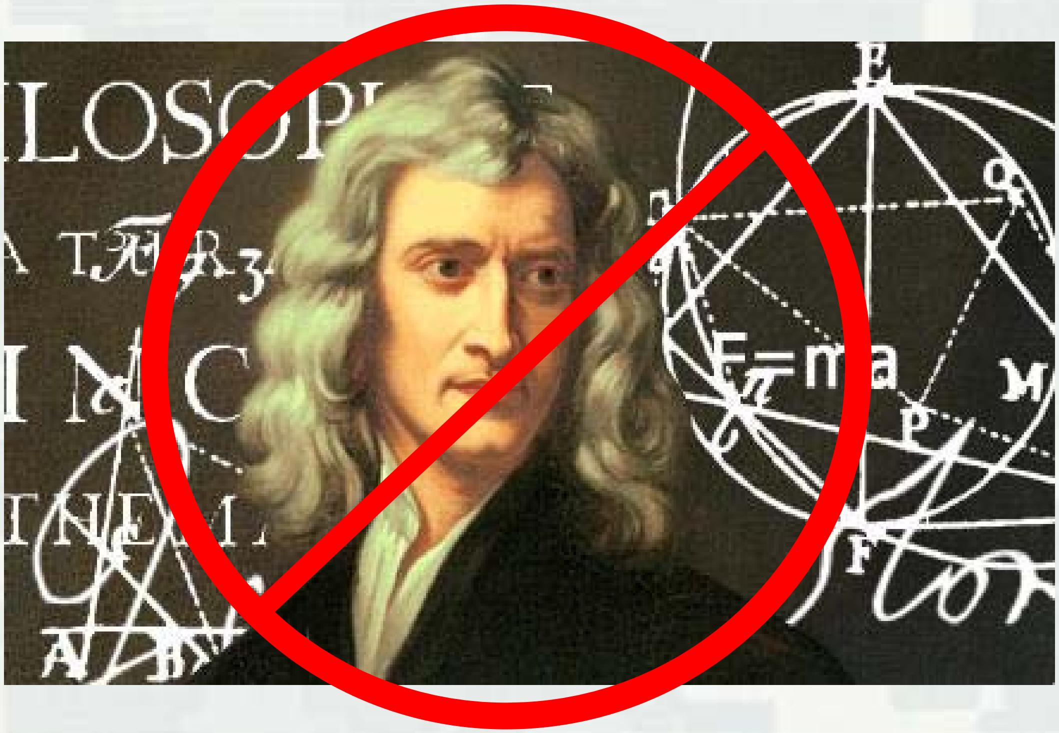
- Non-Cohesive sediments (sands and gravels) can be views as the foundation of most riverbanks, as material that establishes the channel bed, bar and sometimes the banks. These sediments form geomorphic features that provide critical habitat, are dominated by coarse sediments.
- Reservoir sediments often contain a high percentage of fine sediments, and their mechanical behavior is largely controlled by the interparticle attraction caused by electrostatic and physio-chemical forces.

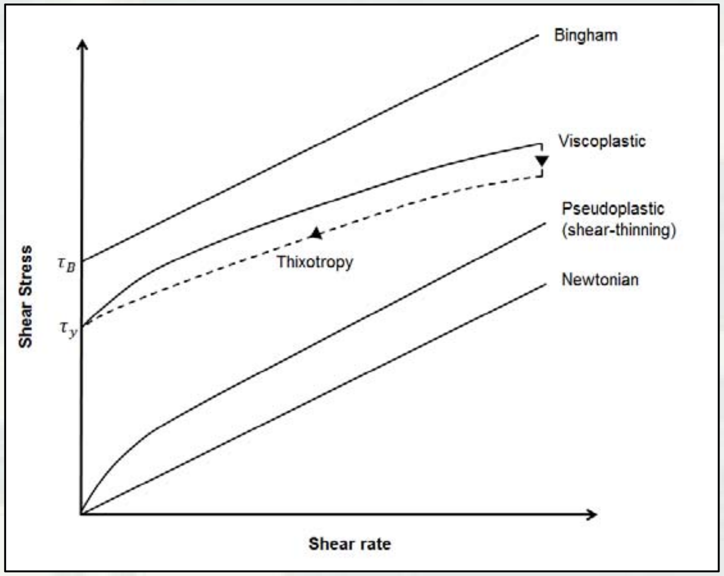
Cohesive Sediment Mechanics

Cohesive Sediment Mechanics

- Cohesive sediment play a useful yet distinct role from non-cohesive, such as a source of turbidity, and its role in transporting nutrients and contaminants absorbed onto clay particles.
- Cohesive sediment are needed for a healthy ecosystem in estuaries, flood plains, and wetlands.
- Human activity can increase sediment loads of cohesive sediment loads can cause problems of increased turbidity in the water column, and sedimentation in river channels, reservoirs, estuaries, and harbors.
- One of the most important features of cohesive sediment (other than flocculation and consolidation) is that the critical shear stress required to erode the bed is significantly higher than that required to deposit.

Cohesive Sediment Mechanics





Typically dominant in Fluid mud, Density/Turbidity Currents, Consolidation, Gelling, etc.

Recap and Summary

- Understanding and prediction of sedimentation patterns is important for a variety of reasons. Delta deposits can cause a stream to aggrade upstream;
  - ► Effecting flood levels and groundwater levels
  - ► Bridge clearance, commercial and recreational navigation
  - ► Loss of storage due to sedimentation
- It is essential to consider cohesive sediment transport processes in the planning, design, operation, and maintenance of a reservoir.

Questions or Comments?

References

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