HEC-RAS 2D: Sediment Transport Theory

Alex Sánchez, PhD
Stanford Gibson, PhD

Hydrologic Engineering Center,
Institute for Water Resources,
U.S. Army Corps of Engineers, U.S.A.

US Army Corps of Engineers

January 30, 2024

1

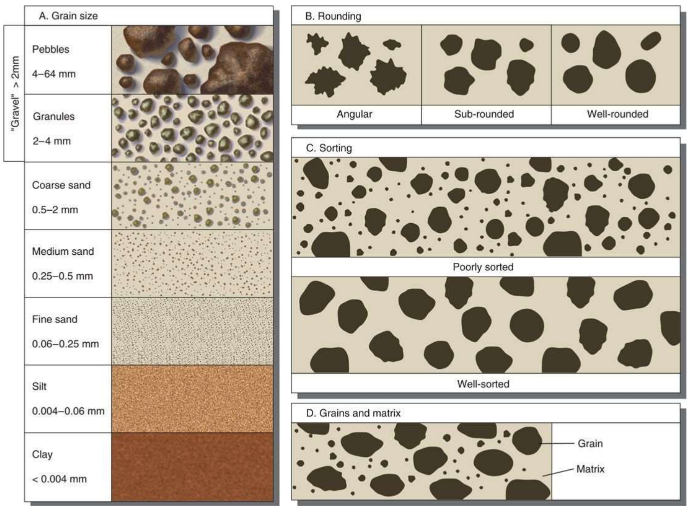
Outline

- Sediment Particles
- Bulk Bed Properties
- Incipient Motion
- Erosion/Entrainment and Deposition/Settling
- Sediment Transport Modes
- Sediment Transport Functions
  How much sediment is transported?
- Transport Processes: Advection and diffusion
- Bed Sorting and Layering

2

2

Sediment Particles



Diameter types

- Sieve diameter (most common)
- Settling diameter
- Nominal diameter

Density

$$\rho_s = \frac{\text{partilcle mass}}{\text{particle volume}}$$

Shape

Roundness

3

3

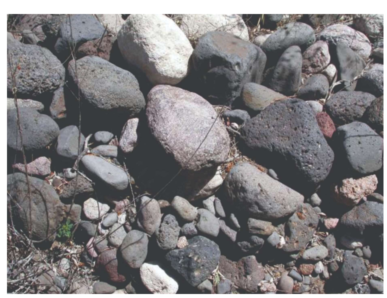
Sediment Bed Material

- Natural rivers have a distribution of size classes with different shapes, densities, etc.

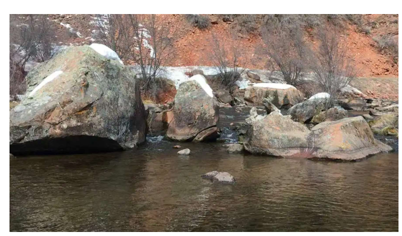
Sand

Gravel

Mud



Cobble



Boulders

4

4

Sediment Bed Bulk Properties

- Porosity

$$\phi = \frac{\text{volume of voids}}{\text{total volume}}$$

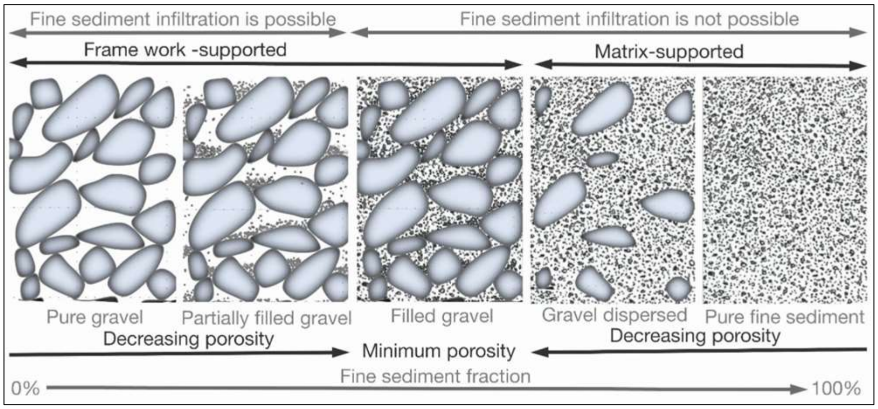
- Solidity

$$1-\phi = \frac{\text{volume of solids}}{\text{total volume}}$$

- Dry density

$$\rho_d = \frac{\text{mass}}{\text{total volume}}$$

(bed mass concentration)



Bui, V.H.; Bui, M.D.; Rutschmann, P. Advanced Numerical Modeling of Sediment Transport in Gravel-Bed Rivers. *Water* **2019**, *11*, 550. https://doi.org/10.3390/w11030550

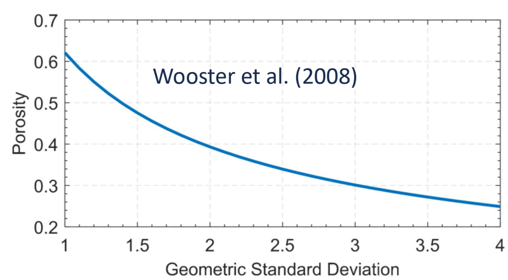
5

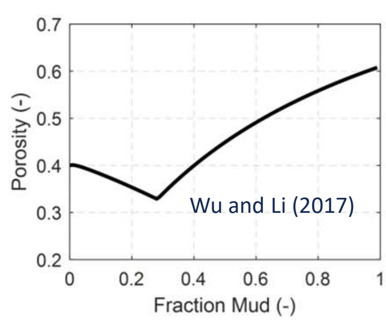
5

Sediment Bed Porosity

In HEC-RAS, for newly deposited sediments

- Porosity
  - Noncohesive fraction computed with Colby formula as a function of the "grain porosities" or the Wooster et al. (2008)
  - Cohesive fraction computed with Colby formula
- Packing is only considered for mixed (cohesive and noncohesive sediments) using the Wu and Li (2017)





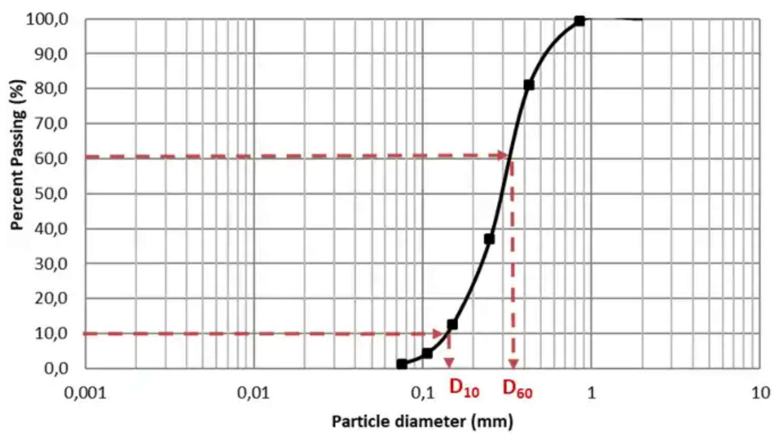
6

6

Grain Size Distribution

- Diameters
  - Geometric mean
  - Percentile diameters
    - D_P

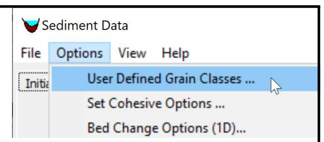
    where P is percent finer
    - D_{50} : Median grain size
- Sorting
  - Standard deviation
  - Lower is more sorted
- Skewness
  - Symmetry of curve
  - Lower is more symmetric
- Kurtosis
  - "Peakedness" of curve

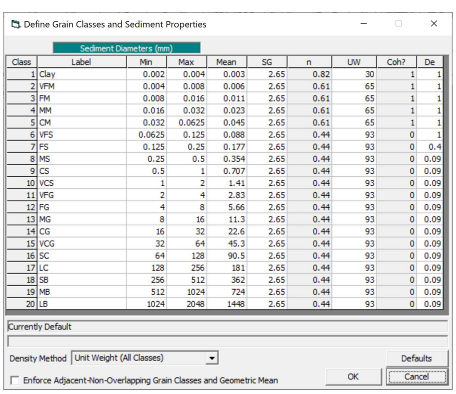


7

7

Grain Classes





Define Grain Classes and Sediment Properties

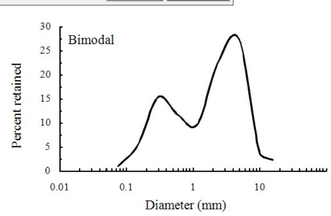
Sediment Diameters (mm)

Class	Label	Min	Max	Mean	SG	n	UW	Coh?	De
1	Clay	0.002	0.004	0.003	2.65	0.82	30	1	1
2	VFM	0.004	0.008	0.006	2.65	0.61	65	1	1
3	FM	0.008	0.016	0.011	2.65	0.61	65	1	1
4	MM	0.016	0.032	0.023	2.65	0.61	65	1	1
5	CM	0.032	0.0625	0.045	2.65	0.61	65	1	1
6	VFS	0.0625	0.125	0.088	2.65	0.44	93	0	1
7	FS	0.125	0.25	0.177	2.65	0.44	93	0	0.4
8	MS	0.25	0.5	0.354	2.65	0.44	93	0	0.09
9	CS	0.5	1	0.707	2.65	0.44	93	0	0.09
10	VCS	1	2	1.41	2.65	0.44	93	0	0.09
11	VFG	2	4	2.83	2.65	0.44	93	0	0.09
12	FG	4	8	5.66	2.65	0.44	93	0	0.09
13	MG	8	16	11.3	2.65	0.44	93	0	0.09
14	CG	16	32	22.6	2.65	0.44	93	0	0.09
15	VCG	32	64	45.3	2.65	0.44	93	0	0.09
16	SC	64	128	90.5	2.65	0.44	93	0	0.09
17	LC	128	256	181	2.65	0.44	93	0	0.09
18	SB	256	512	362	2.65	0.44	93	0	0.09
19	MB	512	1024	724	2.65	0.44	93	0	0.09
20	LB	1024	2048	1448	2.65	0.44	93	0	0.09

Currently Default

Density Method: Unit Weight (All Classes) — Defaults

Enforce Adjacent-Non-Overlapping Grain Classes and Geometric Mean — OK — Cancel



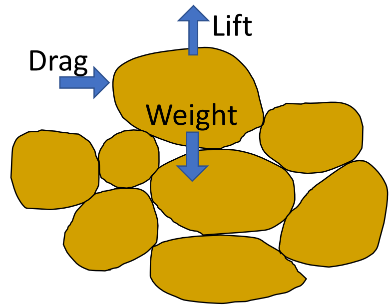
- Continuous grain size distribution discretized into bins or grain classes
- Select grain classes carefully and only use them when necessary
  - Do not add a grain class which represents 0.1% of the bed material
  - Each grain class adds a transport equation, bed change, and sorting equation
- Active grain grasses detected from initial bed gradations and boundary conditions

8

8

Incipient Motion of Noncohesive Beds

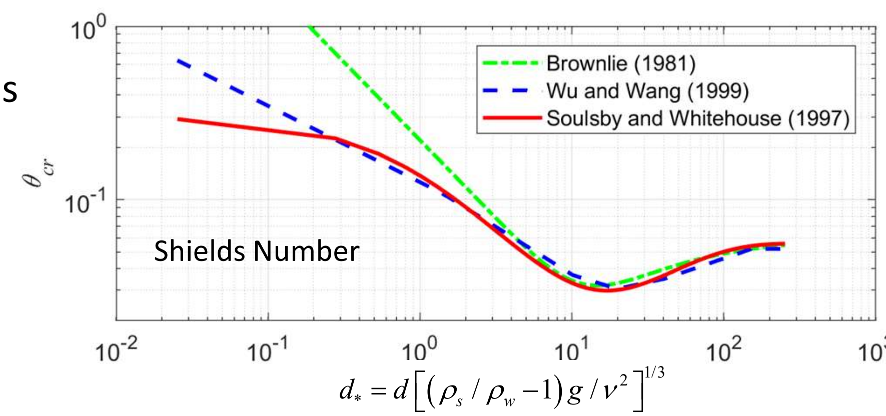
- Usually defined as a threshold/critical shear or velocity which produces transport
- Sometimes defined as a threshold (non-dimensional) transport rate
- Depends on particle shape, density, random arrangement of particles, and many other forces



Critical Shear for Noncohesives

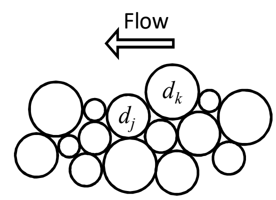
Shields Number is a ratio of forces

$$\theta_{cr} = \frac{\tau_{cr}}{(\rho_s - \rho_w)gd}$$



Hiding and Exposure

- Smaller particles "hidden" from flow and larger particles "exposed" to flow
- Hiding and exposure corrections
  - Incipient motion/mobility $\xi_k = \frac{\theta_{crk}}{\theta_{cr}} = \frac{\tau_{crk}}{\tau_{cr}} = \frac{U_{crk}^2}{U_{cr}^2}$
  - Transport $\eta_k = \frac{q_k^*}{q^*}$ $\quad \eta_k \approx \frac{1}{\xi_k^a}$ $\quad a:$ Coefficient



- Correction on incipient motion done whenever possible unless formula does not have a threshold for incipient motion
- Because finer grain sizes represent a larger portion of the transported material, **applying** hiding/exposure corrections will generally **reduce** the overall transport

11

11

Hiding and Exposure Functions

- HEC-RAS has several options for the hiding and exposure correction
  - Ashida and Michiue (1971)
  - Day (1980)
    - Developed for Ackers and White formula
  - Egiazaroff (1965)
    - Used in AdH
  - Parker et al. (1982)
  - Hayashi (1980)
  - Proffitt and Sutherland (1983)
    - Developed for Ackers and White
  - Wilcock and Crowe
  - Wu et al. (2000)

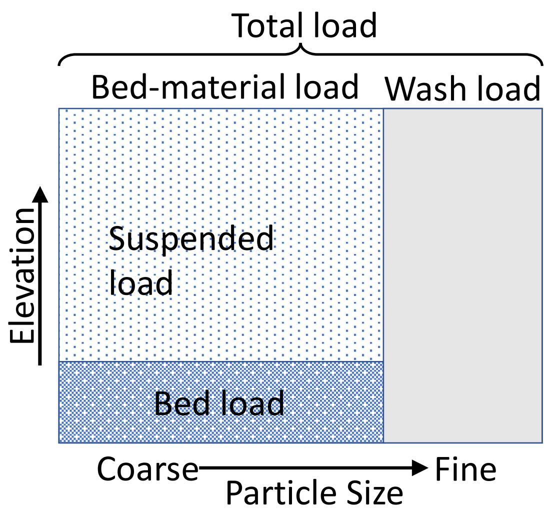
Notes:

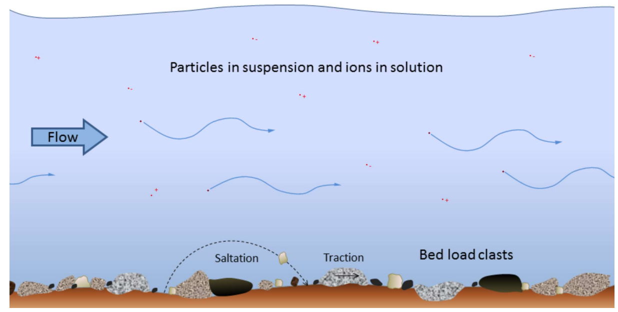
- **ALWAYS** use hiding and exposure corrections (default is off)
- Formulation and exponent can be calibrated using bed gradations or fractional suspended concentrations

12

12

Sediment Loads





- Wash load does not contribute to the bed.
- HEC-RAS simulate the total load
- Bed load particles move by sliding/traction, saltation/jumping, and rolling
- Suspended sediments are entrained in the water column through vertical mixing

13

Transport Processes

- Fluid/particle velocity

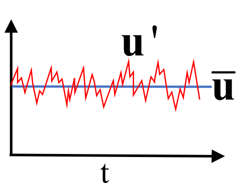
$$\mathbf{u} = \bar{\mathbf{u}} + \mathbf{u}'$$

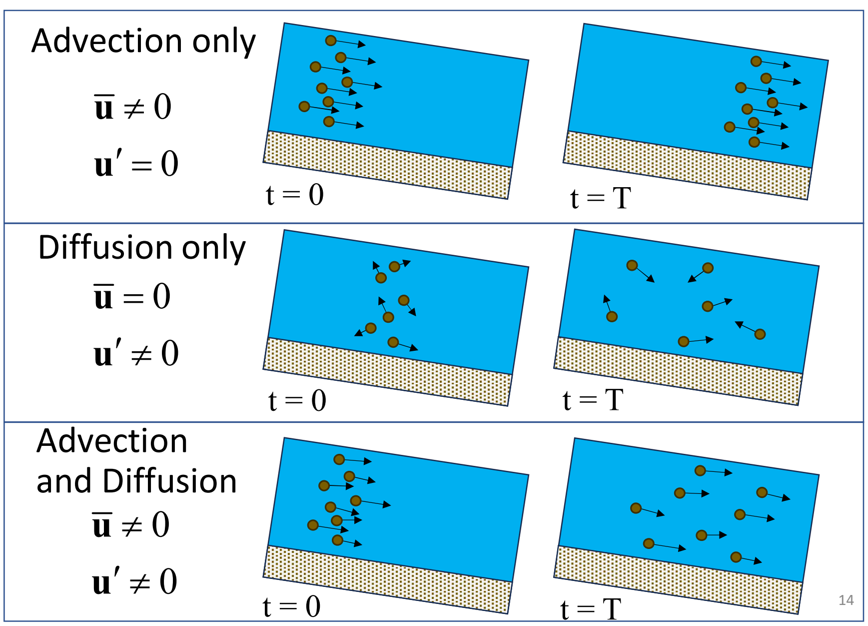
- Mean velocity

$$\bar{\mathbf{u}}$$

- Turbulent velocity

$$\mathbf{u}' \qquad \overline{\mathbf{u}'} = 0$$





14

Erosion and Deposition

- Erosion defined as any removal of bed material
  - Can be bed load or suspended load
- Entrainment is the suspension of bed material into the water column due to vertical mixing
- Settling is the downward velocity of particles in the water column due to gravity
- Deposition defined as the addition of any material to the bed
  - Can be from bed load or suspended load
  - i.e. settling at the bed
- Wash load does not interact with the bed

15

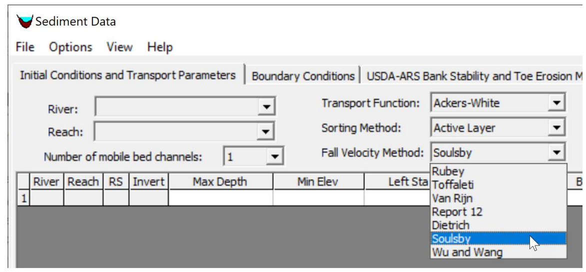
Erosion

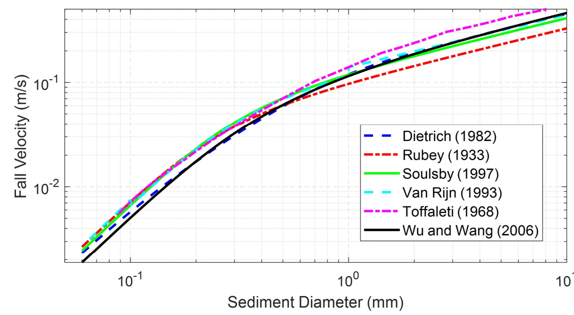
- Physics based formulas for erosion due not exist
- Various empirical and semi-empirical methods exist
- Suspended load sediment modeling
  - Near-bed gradient (Neumann) boundary condition
    - Utilizes a near-bed concentration capacity which can be difficult to estimate
    - Does not require any other parameters
  - Adaptation approach
    - Utilizes an equilibrium transport rate which easier to estimate but
    - Requires an adaptation parameter which can be hard to estimate
- Bed load sediment modeling
  - Most commonly uses an adaptation approach
- Details of adaptation approach discussed later

16

Deposition

- Fall velocity method represents free settling velocity
  - Does not account for hindered settling or flocculation
- Not a calibration parameter
- Use Soulsby except for specific conditions



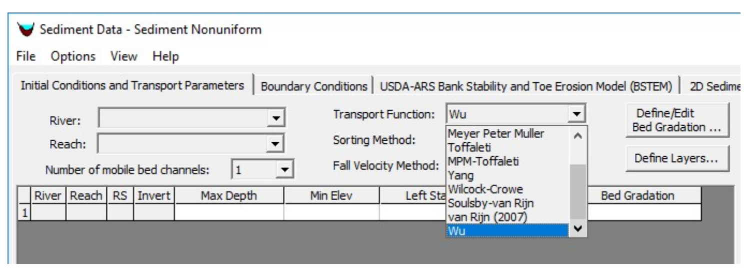


17

17

Transport Functions

- Represent equilibrium sediment transport under uniform steady conditions
- Most important model setting
- Available formulas
  - Ackers and White (1973)
  - Engelund-Hansen (1967)
  - Lausen-Copeland (1989)
  - Meyer-Peter-Muller (1948)
  - Soulsby-van Rijn (1997)
  - Toffaleti (1968)
  - Van Rijn (1984ab, 2007ab)
  - Wilcock and Crowe (2003)
  - Wu et al. (2000)
  - Yang (1984)



- Most common for 2D are:
  - Soulsby van Rijn
  - Van Rijn
  - Wu

18

18

Ackers and White (1973)

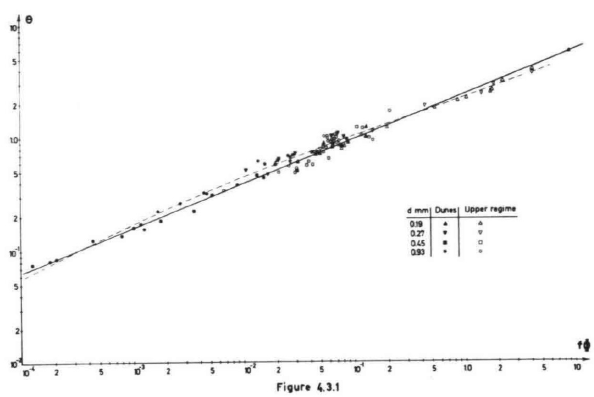
- Total-load Formula
- Excess mobility based on stream power
- Fractional load formulation adopted for nonuniform sediments by Day (1980) and Proffitt and Sutherland (1983) for nonuniform sediments
- Works well for nonuniform sands and gravels

$$q_{tk}^{*} = \rho_w g h U X_{tk}^{*} \qquad \frac{X_{tk}^{*} h \rho_w}{d_k \rho_{sk}} \left(\frac{u_*}{U} \right)^{n} = \Lambda \left(\frac{F_{grk}}{A_c} - 1 \right)^{m}$$

$$F_{grk} = \eta_k \frac{u_*^n}{\sqrt{R_k g d_k}} \left[\frac{U}{\sqrt{32} \log_{10}(10h / d_k)} \right]^{1-n} \qquad R_k = \rho_{sk} / \rho_w - 1$$

Engelund-Hansen (1967)

- Total-load Formula
- Threshold for transport
  - Originally did not use one
  - Included in HEC-RAS 2D Sediment
- Uniform sediments dominated by suspended load

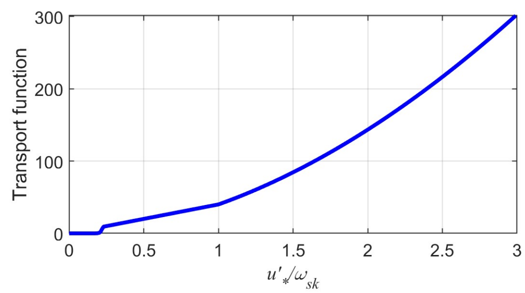


$$q_{tk}^{*} = \begin{cases} 0.05 \eta_k \rho_{sk} U^2 \sqrt{\dfrac{d_k}{g R_k}} \left(\dfrac{\tau_b}{g(\rho_{sk} - \rho_w) d_k} \right)^{3/2} & \text{for } \tau_b > \tau_{crk} \\ 0 & \text{otherwise} \end{cases}$$

Laursen-Copeland (1968, 1989)

- Total-load Formulas
- Nonlinear excess shear formulation with empirical transport function
- Based on flume experiments and data from Arkansas River
- Copeland extended Laursen equation to gravel

$$q_{tk}^{*} = a\rho_w U h \left(\frac{d_k}{h}\right)^{7/6} \left(\frac{\theta_b'}{\theta_{crk}} - 1\right)^{n} f_{tk}^{LC}\left(\frac{u_*'}{\omega_{sk}}\right)$$



21

Meyer-Peter-Müller (1948)

- Bed-load Formula
- Excess shear formulation
- Recalibrated several times in literature
- Most appropriate for uniform gravel
- Tends to under-predict for sands and silts

$$q_{bk}^{*} = A_M \rho_{sk} \sqrt{R_k g d_k^3} \left(\theta_b' - \theta_{crk}\right)^{E_M}$$

$$MPM \Rightarrow A_M = 8, E_M = 2/3, \text{ and } \theta_{crk} = 0.047$$

$$\text{Wong and Parker (2006)} \Rightarrow A_M = 3.97, E_M = 1.6, \text{ and } \theta_{crk} = 0.0495$$

22

22

Soulsby-van Rijn (1997)

- Total-load Formulas
- Developed by curve-fitting to a 2DV sediment transport model SEDTRANS by van Rijn
- Uses depth-averaged threshold current velocity
- Originally proposed for well sorted sands and extended here for nonuniformly sized sediments

$$q_{bk}^{*} = 0.005Uh\left(\frac{U-U_{crk}}{\sqrt{R_k g d_k}}\right)^{2.4}\left(\frac{d_k}{h}\right)^{1.2}$$

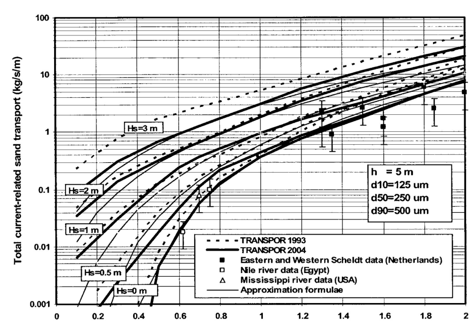
$$q_{sk}^{*} = 0.012Uh\left(\frac{U-U_{crk}}{\sqrt{R_k g d_k}}\right)^{2.4}\left(\frac{d_k}{h}\right)d_{*k}^{-0.6}$$

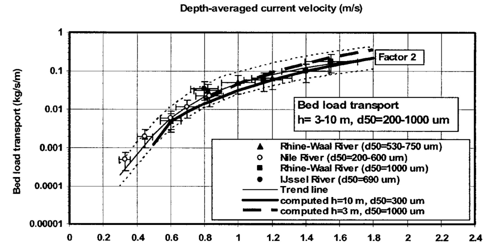
23

23

Van Rijn (1984ab, 2007ab)

- Total-load Formula
- Developed by curve-fitting to lab and field measurements
- Uses depth-averaged threshold current velocity
- Originally proposed for well sorted sands and extended here for nonuniformly sized sediments
- Suspended-load formula the same as the Soulsby-van Rijn





$$q_{bk}^{*} = 0.015Uh\left(\frac{U-U_{crk}}{\sqrt{R_k g d_k}}\right)^{1.5}\left(\frac{d_k}{h}\right)^{1.2}$$

$$q_{sk}^{*} = 0.012Uh\left(\frac{U-U_{crk}}{\sqrt{R_k g d_k}}\right)^{2.4}\left(\frac{d_k}{h}\right)d_{*k}^{-0.6}$$

24

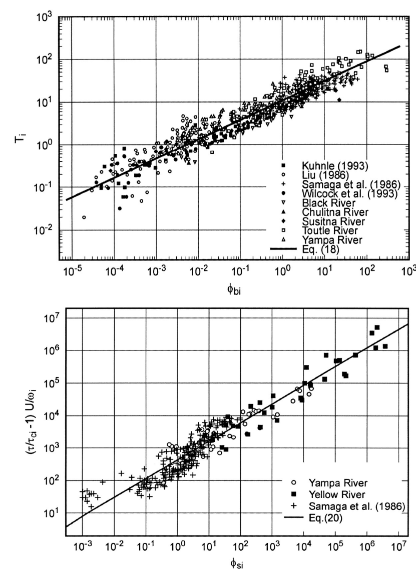
24

Wu et al. (2000)

- Total-load Formula
- Developed for nonuniform sediments
- Based on extensive lab and field measurements
- Nonlinear excess shear formulation for bed-load
- Stream-power formulation for suspended-load

$$q_{bk}^{*} = 0.0053\sqrt{R_k g d_k^3}\left(\frac{\tau_b'}{\tau_{crk}} - 1\right)^{2.2}$$

$$q_{sk}^{*} = 2.62\times10^{-5}\sqrt{R_k g d_k^3}\left[\left(\frac{\tau_b}{\tau_{crk}} - 1\right)\frac{U}{\omega_{sk}}\right]^{1.74}$$

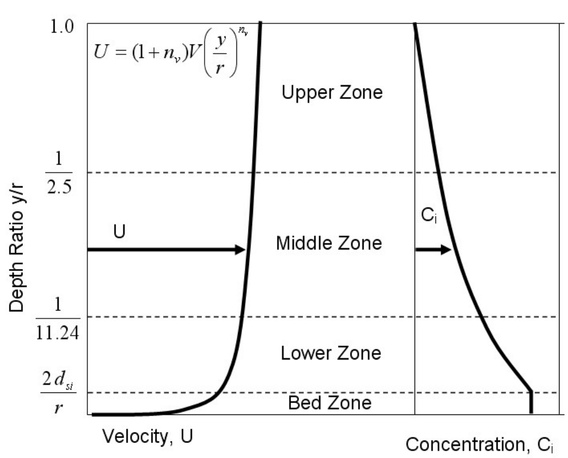


25

25

Toffaleti (1968)

- Total-load formulas
- Developed primarily for sand
- Splits the water column into 3 zones
- Assumes Rouse concentration profile
- Originally developed for bulk transport but here it is applied to individual grain classes
- Usually applied at "large" rivers since most of the data used to develop it were from large suspended-load dominant rivers
- Bed-load formula does not perform well for gravel and can be replaced with MPM



26

26

Wilcock and Crowe (2003)

- Bed-load Formula
- Developed for graded beds with sand and gravel
- No critical shear for transport
- However, it quickly goes to zero

$$q_{bk}^{*} = \frac{u_*^3 W_k^*}{R_k g}$$

$$W_k^* = \begin{cases} 0.002\phi^{7.5} & \text{for } \phi < 1.35 \\ 14\left(1 - \dfrac{0.894}{\phi^{0.5}}\right)^{4.5} & \text{for } \phi \geq 1.35 \end{cases} \qquad \phi = \frac{\tau_b}{\tau_{r,k}}$$

27

27

Yang (1979, 1984)

- Total-load formula
- Regression of potential energy dissipation
- Best for fine to medium sands
- Overestimates for coarse sands and gravel
- Sharp discontinuity at diameter of 2 mm

$$\log_{10}\left(C_{tk}^{*}\right) = M + N\log_{10}\left[\frac{S_f}{\omega_{sk}}\left(U - U_{crk}\right)\right]$$

$$M = M\left(\frac{\omega_{sk} d_k}{\nu}, \frac{u_*}{\omega_{sk}}\right), \; N = N\left(\frac{\omega_{sk} d_k}{\nu}, \frac{u_*}{\omega_{sk}}\right)$$

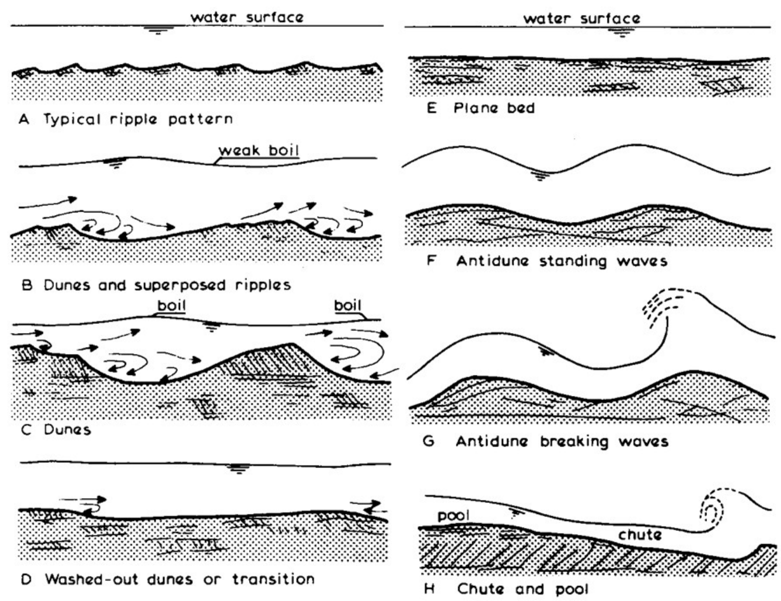
28

28

Bed Forms and Roughness

- Total Roughness sum of
  - Bed form
  - Grain/skin
  - Transport (usually ignored)

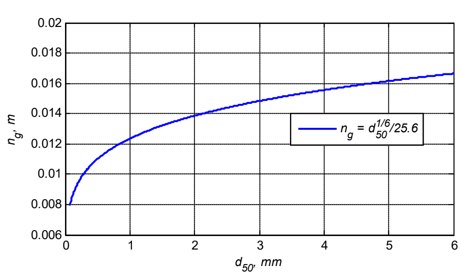
$$k_s = k_{s,f} + k_{s,g} + k_{s,s}$$

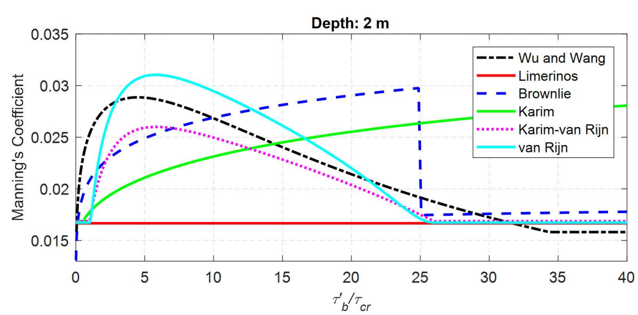


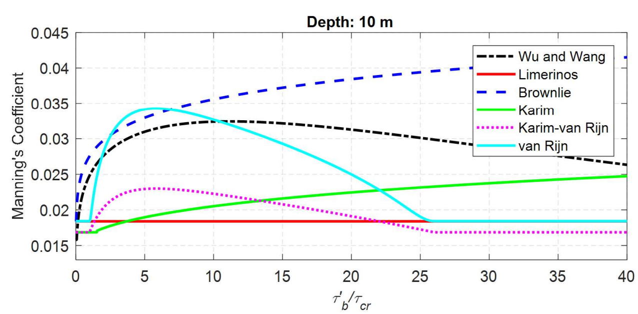
29

Bed Roughness and Bed Shear

- Total Roughness sum of
  - Bed form
  - Grain/skin
  - Transport (usually ignored)
- Bed shear decomposed into total shear and grain shear
- Suspended load generally a function of total shear
- Bed load a function of grain shear







30

Equilibrium vs Non-Equilibrium Transport

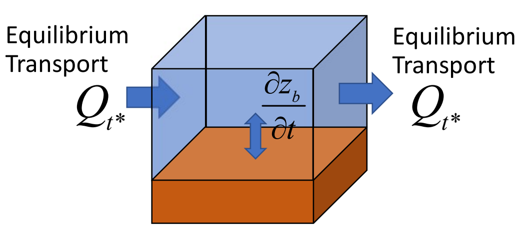
- Equilibrium
  - Actual transport rate = equilibrium transport rate
  - No under-loading or over-loading which is when the actual transport is less or more than the equilibrium transport rate
  - Assumes steady and uniform flow and sediment conditions
- Non-equilibrium
  - Actual transport rate ≠ equilibrium transport rate
  - Can have under- or over-loading
  - Applicable to unsteady and nonuniform flow and sediment conditions

31

31

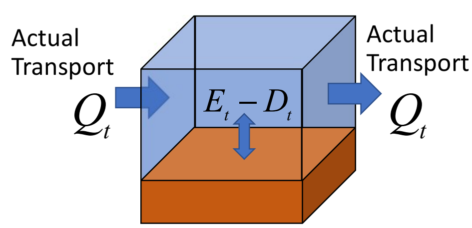
Equilibrium vs Non-Equilibrium Modeling

Equilibrium Modeling Approach



1. Compute inward and outward equilibrium transport rates
2. Bed change is mass balance in control volume

Non-Equilibrium Modeling Approach



1. Solve transport equation(s) for actual concentrations
   - Erosion from empirical formulas
   - Deposition from actual concentration
2. Bed change from erosion and deposition

32

32

Deriving Exner

- Starting with the transport and bed change equations while ignoring the temporal and diffusion terms

$$\frac{\partial(hC_t)}{\partial t} + \frac{\partial(hUC_t)}{\partial x} = \frac{\partial}{\partial x}\left(\varepsilon_t h \frac{\partial C_t}{\partial x}\right) + E_t - D_t \qquad \rho_s(1-\phi_b)\frac{\partial z_b}{\partial t} = D_t - E_t$$

- Assuming the concentration is at equilibrium and defining the transport rate

$$C_t = C_{t*} = \frac{Q_{t*}}{hU}$$

- Combining the equations leads to the Exner equation

$$\rho_s(1-\phi_b)\frac{\partial z_b}{\partial t} + \frac{\partial Q_{t*}}{\partial x} = 0$$

33

Equilibrium vs. Non-Equilibrium Transport

Equilibrium

- Pros
  - Simpler
  - Computationally efficient
  - Less parameters
  - Works well for large-scale models
- Cons
  - Less realistic
  - Breaks down for high-resolution models

Non-Equilibrium

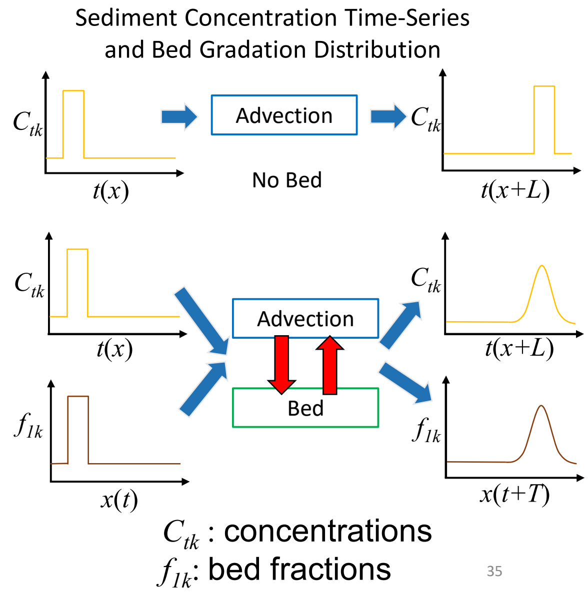
- Pros
  - Physically-based
  - Works for all scales
- Cons
  - Computationally expensive
  - More parameters to calibrate

34

34

Dispersion from Bed Mixing

- Most natural conditions are **advection-dominated**
- Diffusion is utilized here to describe the horizontal mixing of sediment **in the water column** due to turbulent mixing and dispersion
- **Dispersion** of bed material also occurs due to the bed mixing
    - Bed provides a storage mechanism



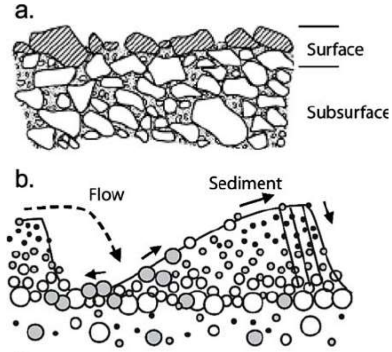
35

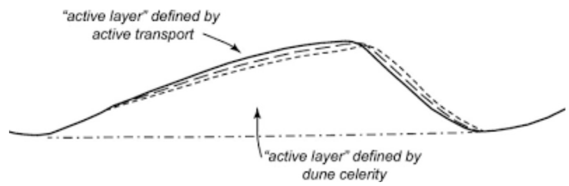
35

36

Active Layer

- Top bed layer which exchanges material with transport
- Grain size, scale, and time dependent
- At modeling scales is at least half the bed form thickness
- Active layer should be thicker for very dynamic models or models with coarse grids and large time steps



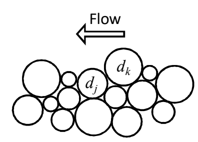


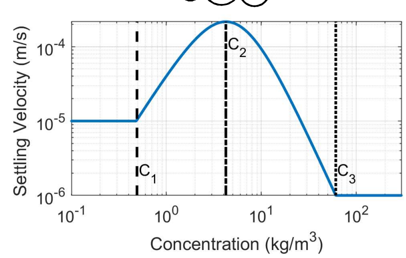
37

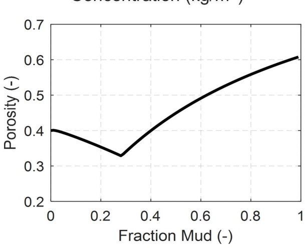
37

HEC-RAS 2D Sediment

- Key Features
  - Mixed cohesive and non-cohesive
  - Variable particle and bed bulk density
  - Quasi-3D effects
  - Hiding and exposure corrections
  - Bed-slope effects
  - Bed roughness predictors
  - Packing model for bed porosity
  - Avalanching
  - Hindered settling
  - Flocculation $f(C,T)$
  - Consolidation
  - Vertically varying cohesive properties
  - Sheet and splash erosion
  - Morphologic Acceleration
  - **Subgrid bathymetry, bed sorting, erosion, deposition, and hydrodynamics**



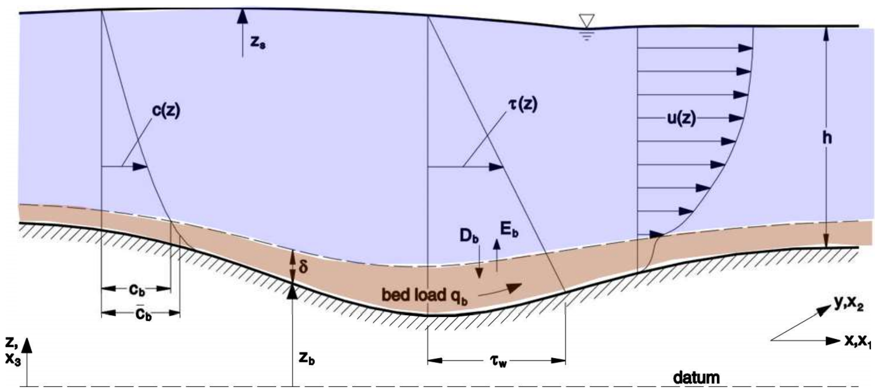




38

38

Sediment Model Definitions



Volumetric Bed-load transport: $q_b = C_b u_b \delta_b$

C_b = volumetric concentration in the bed-load layer
u_b = particle velocity (m/s)
δ_b = thickness of bed-load layer (m)

Suspended-load transport: $q_s = \int_{\delta_b}^{h} ucdz$

39

Concentration Definition

- **Depth-averaged**

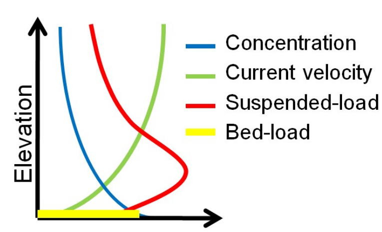
$$\hat{C}_{tk} = \frac{1}{h}\int_0^h c_{tk}dz \qquad q_{tk} = \beta_t U h \hat{C}_{tk} \qquad \beta_t = \frac{1}{Uh\hat{C}_{tk}}\int_0^h uc_{tk}dz$$

  - Coefficient for transport (advection term)
  - **Used in HEC-RAS 1D**

- **Velocity weighted** (Einstein definition)

$$C_{tk} = \frac{1}{Uh}\int_0^h uc_{tk}dz \qquad q_{tk} = UhC_{tk}$$

  - Simpler formula for transport (advection term)
  - **Used in HEC-RAS 2D**
  - Coefficient in temporal term



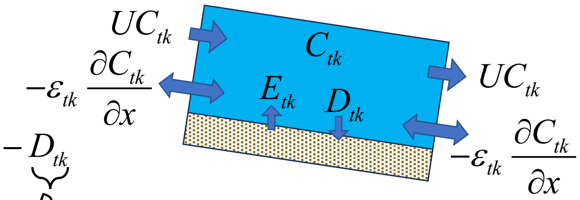
40

40

Total-load Transport Equation

- Unsteady Advection-Diffusion Equation

$$\underbrace{\frac{\partial}{\partial t}\left(\frac{hC_{tk}}{\beta_{tk}}\right)}_{\text{Temporal or Storage}} + \underbrace{\nabla\cdot\left(h\mathbf{U}C_{tk}\right)}_{\text{Advection}} = \underbrace{\nabla\cdot\left(\boldsymbol{\varepsilon}_{tk}h\nabla C_{tk}\right)}_{\text{Diffusion}} + \underbrace{E_{tk}}_{\text{Erosion}} - \underbrace{D_{tk}}_{\text{Deposition}}$$



- Simulating total-load instead of separate bed- and suspended-loads reduces computational costs because it requires half as many transport equations

k : Grain class
h : Water depth
C_{tk} : Total-load concentration
β_{tk} : Total-load correction factor
$\mathbf{U}$: Current velocity
$\boldsymbol{\varepsilon}_{tk}$: Total-load diffusion coefficient
E_{tk} : Total-load erosion rate
D_{tk} : Total-load deposition rate

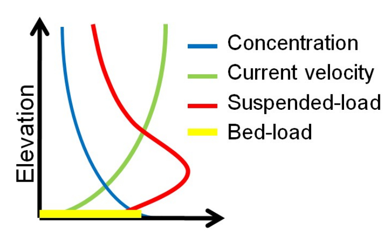
41

41

Load Correction Factor

- Accounts for vertical shape of concentration and velocity profiles
- Represents the reduction in sediment transport velocity and delay in sediment response
- Total-load correction factor

$$\beta_{tk} = \frac{1}{r_{sk}/\beta_{sk} + (1-r_{sk})/\beta_{bk}}$$



$$r_{sk} = \frac{q_{sk}}{q_{tk}}$$

- Suspended load correction factor

$$\beta_{sk} = \frac{1}{UhC_{tk}}\int_0^h uc_k dz$$

- Bed load correction factor

$$\beta_{sk} = \frac{u_{bk}}{U}$$

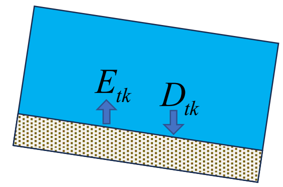
42

42

Bed Change

- Fractional Bed Change

$$\underbrace{\rho_{sk}(1-\phi_b)\frac{\partial z_{bk}}{\partial t}}_{\text{Bed change}} = \underbrace{D_{tk}}_{\text{Deposition}} - \underbrace{E_{tk}}_{\text{Erosion}} + \underbrace{\nabla\cdot\left(\kappa_{bk}\left|q_{bk}\right|\nabla z_b\right)}_{\text{Bed slope term}}$$



- Total Bed Change

$$\frac{\partial z_b}{\partial t} = \sum_k \frac{\partial z_{bk}}{\partial t}$$

z_b : Bed elevation [L]

ρ_{sk} : Grain density [M/L^3]

ϕ_b : Bed Porosity [–]

D_{tk} : Fractional deposition rate [M/L^2/T]

E_{tk} : Fractional erosion rate [M/L^2/T]

κ_{bk} : Bedslope coefficient [–]

43

43

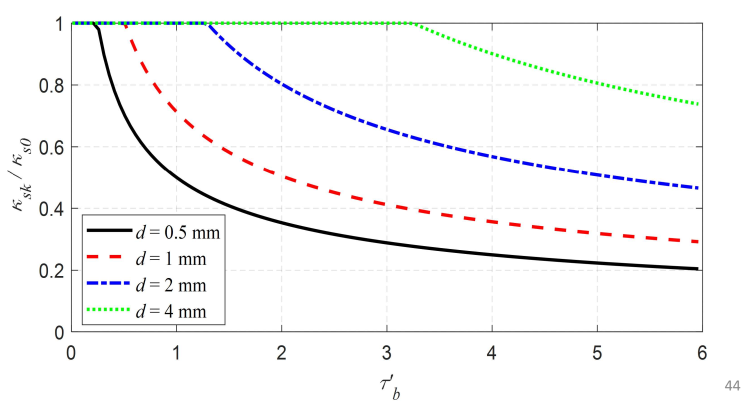
Bed Slope Coefficient

- Accounts for down-slope movement of sediment during transport
- Larger grains more influenced by bed-slope
- Bed-slope effect less with increasing transport
- Tends to smooth bed elevations and thereby improve stability

$$\kappa_{bk} = \kappa_{b0}\sqrt{\frac{\tau_{crk0}}{\max(\tau_b', \tau_{crk0})}}$$

$$\kappa_{b0} \approx 0.1 - 0.5$$

$$\nabla\cdot\left(\kappa_{bk}\left|q_{bk}\right|\nabla z_b\right)$$

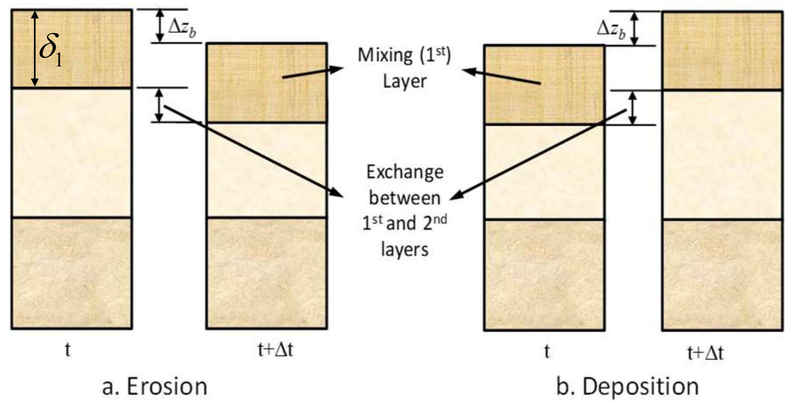


44

44

Bed Sorting and Layering

- Bed divided into discrete layers
- Each layer has a bed gradation
- Top layer referred to as the active layer
- Active layer exchanges material with transport
- Exchange between first and second layers



$$\delta_1 = \max\left(f_{1,90} d_{90}, 0.5\Delta, \delta_{1,\min}\right)$$

Δ : Bedform height

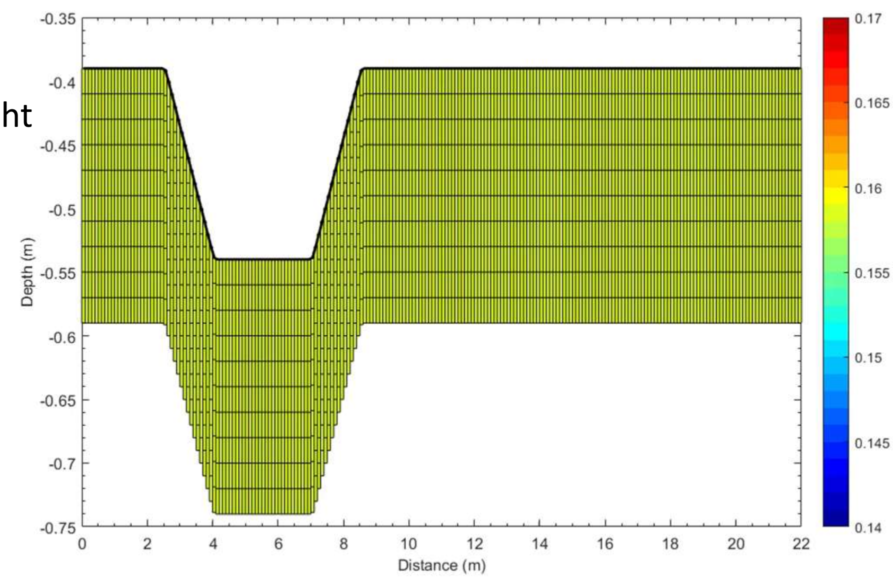
45

45

Bed Layering Example

- Flume experiment
- Flow from left to right
- 10 layers

Color Indicates Median Grain Size



46

46

Notes on Bed Sorting Model

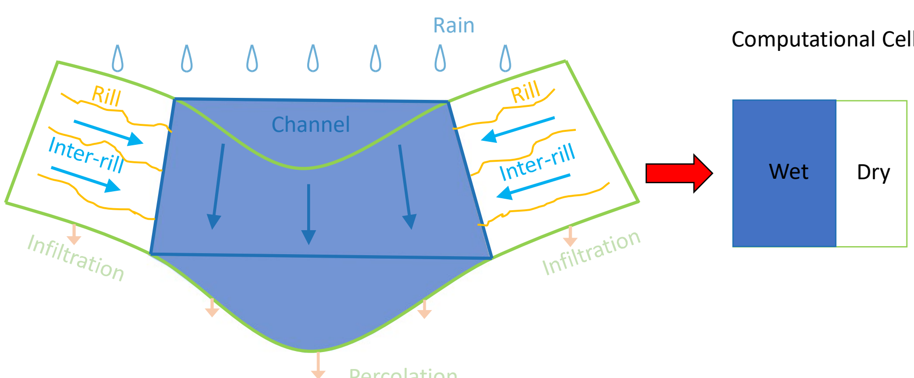
- Two types
  - ► Constant Bulk Density Model
  - ► Variable Bulk Density Model
- Automatically selected based on input input
- Constant bulk density model is simpler, faster, and more stable obviously because it has few

47

47

Subgrid Modeling

- Representation of the physical terrain and processes at a subgrid scale
- Allows for larger grid cells reducing computational cells, and computational times

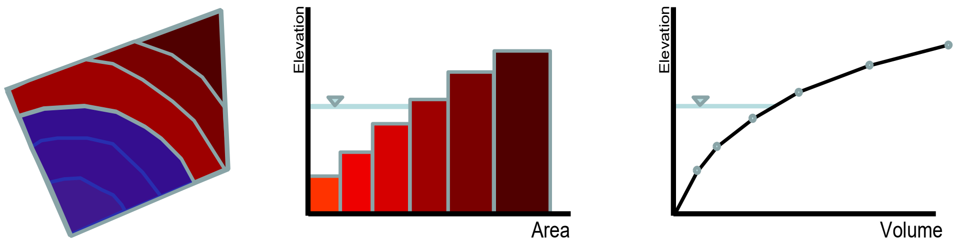


48

48

Subgrid Modeling

Hydrodynamics



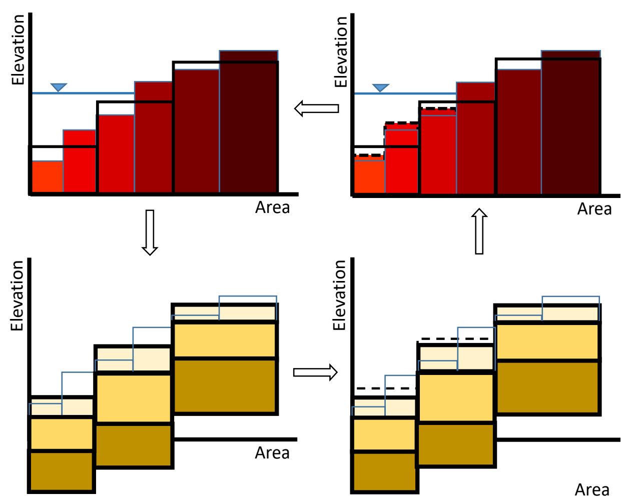
49

49

Subgrid Modeling

Flow

Sediment



50

50

Shallow Water Eqs. vs. Diffusion Wave Eq.

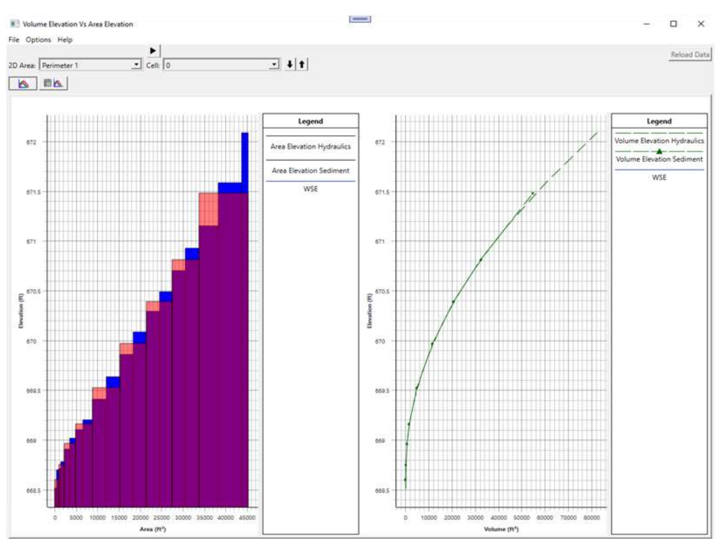
- Use SWE for:
  - Flows with dynamic changes in acceleration
  - Studies with important wave effects, tidal flows
  - Detail solution of flows around obstacles, bridges or bends
  - Simulations influenced by Coriolis, mixing, or wind
  - To obtain high-resolution and detailed flows
- Use DWE for:
  - Flow is mainly driven by gravity and friction
  - Fluid acceleration is monotonic and smooth, no waves
  - To compute approximate global estimates such as flood extent
  - To assess approximate effects of dam breaks
  - To assess interior areas due to levee breeches
  - For quick estimations or preliminary runs

51

51

Limitations

- Model initialization
- Terrain modification
- Coupling of 1D and 2D
- Dredging
- Secondary flow
- Particle infiltration/trapping



52

52

Thank You!

HEC-RAS Website:
https://www.hec.usace.army.mil/software/hec-ras/

Online Documentation:
https://www.hec.usace.army.mil/confluence/rasdocs

US Army Corps of Engineers®