Unsteady Flow Simulation of Alternate Bars in a Semi-Circle Bend

— Presented by Jennifer Duan, Ph.D., P.E.
Associate Research Professor
Desert Research Institute
University of Nevada Higher Education

SOUTHERN NEVADA SCIENCE CENTER

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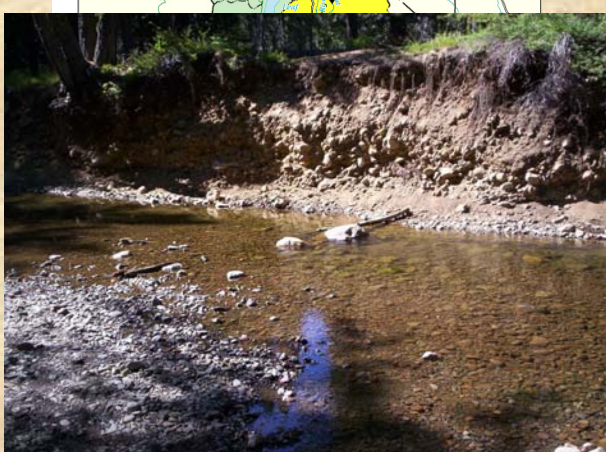
WHY STUDY SEDIMENT SORTING IN BENDS?



Tributaries to Lake Tahoe

Las Vegas Wash Meanders Into Lake Mead

WHY STUDY SEDIMENT SORTING IN BEND

- Sediment in natural rivers always consists of different sized grains with/without cobble, gravel, and sand.
- Meanders migration and alternate bars formation are driven/caused by selective sediment transport.
- The majority of sediment transport equations are for uniform sized sediment, and sorting in natural meandering streams has not been understood completely.
- Studies of vertical sorting of bed material during active bed deposition/erosion is important for designing or predicting stable rivers.

HYDRODYNAMIC MODEL: GOVERNING EQUATIONS

$$\frac{\partial(hu_j)}{\partial x_j} = 0$$

- Continuity Equation

$$\frac{\partial(hu_i)}{\partial t} + \frac{\partial(hu_i u_j)}{\partial x_j} + \frac{\partial(hD_{ij})}{\partial x_j} = -gh\frac{\partial \zeta}{\partial x_i} + \frac{\partial}{\partial x_j} h(\nu \frac{\partial u_i}{\partial x_j} - \overline{u_i^{'} u_j^{'}}) - \tau_{bi}$$

- Momentum Equation

$$-\overline{u_i^{'} u_j^{'}} = \nu_t (\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}) - \frac{2}{3} k \delta_{ij}$$

- Reynolds Stresses

$$D_{ij} = \int_{z_0}^{z_0+h} (\overline{\overline{u_i}} - u_i)(\overline{\overline{u_j}} - u_j) dz$$

- Dispersion terms

TURBULENT MODEL

The eddy viscosity is obtained from standard k-epsilon model (Rodi 1984).

$$\frac{\partial k}{\partial t}+\frac{\partial (u_j k)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[(\nu+\frac{\nu_t}{\sigma_k})\frac{\partial k}{\partial x_j}\right]+G_{ij}-\varepsilon$$

$$\frac{\partial \varepsilon}{\partial t}+\frac{\partial (u_j \varepsilon)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[(\nu+\frac{\nu_t}{\sigma_k})\frac{\partial \varepsilon}{\partial x_j}\right]+C_{\varepsilon 1}\frac{\varepsilon}{k}G_{ij}-C_{\varepsilon 2}\frac{\varepsilon^2}{k}$$

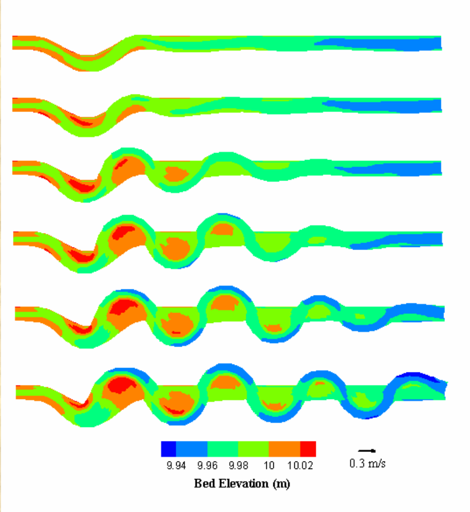
$$G_{ij}=-\overline{u_i^{'}u_j^{'}}\frac{\partial u_i}{\partial x_j}=\nu_t(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})\frac{\partial u_i}{\partial x_j}$$

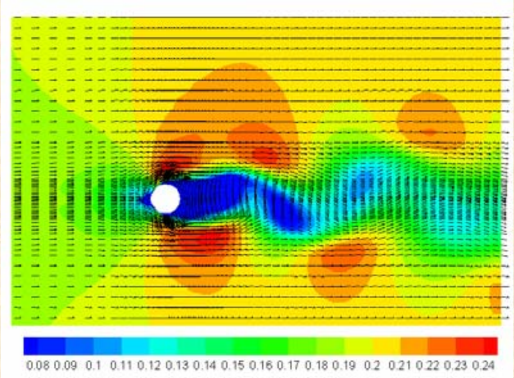
$$C_\mu=0.09,\ C_{\varepsilon 1}=1.44,\ C_{\varepsilon 2}=1.92,\ \sigma_k=1.0,\ \sigma_\varepsilon=1.3,\ \sigma=0.85.$$

Finite Element method (Hu and Wang 1990, Duan 2004) was used to solve the equation.

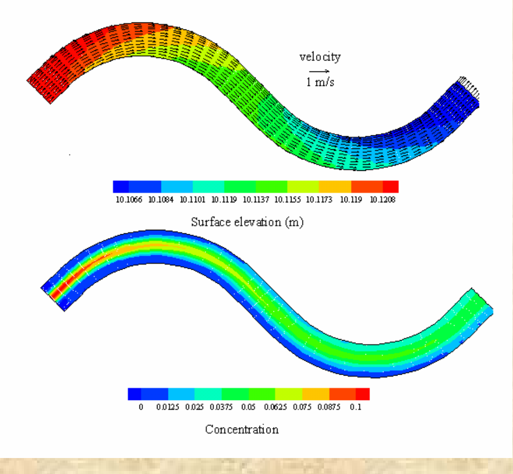
FLOW MODEL REFERNCES

Duan, J.G. and Julien, P. (2005). Numerical simulation of the inception of meandering channel, *Earth Surface Processes and Land Forms*, Vol. 30, 1093-1110.



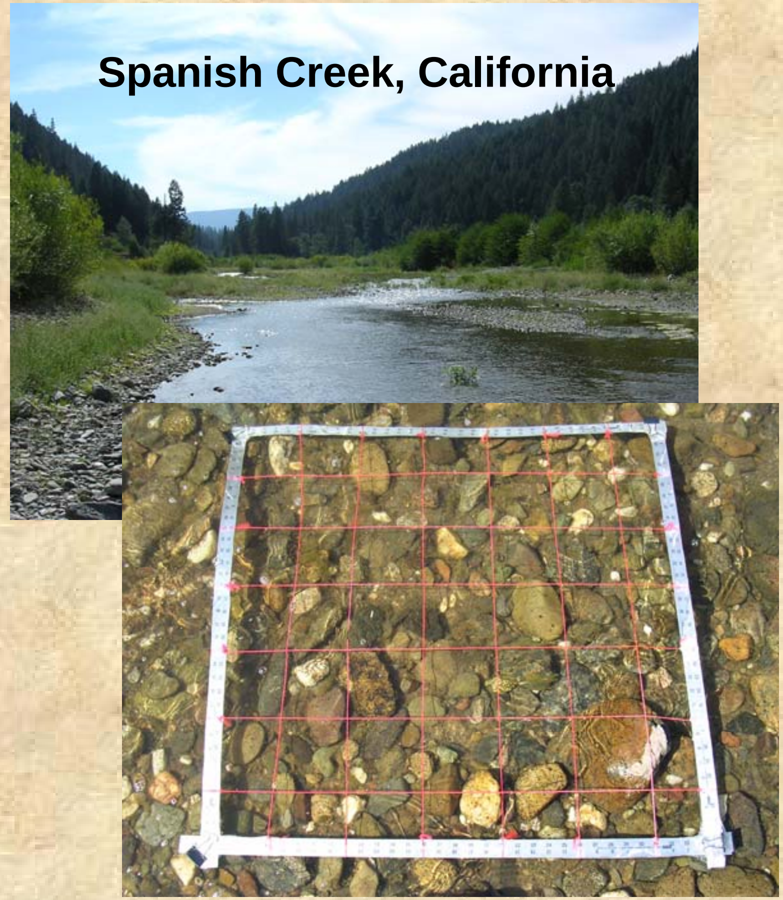


Duan, J.G., Two-dimensional simulation of flow field around bridge piers, *Journal of Hydraulic Engineering*, in review (editorial board)



Duan, J.G. (2004) Simulation of flow and pollutant dispersion in meandering channels, *Journal of Hydraulic Engineering*, Vol. 130, No.10, 964-976.

Selectivity of Sediment Transport



Sediment by nature is non-uniform (e.g. uni-mode, bi-mode, or tri-mode) and being transported selectively.

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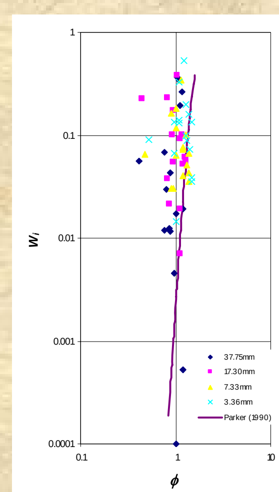
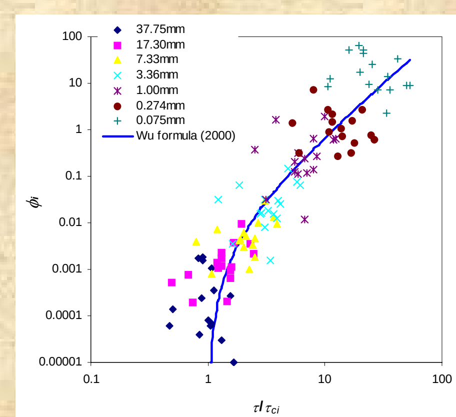
PREDICT SEDIMENT TRASNPORT BY SIZE FRACTIONS

- **Many fractional transport equations existed (Meyer-Peter 1948; Yang 1977, Parker 1982; Parker 1990; Wilcock and Crowe 2003; etc.).**
- **Surface based fractional transport equation is more appropriate if surface material layer is thick and considerably different from substrate.**
- **Different equations could predict results that are orders of magnitude different (Duan, Li, and Scott et al. JHR, in press).**

Measure Sediment in LV



Parker (1990)



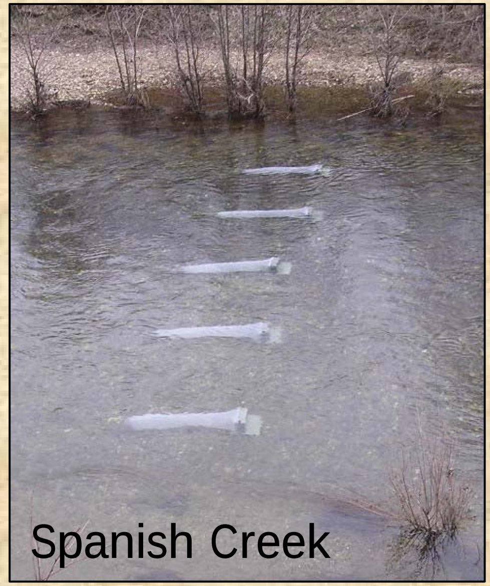
Wu et al. (2002)

OBJECTIVES

- This study aims to demonstrate the basic principles in simulating alternate bars and sediment sorting in bends.
- Sediment transport equations are selected as demonstration examples. Empirical coefficients in some equations are used as calibration parameters.
- Qualitative results will be obtained if using different sediment equations.


Spanish Creek


Las Vegas Wash


Spanish Creek

BED LOAD TRANSPORT

Shear-stress based bed load transport equation for uniform sized sediment (Meyer-Peter and Muller, 1948) was used as an example.

A hiding factor, such as Einstein (1950), is used to allocate the total transport rate to each sized fraction by using the median diameter of each individual-sized class.

$$q^*_{b,k} = (\zeta)_k \, q^*_b$$ **- transport equation**

$$(\zeta)_k = \left(\frac{d_k}{d_{50}} \right)^q$$ **- hiding factor**

where *q* is an exponent. If, q=0 bed load transport rate for each sized fraction is independent of particle size; q=1 bed load transport is size selective, and proportional to its size.

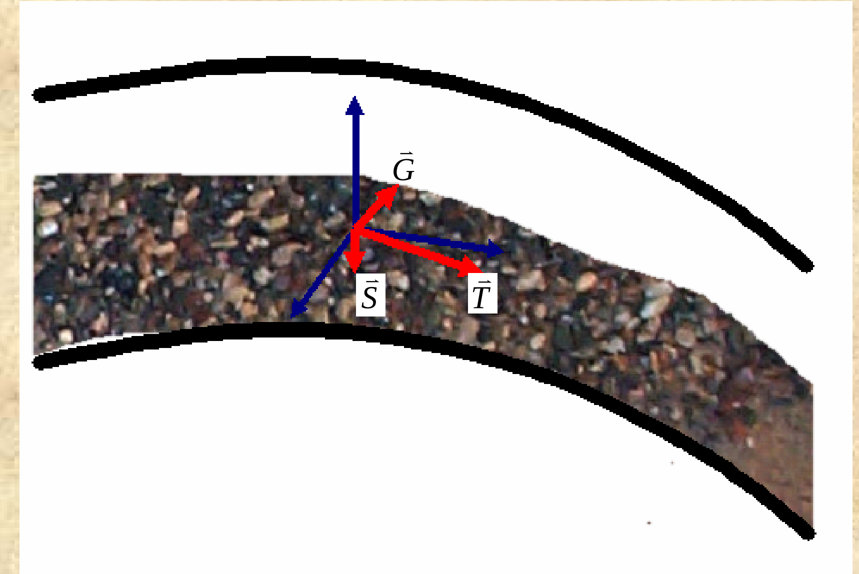
LIMITATION OF HIDING FUNCTION (Duan and Scott, WRR, in review)

- In alluvial channel beds composed of a sediment mixture, smaller particles are entrapped behind or below larger particles until they are brought into motion by turbulent bursts or sheltering particles are dislodged.
- The sheltering factor is to quantify the effect that the larger particles directly shelter the smaller ones from experiencing fluid drag force.
- The hiding factor is proportional to the ratio of shear stress acting on each individual sized particle and a characteristic particle size relating to fluid forces (e.g. shear stress) acting on bed surface.

Las Vegas Wash

San Anthony Falls Lab

WHERE BED LOAD MOVE TO?



- Incipient motion of various sized sediment particles relates to the bed slopes it resides on (e.g. streamwise and transverse slopes.)

- Secondary flow due to curvature and topography, near bed turbulence, and down-slope gravitational force drive bed-load transport deviate from streamwise direction.

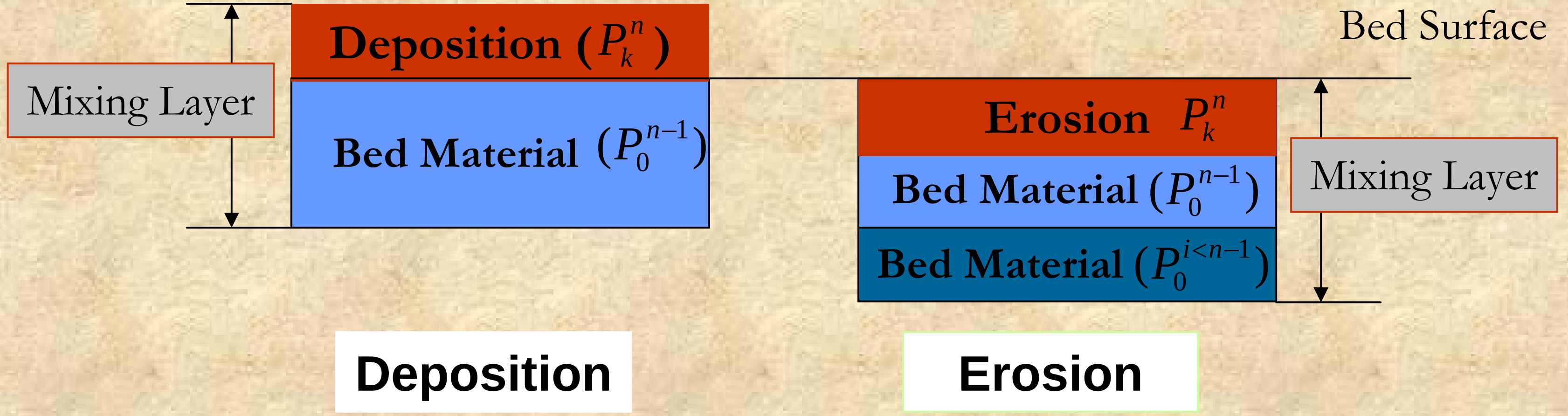
$$\tan\phi = \frac{q_n}{q_s} = \frac{u_{bn}}{u_{bs}} - \beta \frac{\partial \eta}{\partial n}$$

BED ELEVATION CHANGES

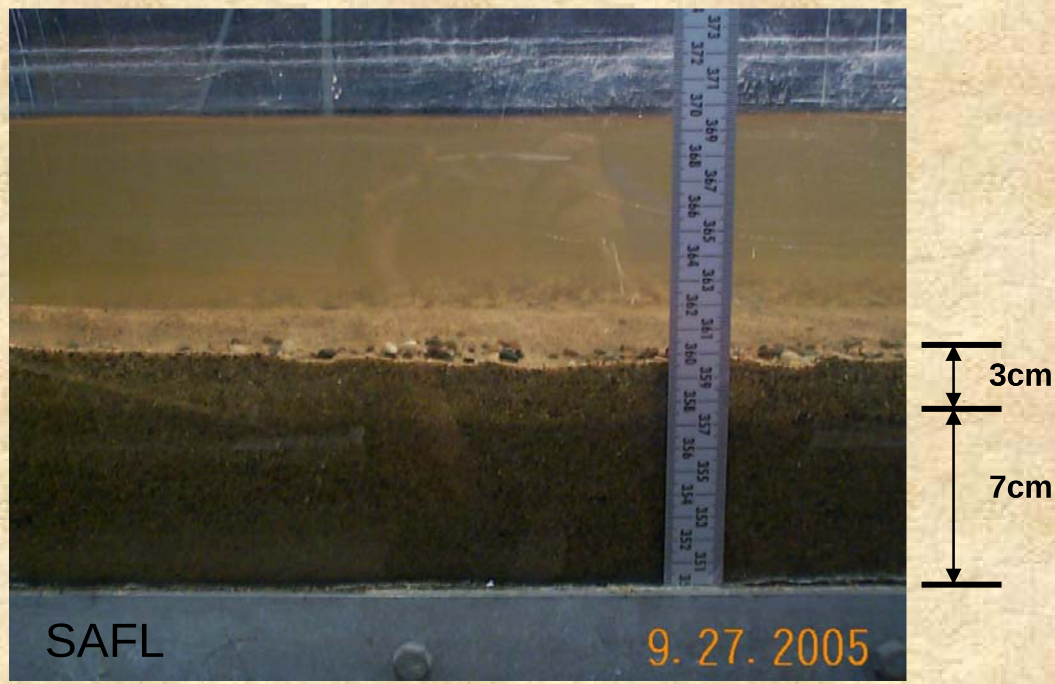
- **Sediment continuity equation was solved for bed elevation change.**

$$(1-P)\rho_m \frac{\partial Y_k}{\partial t} + (D_b - E_b)_k + \frac{\partial \alpha_x q_{b,k}}{\partial x} + \frac{\partial \alpha_y q_{b,k}}{\partial y} = 0$$

- **Sediment gradation in the mixing layer was determined as**



MIXING LAYER

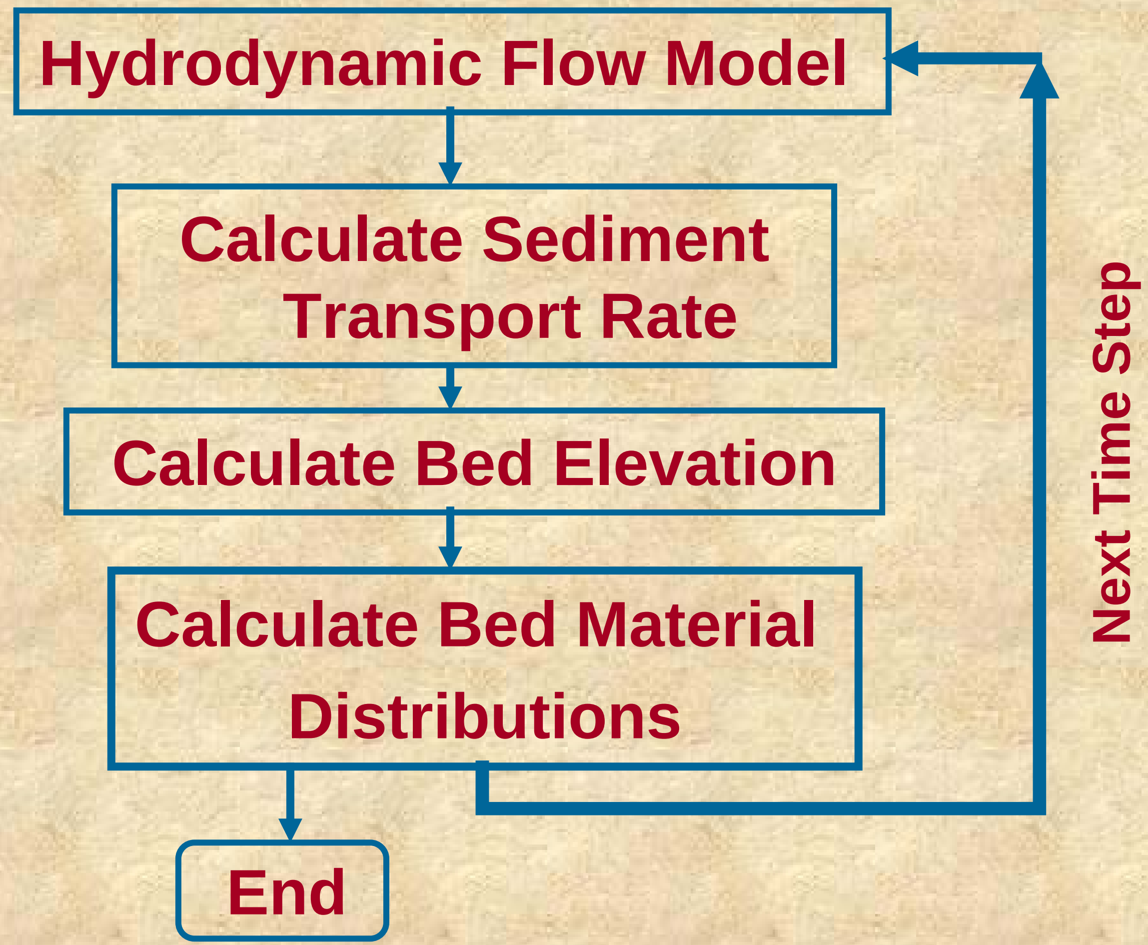


Definition: Mixing layer is the layer of sediment participating in bed load transport.

Depth: Mixing layer depth =2.0*D90, or others in literature found to be too small.

In this model, the depth of mixing layer is assumed equal to a fraction of the initial bed material depth (20%) , and remains the same during the simulation.

FLOWCHART OF DEVELOPED MODEL



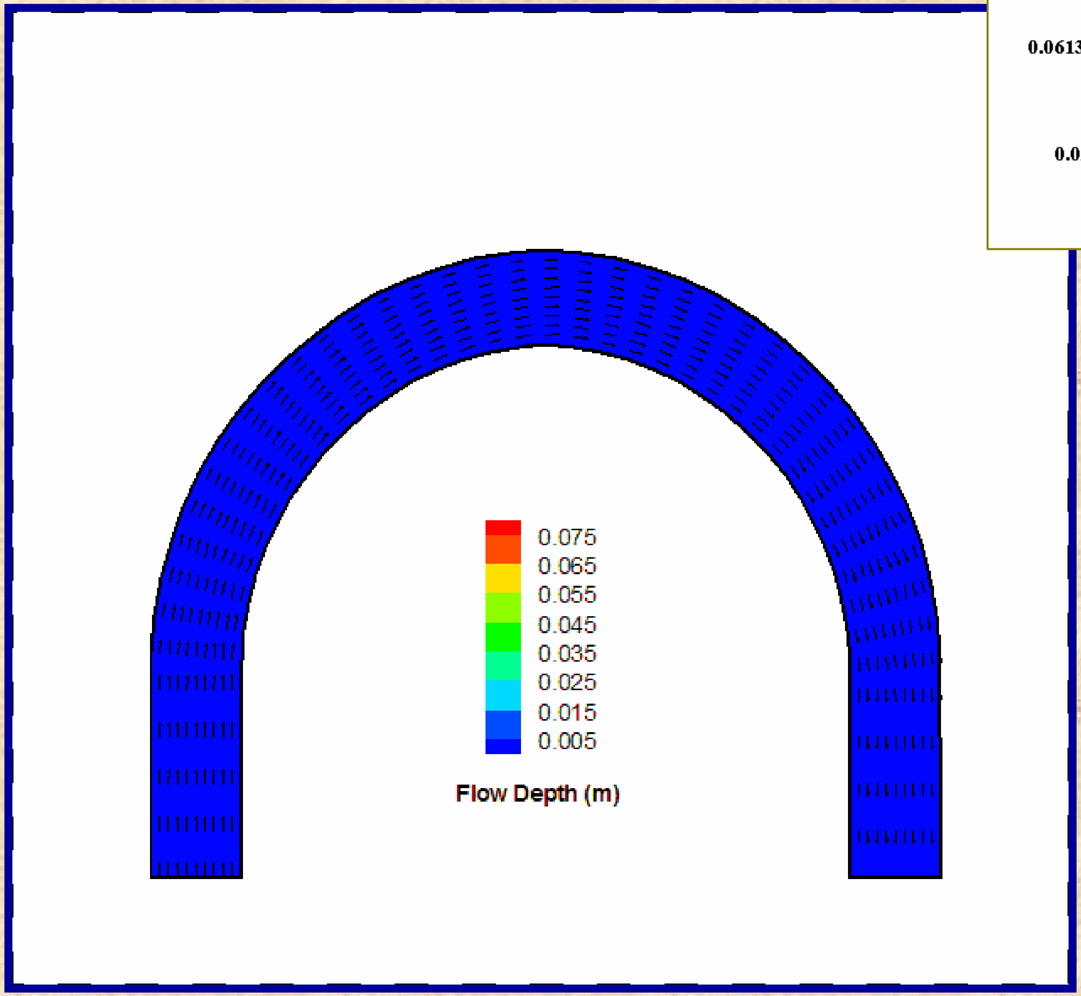
MODEL TESTING EXPERIMENT

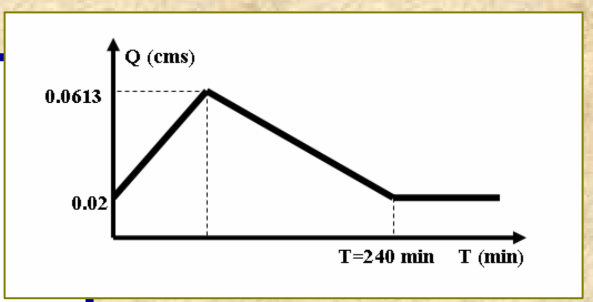
- Yen and Lee (1995) conducted experiments in a laboratory channel bend having a central angle of 180.
- Channel width is 1m and the radius of centerline curvature is 4m.
- A 20cm thick layer of sand with eight different size groups was placed .
- Hydrographs with a base flow of 0.02cms and the maximum peak flow of 0.0613cms were released at the upstream.

Table 1. Hydraulic Parameters of Experimental Run #3

Peak Flow Discharge (m3/s)	0.0613
Peak Flow Depth (m)	0.113
Duration of Rising Limb (min)	80
Duration of Hydrograph (min)	240

SIMULATED RESULTS

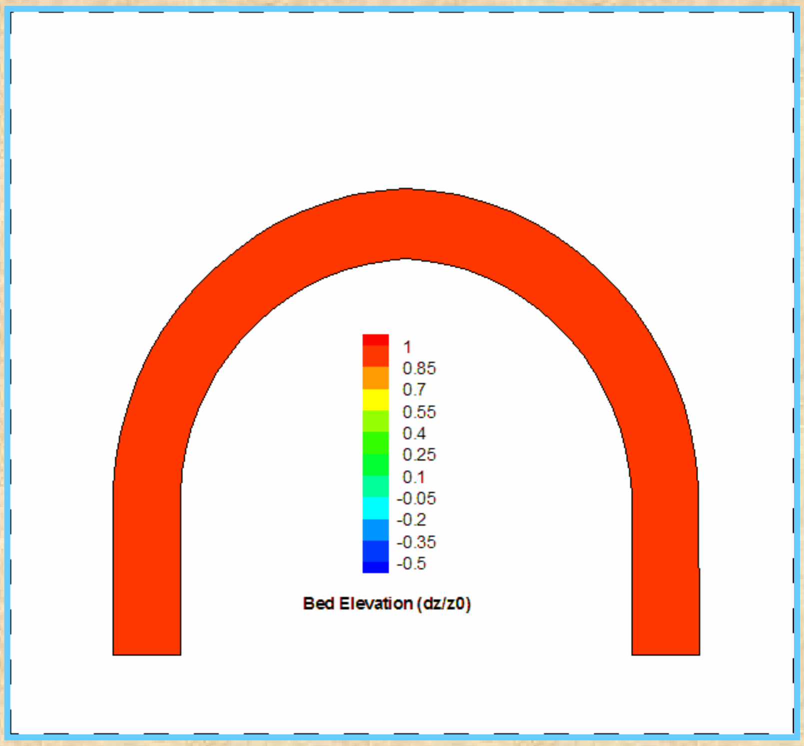


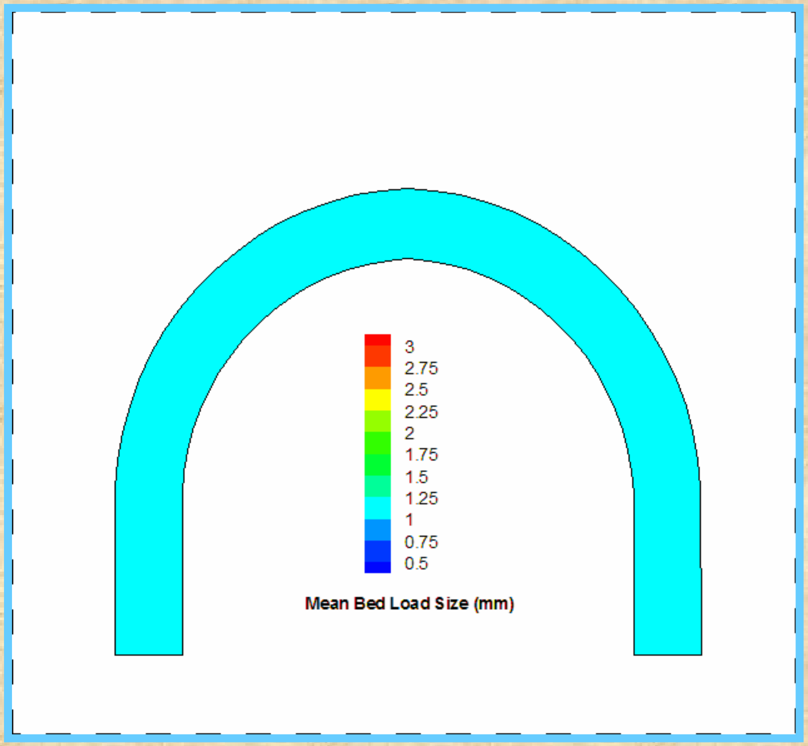


Hydrograph

Flow Depth and Velocity Vector

SIMULATED RESULTS



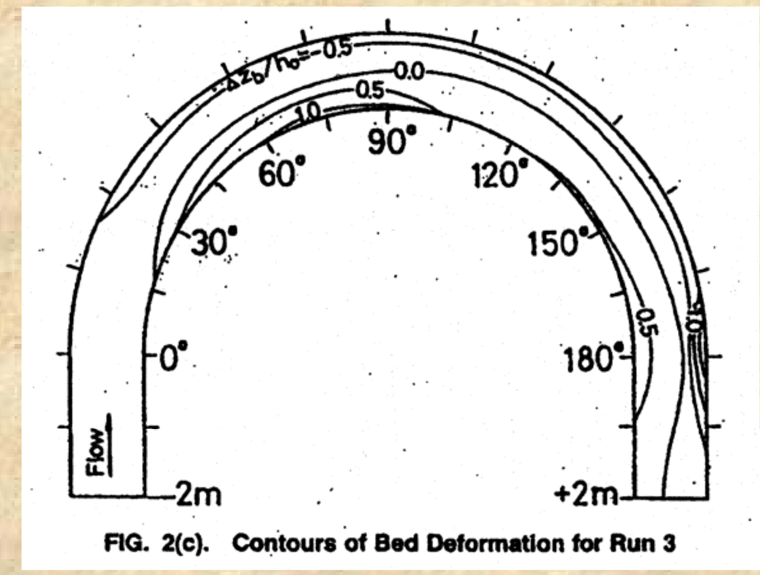


Bed Elevation Changes

Mean Sediment Sizes

Comparisons of Calculated and Measured

Measured



Simulated

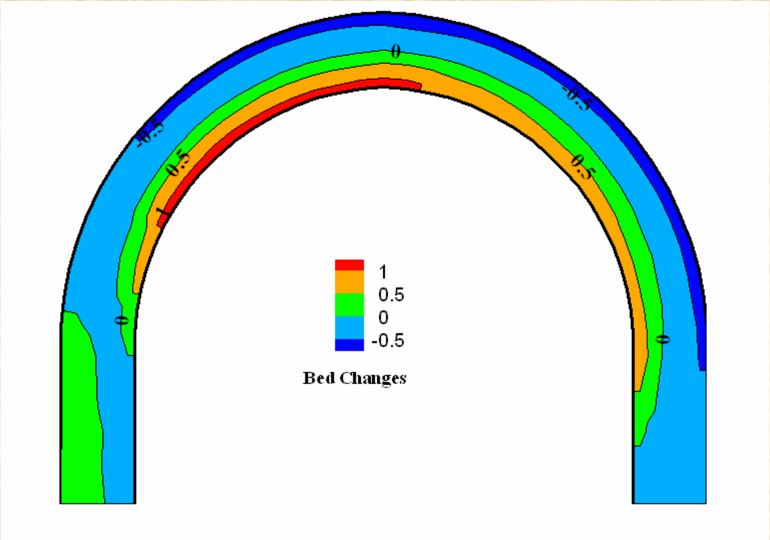


Figure 1. Comparison of Simulated and Experimental Measurements of Bed Elevation Changes for Run #3.

Comparisons of Measured and Calculated

Measured

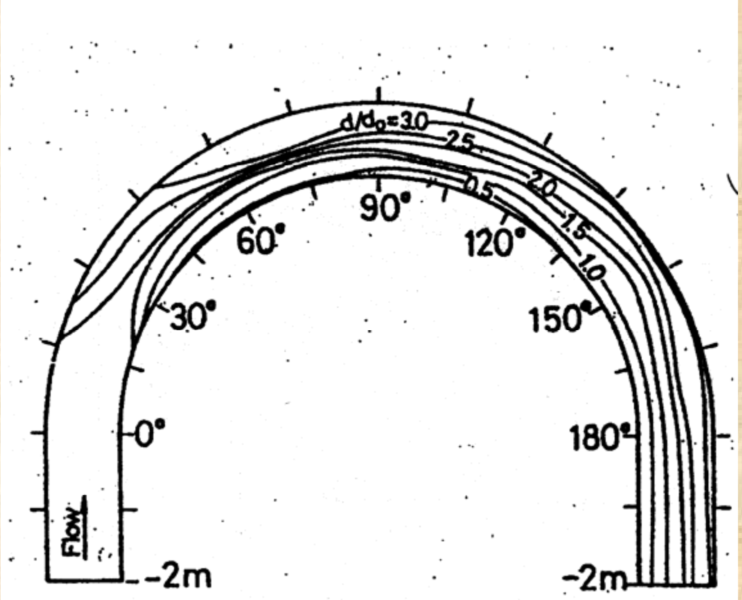


FIG. 3(c). Contours of Median Sediment Size for Run 3

Simulated

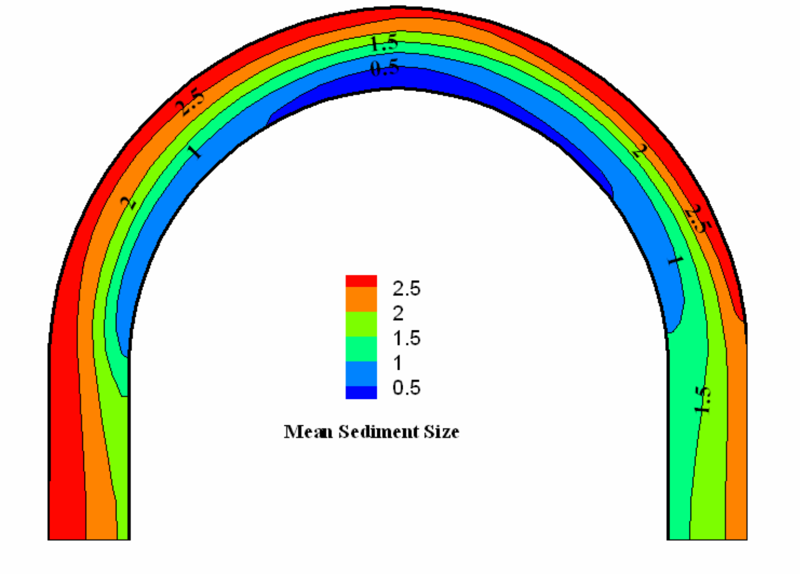


Figure 2. Comparison of Simulated and Experimental Measurements of Sediment Size Distribution for Run #3.

CONCLUSIONS

- Formations of alternate bars in meandering stream are dominated by fractional bed load transport and sediment sorting in both longitudinal and transverse directions.
- Bed load sorting relates to flow field (mean and fluctuated near bed turbulence), sediment size, bed topography.
- The depth of mixing layer and the exchange between bed load and mixing layer can not be quantitatively simulated, and further physical experimental studies are needed.
- Besides empirical bed load equations, discrete particle dynamic model could be another method to simulate selective bed load transport.

ACKNOWLEDGEMENT

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Related Publications in Sediment Transport

Duan, J. G., Chen, Li, and Scott, S. Application of fractional bed load transport equations to a desert gravel -bed stream, *J. Hydraul. Research*, in press.

Duan, J. G., Chen, L., and Barkdoll, B. Surface-based fractional transport predictor: deterministic or stochastic, *J. Hydraul. Eng.*, in review.

Duan, J. G. and Scott, S. Bi-modal fractional bed load transport, *Water Resources Research*, in review.

Duan, J.G. (2005). Analytical approach to calculate the rate of bank erosion. *J. Hydraul. Eng.*, Vol.131, No. 11.

Chen, D. and Duan, J.G. (2005). Modeling width adjustment in meandering channels, *Journal of Hydrology*, doi:10.1016/ j.jhydrol.2005.07.034.