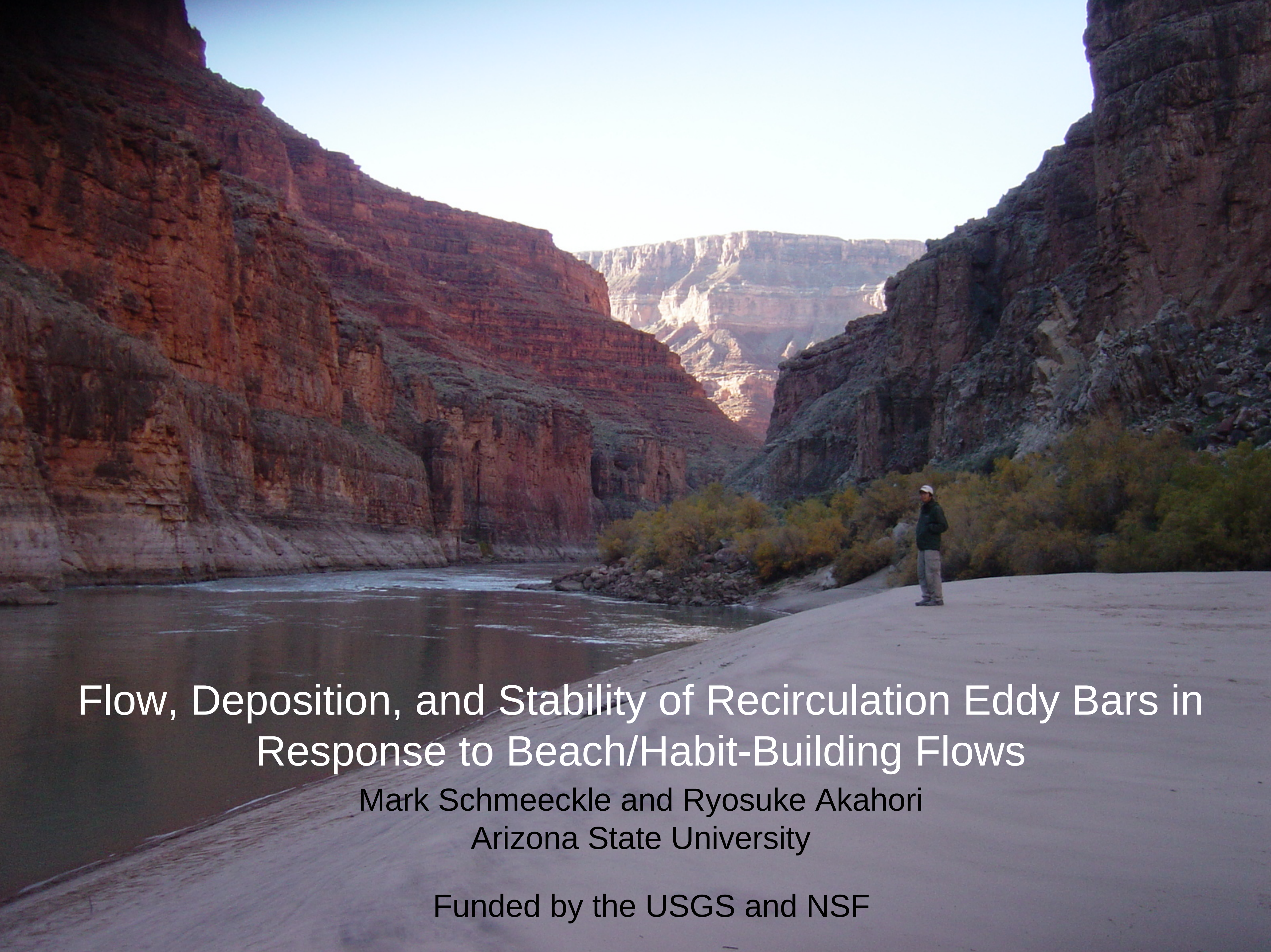

Flow, Deposition, and Stability of Recirculation Eddy Bars in Response to Beach/Habit-Building Flows

Mark Schmeeckle and Ryosuke Akahori
Arizona State University

Funded by the USGS and NSF

Main Questions

- How is sediment deposited in recirculation eddy beach bars during BHBFs?
- How is sediment eroded in response to flows of various types of flows after a BHBF?
- Are flow constraints specified in the ROD overly or under-restrictive in promoting beach stability?

Beach Erosion Mechanisms

- Turbulent transport when beach is underwater
- Seepage erosion/piping and rilling by groundwater outflow during falling stage
- Failure by elevated groundwater pore pressure during
- Wave erosion

From the EIS of 1995

The sandbar slope stability model of Budhu (1992) is applied in this EIS (see figure III-20). Sandbars are initially deposited at angles ranging from 20 to 45 degrees with an average of 26 degrees. As the river stage recedes, this slope may be unstable. Seepage-induced erosion tends to reduce the slope of new deposited sands to about 11 degrees. On some sandbars, a rapid decrease in river stage sets up conditions for bar failure. The next rising river stage (at almost any ramp rate) could easily cause a failure to occur.

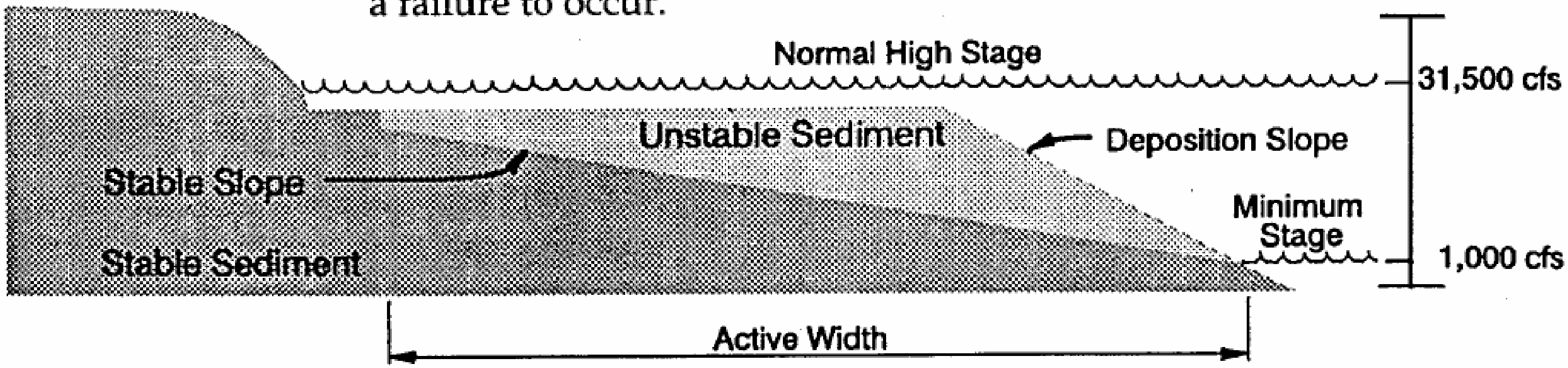

Figure III-20.—Conceptual cross section of a sandbar affected by fluctuating flows. Daily fluctuations create an unstable zone within the sandbar. The minimum stage determines the boundary between the stable and unstable zones.

From Budhu (1992)

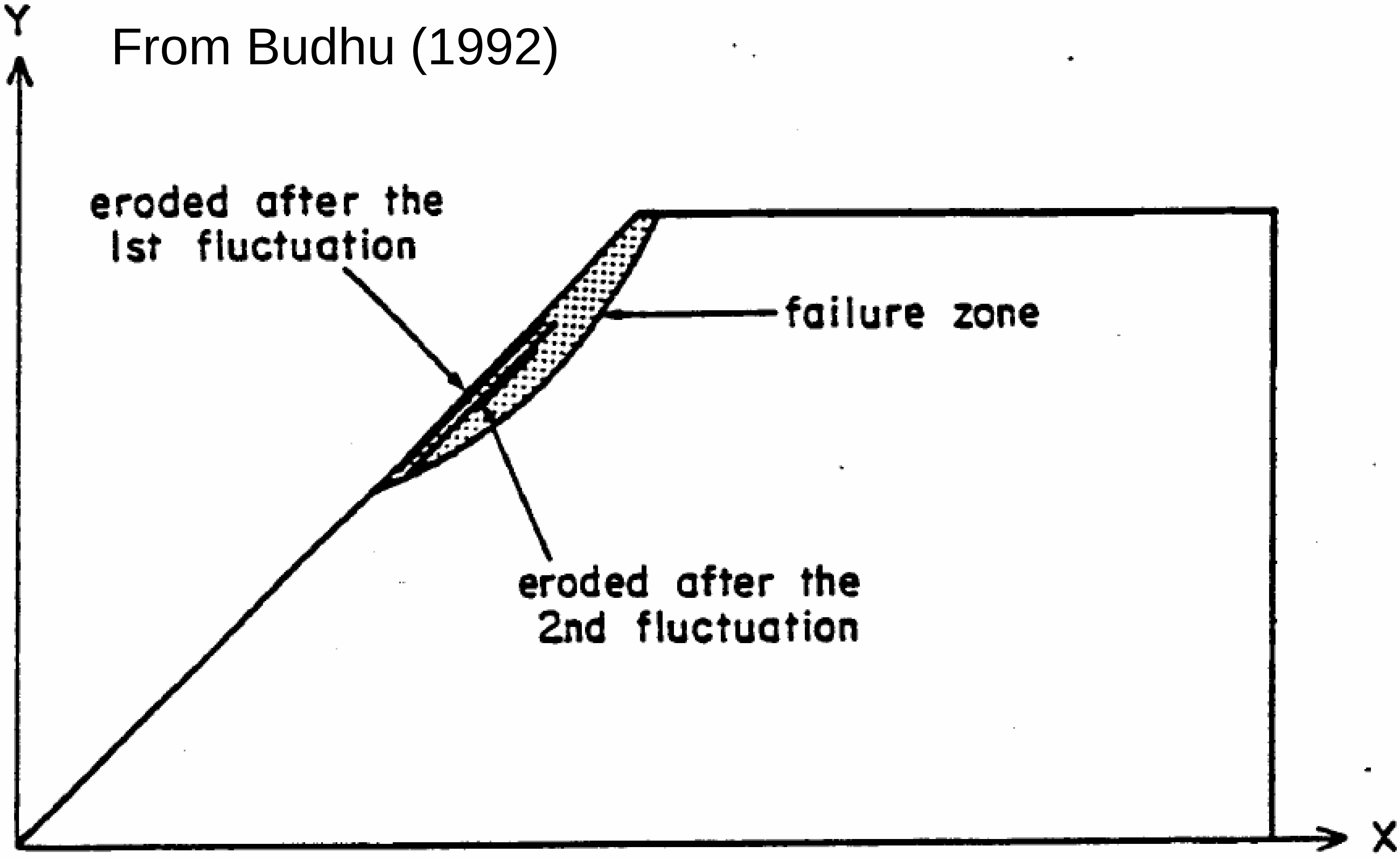

Fig. 20 Model prediction of seepage driven erosion.

From Budhu (1992)

TABLE 1: FLOW RATES TO PREDICT EROSION

CASE NUMBER	Up ramping RATE $m^3/s/hr$	Down ramping RATE $m^3/s/hr$	COMMENTS
1	48.1	48.1	
2	29.0	145	
3	25.5	386.9	
4	116.0	30.4	
5	9.6, 103	77.3	
6	70.8	34	*GCESEIS 3
7	113.2	70.8	*GCESEIS 4
8	141.5	113.2	*GCESEIS 5

*Glen Canyon Dam EIS Alternatives provided for comparison with model up ramping rates

Note: The current Record of Decision requires a maximum upramp rate of 113 m^3/s/hr and downramp rate of 42 m^3/s/hr.

From Budhu (1992)

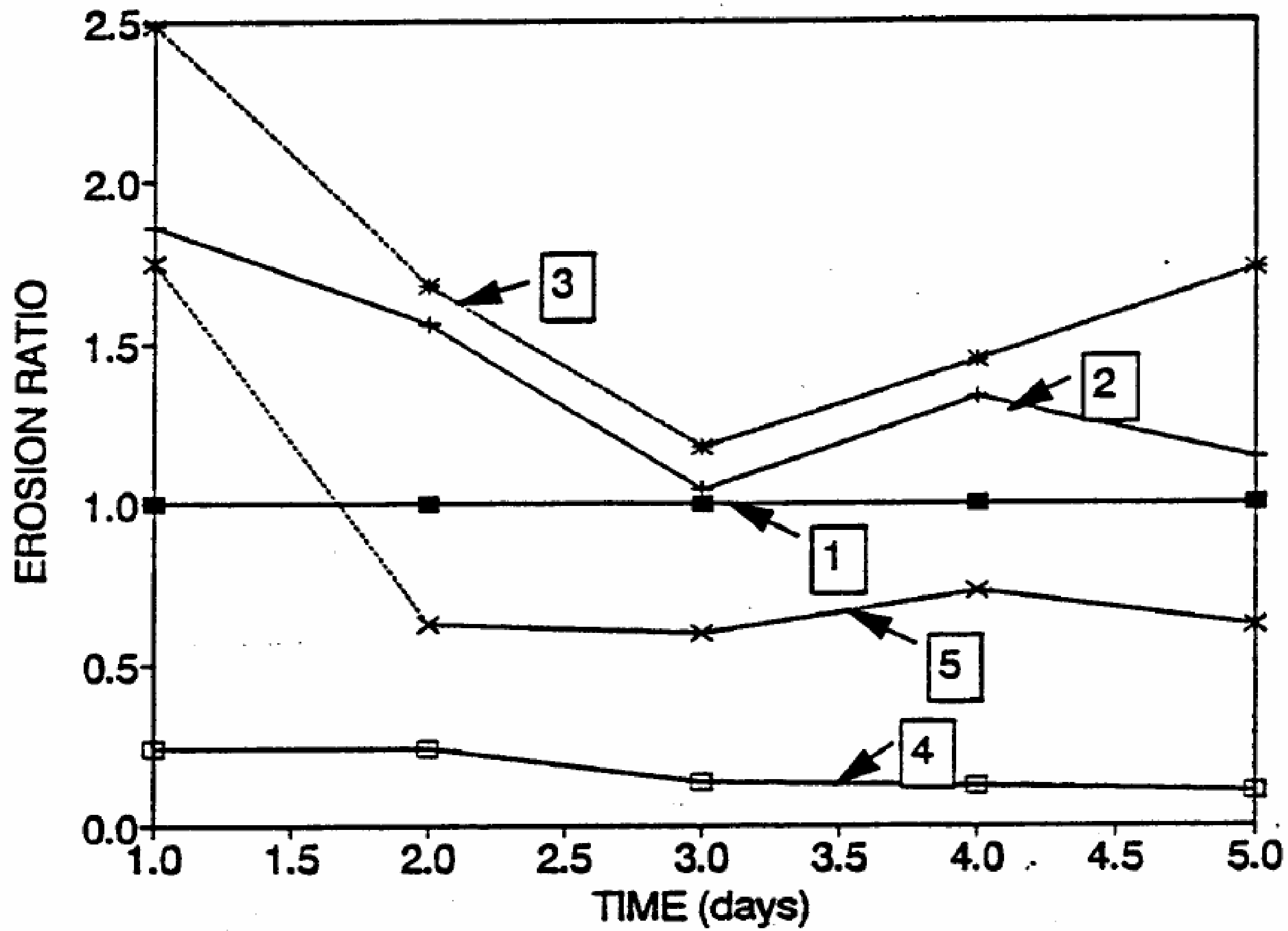

Fig. 21 Model prediction of erosion for various discharge regimes.

The predicted erosion for the selected flow regimes are shown in Fig. 21. The volume of erosion for the minimum up ramping and the minimum down ramping discharge rate (case 1) was used to normalize the results of the model predictions.

From Budhu (1992)

TABLE 1: FLOW RATES TO PREDICT EROSION

CASE NUMBER	Up ramping RATE $m^3/s/hr$	Down ramping RATE $m^3/s/hr$	COMMENTS
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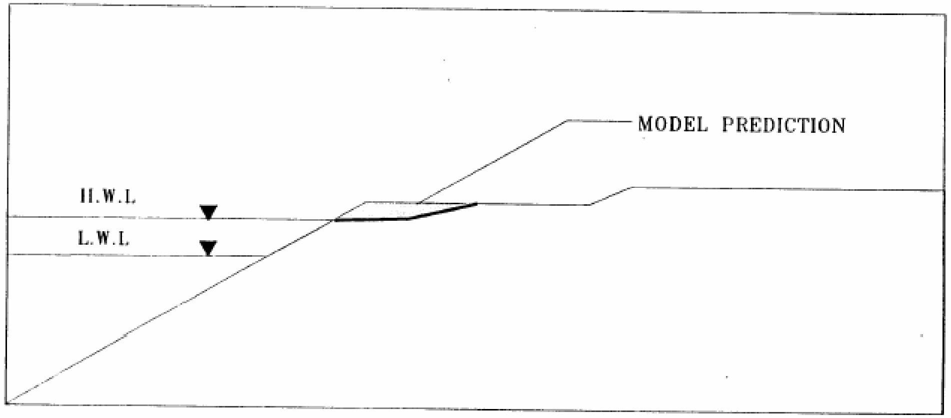


Fig. 29 Seepage-stress model prediction of mass wasting under EAS 4 for sand bar 172L.

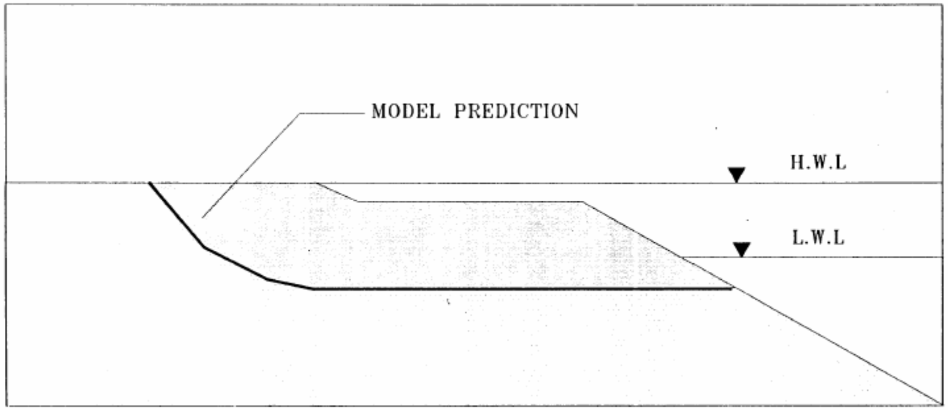


Fig. 30 Seepage-stress model prediction of mass wasting under EAS 5 for sand bar 172L.

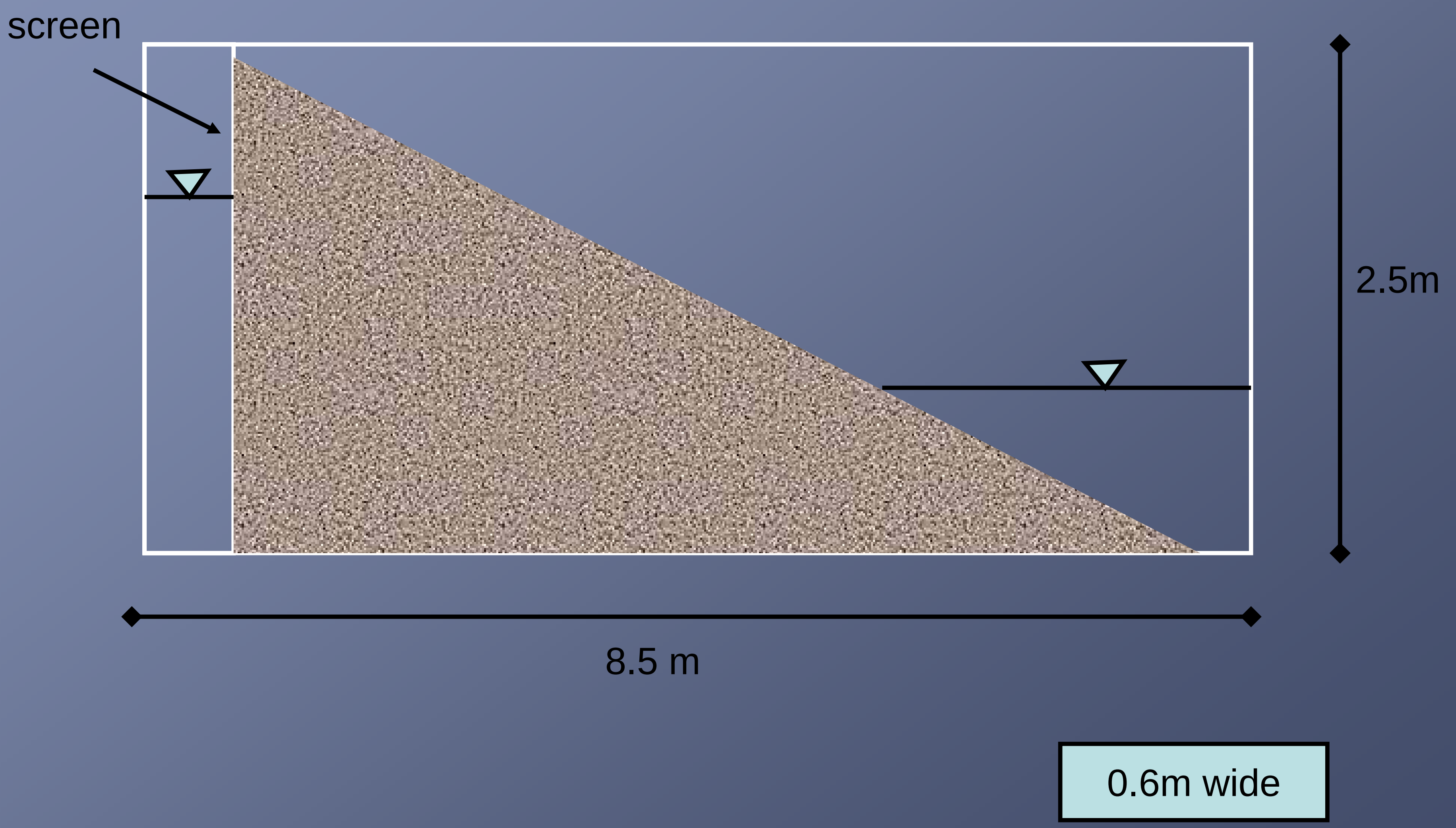
Comprehensive model of beach stability

- NAU (Springer, Sabol, and others) groundwater flow experiments and models
- ASU working on 3-D eddy model of erosion and deposition; seepage erosion experiments; cohesive sediments
- USGS GCMRC (Wright, Melis, Topping, Brown, and others) – Field measurement of flows, bar response, sedimentology

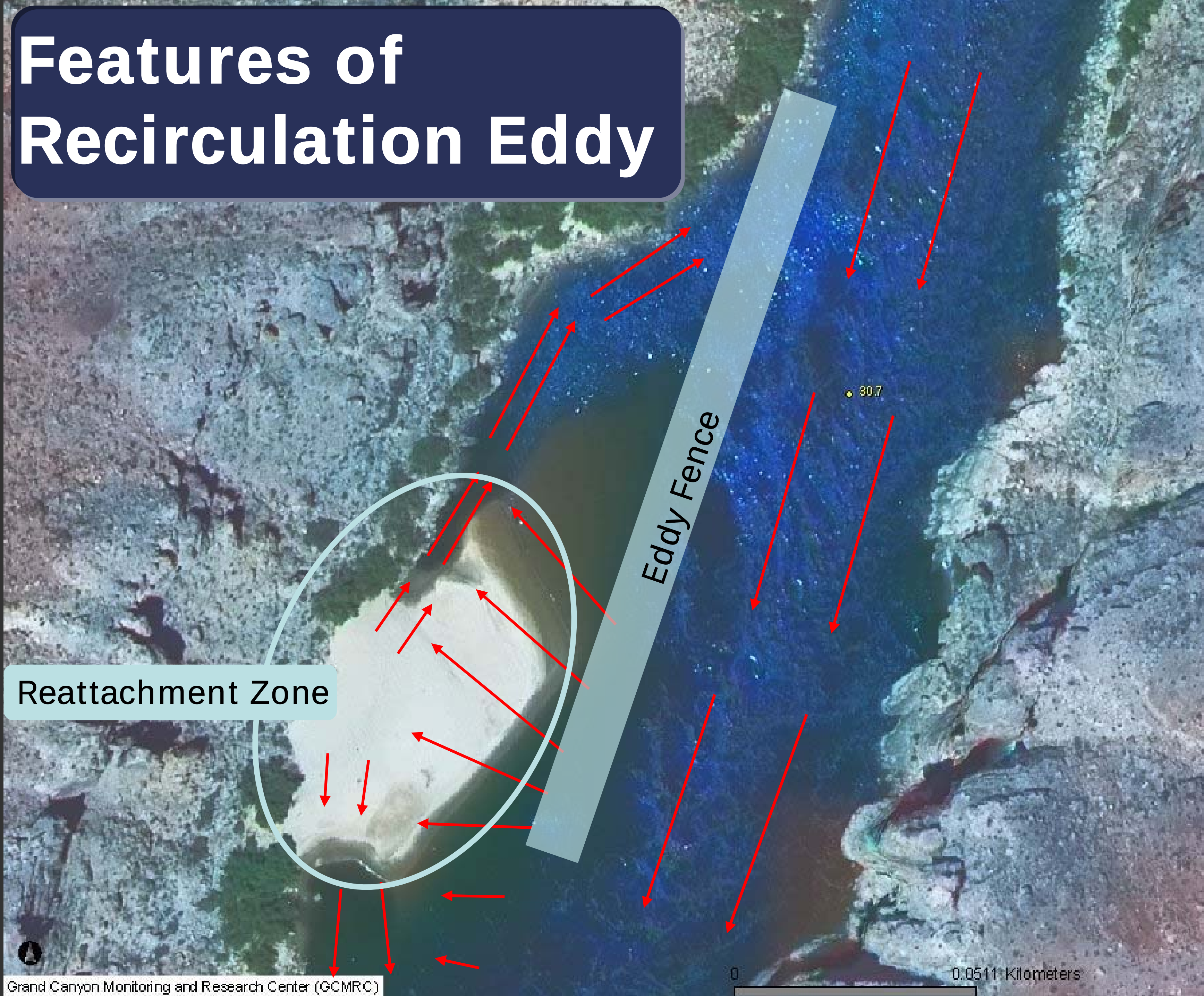
30 Mile Sandbar Before Flood

30 Mile Sandbar After Flood

Beach Stability Slot

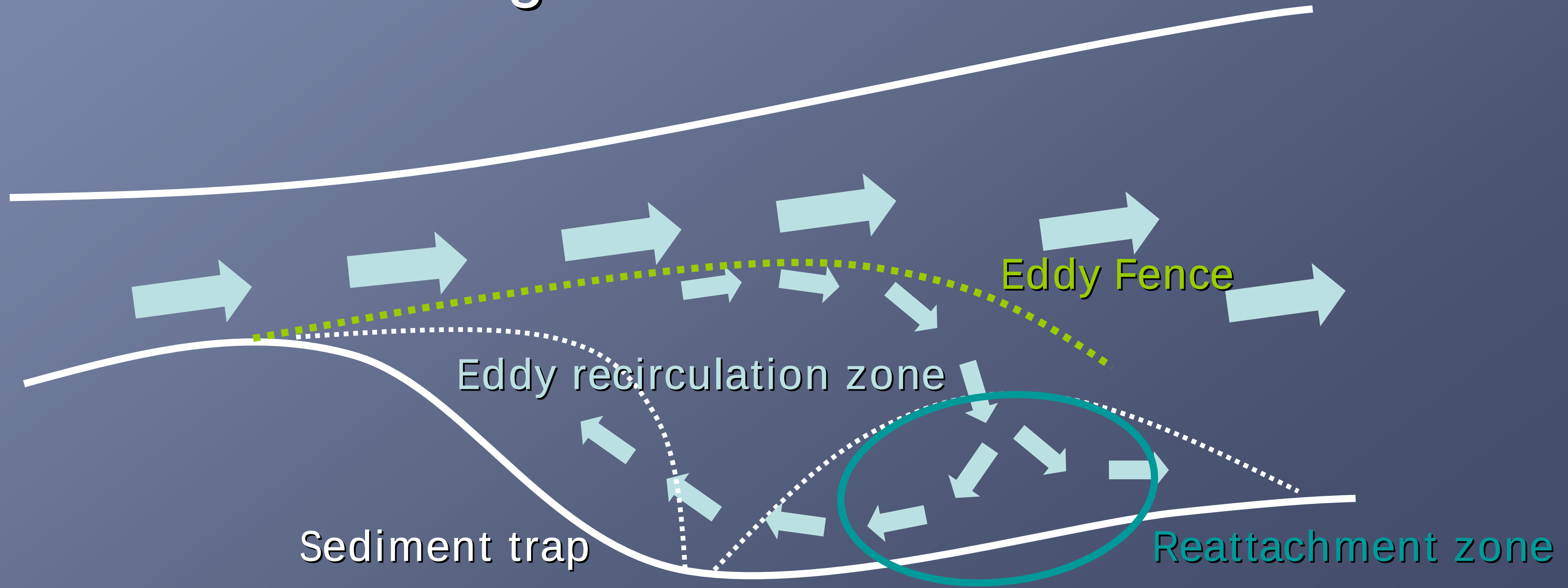


Features of Recirculation Eddy



Features of Recirculation Eddy

- Eddy Recirculation zone
- Eddy Fence (Free Shear Layer)
- Reattachment zone
    - intense large scale turbulence



Previous Numerical Approaches

- 2-D depth averaged model

  -Can't treat secondary flow

  -Relies on adjusting unknown lateral diffusion

- 2-D/ Quasi 3-D models w/ secondary flow based on streamline curvature

  -Unknown secondary flow structure in recirculation zones w/ complex topography

- RANS 3-D model (e.g. k-ε)

  -Cannot capture time variability in the reattachment zone -especially large scale turbulence produced along the free shear layer

Previous Numerical Approaches

- Some models assume hydrostatic pressure
  - Flow at the point of separation and reattachment zone have large advective accelerations in the vertical momentum equation
- Most models assume either a rigid lid or no time-variance of the water surface
  - Time variance of the water surface is critical to accurately model large scale turbulence
  - Adequacy of assuming a rigid lid has not been proven

Employed Features

- Full 3-dimensional equations (non-hydrostatic)

- Large Eddy Simulation (LES) turbulent model – no time-averaging

- Body Fitted Coordinates (BFC) system and Moving Grid system – free water surface

Full 3D Equations

Continuity Equation

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum Equations
(Navier-Stokes Equation)

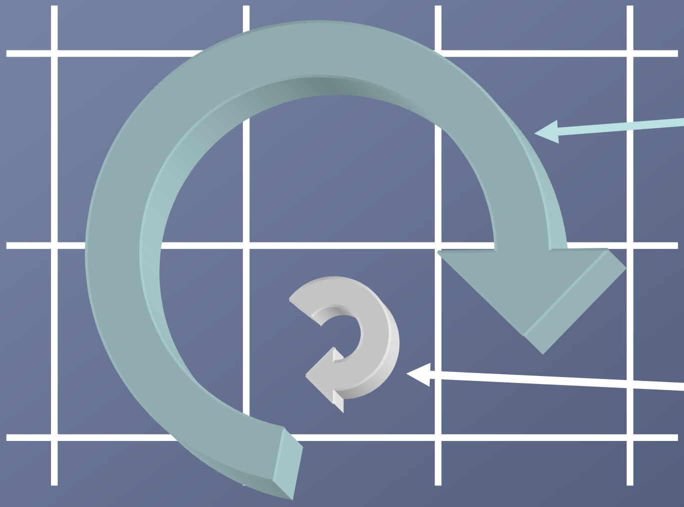
$$\frac{\partial u_i}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} - \frac{\partial\left(u_i u_j\right)}{\partial x_j} + \nu\frac{\partial^2 u_i}{\partial x_j x_j} + g_i$$

in which, x_i or x_j = x, y, z, and u_i or u_j = u, v, w

Large Eddy Simulation (LES)-1

- N-S equations are spatially-filtered, NOT time- or ensemble-averaged.

$u = \overline{u}$ (spatially filtered) + u' (fluctuation)



Eddies, larger than grid scale, are directly calculated by spatially-filtered N-S equations.

Eddies, smaller than grid scale (sub-grid scale: SGS), are parameterized.

Large Eddy Simulation (LES) - 2

- Smagorinsky model is the simplest model for SGS closure.

Additional term

Spatially-filtered Momentum Equations (Navier-Stokes Equations)

$$\frac{\partial \overline{u}_i}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} - \frac{\partial\left(\overline{u}_i\overline{u}_j + \tau_{ij}\right)}{\partial x_j} + \nu\frac{\partial \overline{u}_i^2}{\partial x_j x_j} + g_i$$

Additional terms after Spatial filtering

$$\tau_{ij} = \overline{u_i u_j} - \overline{u}_i\overline{u}_j - \frac{2}{3}\delta_{ij}q = L_{ij} + C_{ij} + R_{ij} - \frac{2}{3}\delta_{ij}q$$

$$L_{ij} = \overline{\overline{u}_i\overline{u}_j} - \overline{u}_i\overline{u}_j, \quad C_{ij} = \overline{\overline{u}_i u_j'} + \overline{\overline{u}_j u_i'}, \quad R_{ij} = \overline{u_i' u_j'}$$

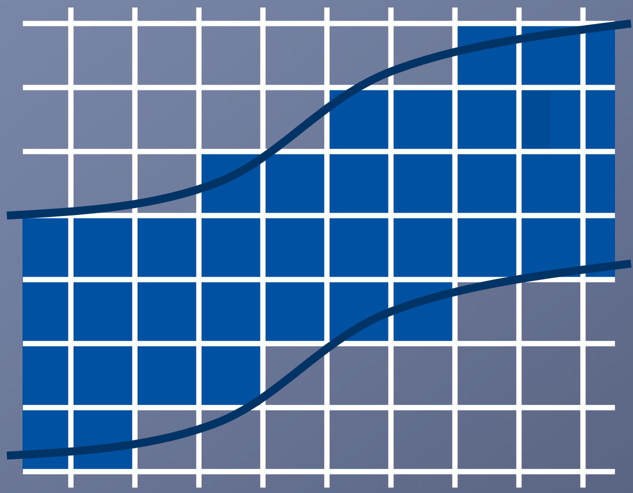
Smagorinsky Model

$$L_{ij} + C_{ij} \approx 0, \quad R_{ij} - \frac{1}{3}\delta_{ij}q \approx -2\nu_t S_{ij}$$

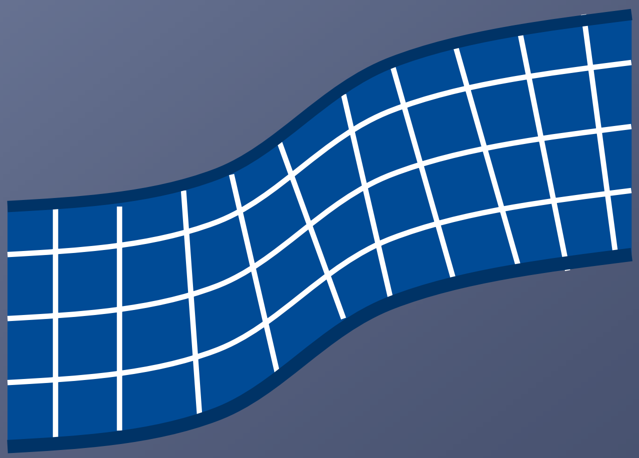
$$\nu_t = \left(C_s\Delta\right)^2\left|\overline{S}\right|, \quad \overline{S}_{ij} = \frac{1}{2}\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right), \quad \left|\overline{S}\right| = \left(2\overline{S}_{ij}\,\overline{S}_{ij}\right)^{1/2}$$

Body Fitted Coordinates (BFC)

- Body Fitted Coordinates (BFC) is employed to fit the grid to arbitrarily shaped boundary



Cartesian Coordinates System



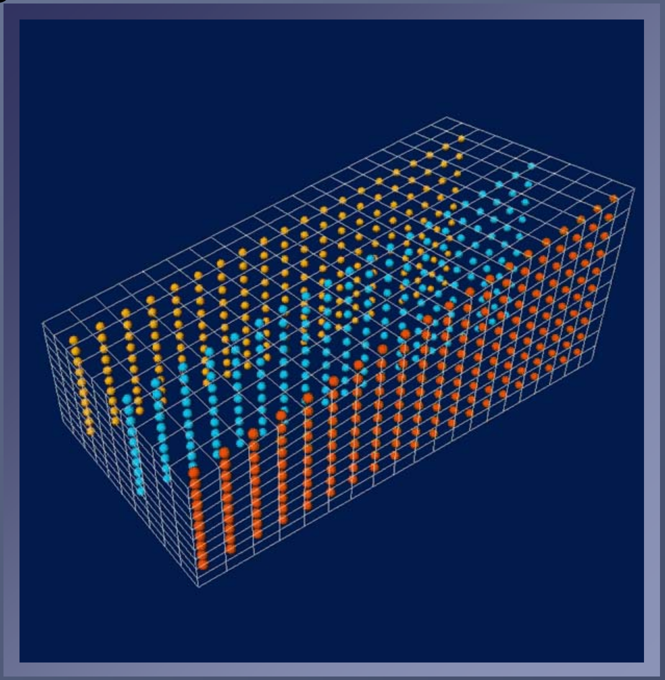
BFC Coordinates System

Moving Grid System

- Moving Grid system enables the model to trace temporally changing free water surface boundary.

$$\begin{pmatrix} \frac{}{} \\ \frac{}{} \\ \frac{}{} \\ \frac{}{} \end{pmatrix} \begin{pmatrix} t & x & y & z \\ t & x & y & z \\ t & x & y & z \\ t & x & y & z \end{pmatrix} \begin{pmatrix} \frac{}{t} \\ \frac{}{x} \\ \frac{}{y} \\ \frac{}{z} \end{pmatrix}$$

Operators for coordinates transformation into a combined system of the BFC and a moving grid system

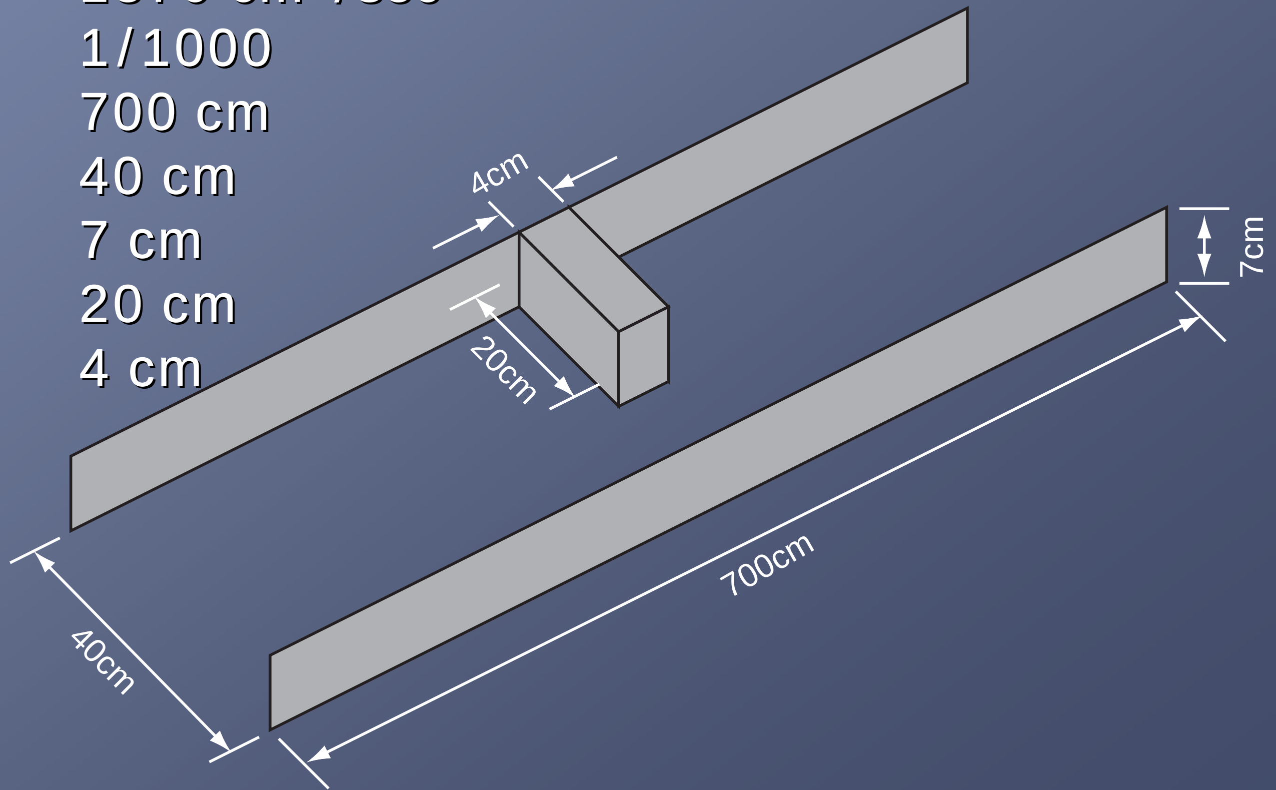


Example of combination of BFC and moving grid system

Existing Spur-dike Experiment

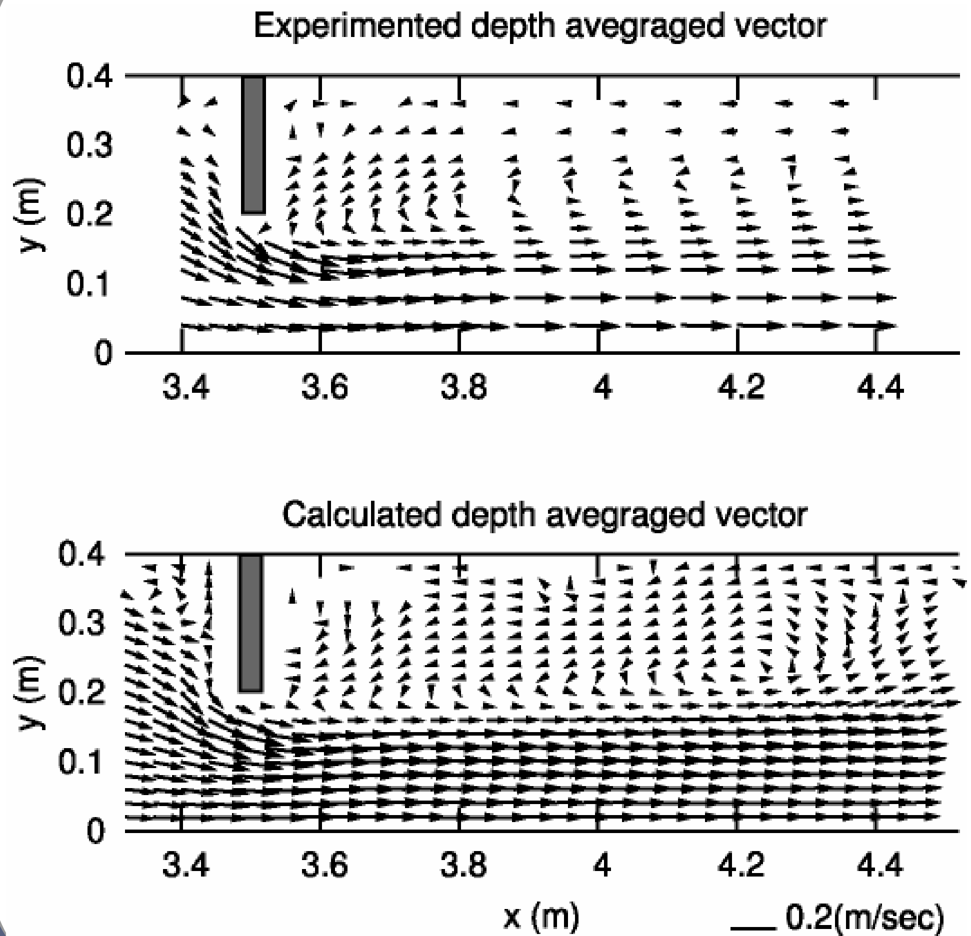
- Calculation results compared with existing experimental results (Muneta and Shimizu, 1994).

Discharge	1870 cm^3/sec
Slope	1/1000
Channel length	700 cm
Channel width	40 cm
Downstream depth	7 cm
Spur dike length	20 cm
Spur dike width	4 cm



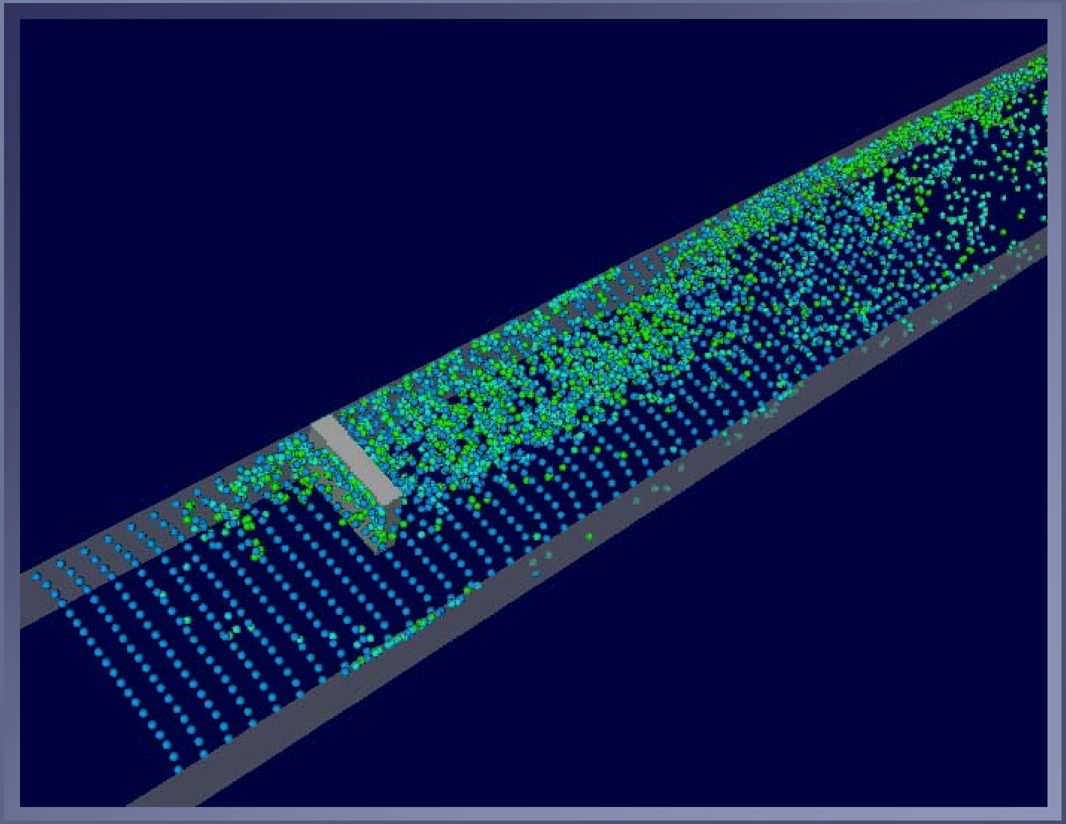
Comparison (depth-averaged)

- Depth-averaged recirculation eddy is observed both in experiment and calculation results.
- Calculated result shows good agreement.



Results (particle tracing)

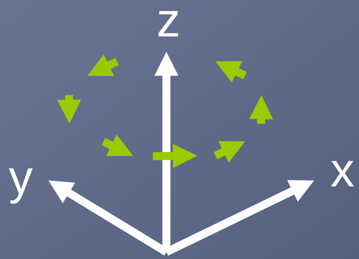
- Particle tracing method is applied.
- Recirculation is clearly observed.
- Reattachment point is varying over time.
- Jet-like stream can be seen beside a spur-dike, and it has strong secondary-flow.

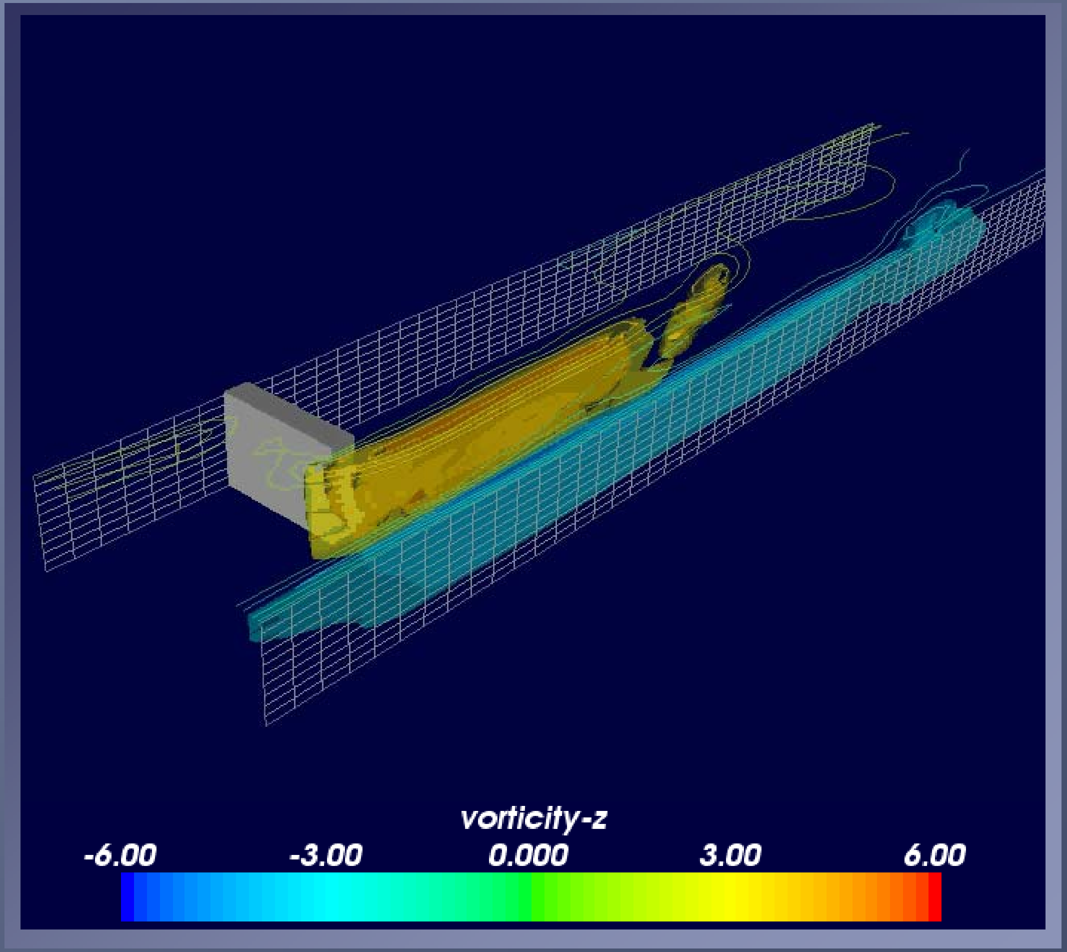


Time: from 100(sec) to 170(sec)

Results (vorticity: z-axis)

- Intense horizontal vorticity generated in the free-shear layer (eddy fence)
- Horizonatal eddies are intermittently shed into the reattachment zone



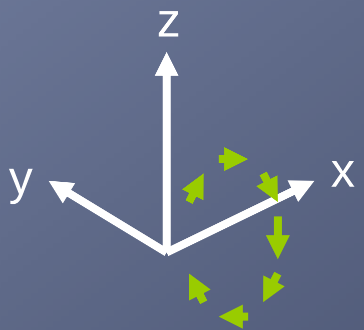


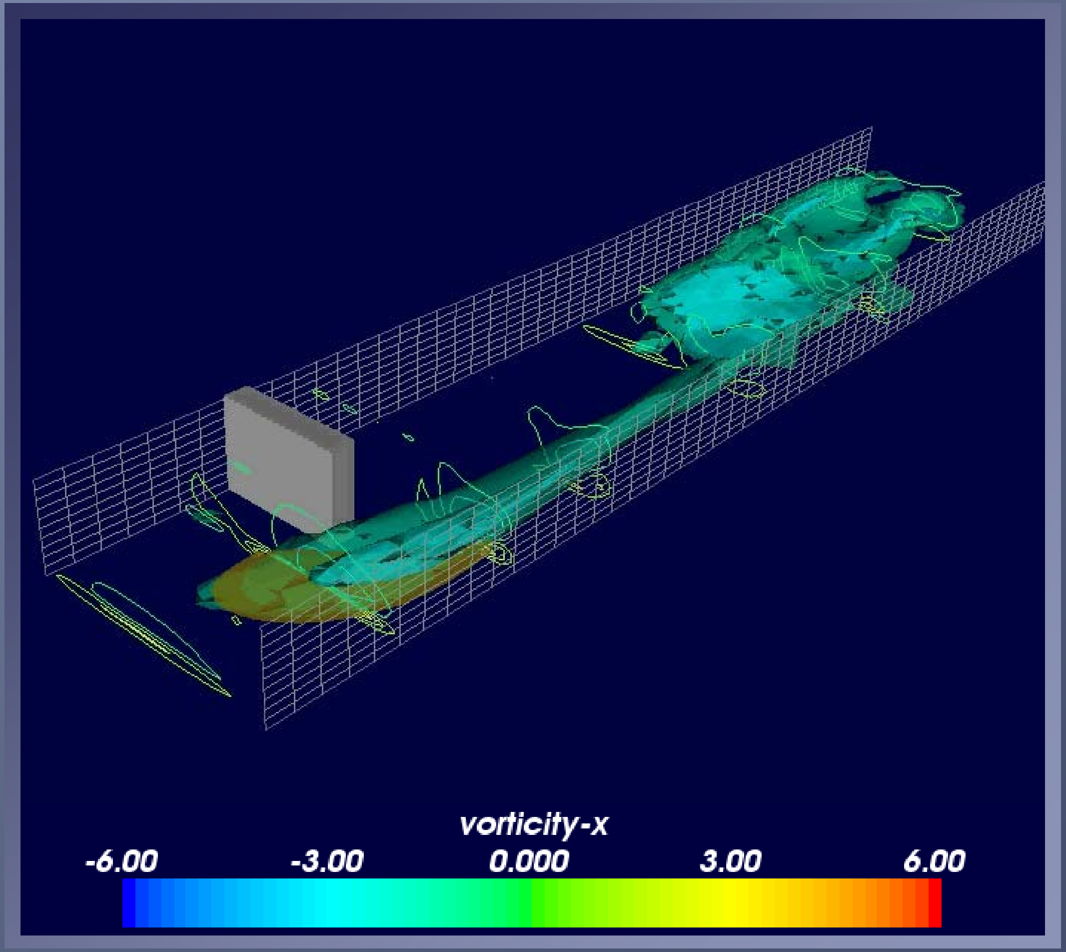
Time: from 100(sec) to 170(sec)

Results (vorticity: x-axis)

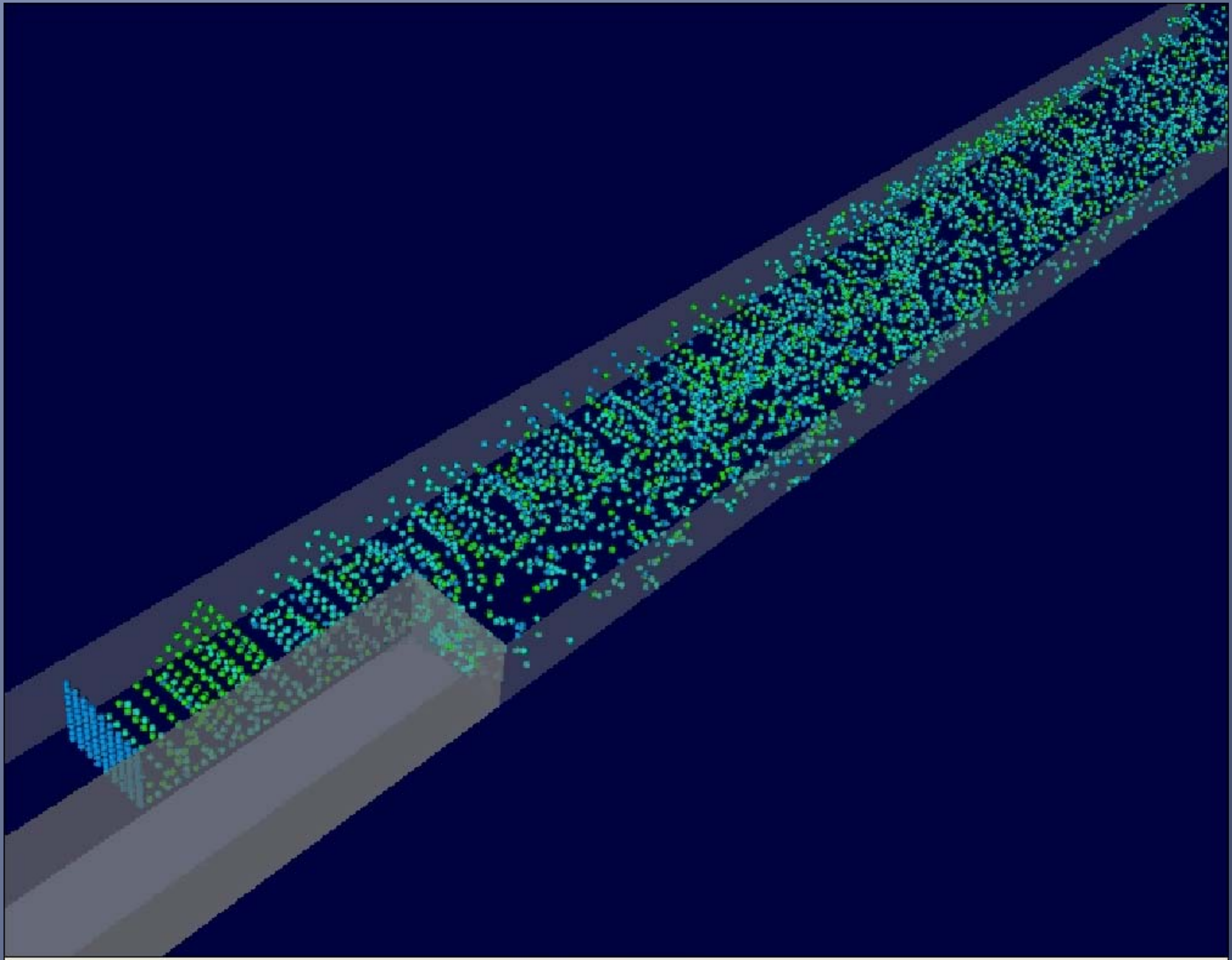
- Stable counter-clockwise vorticity exists beside a spur-dike.

- Large-scale vorticity generated in the reattachment zone





Time: from 100(sec) to 170(sec)

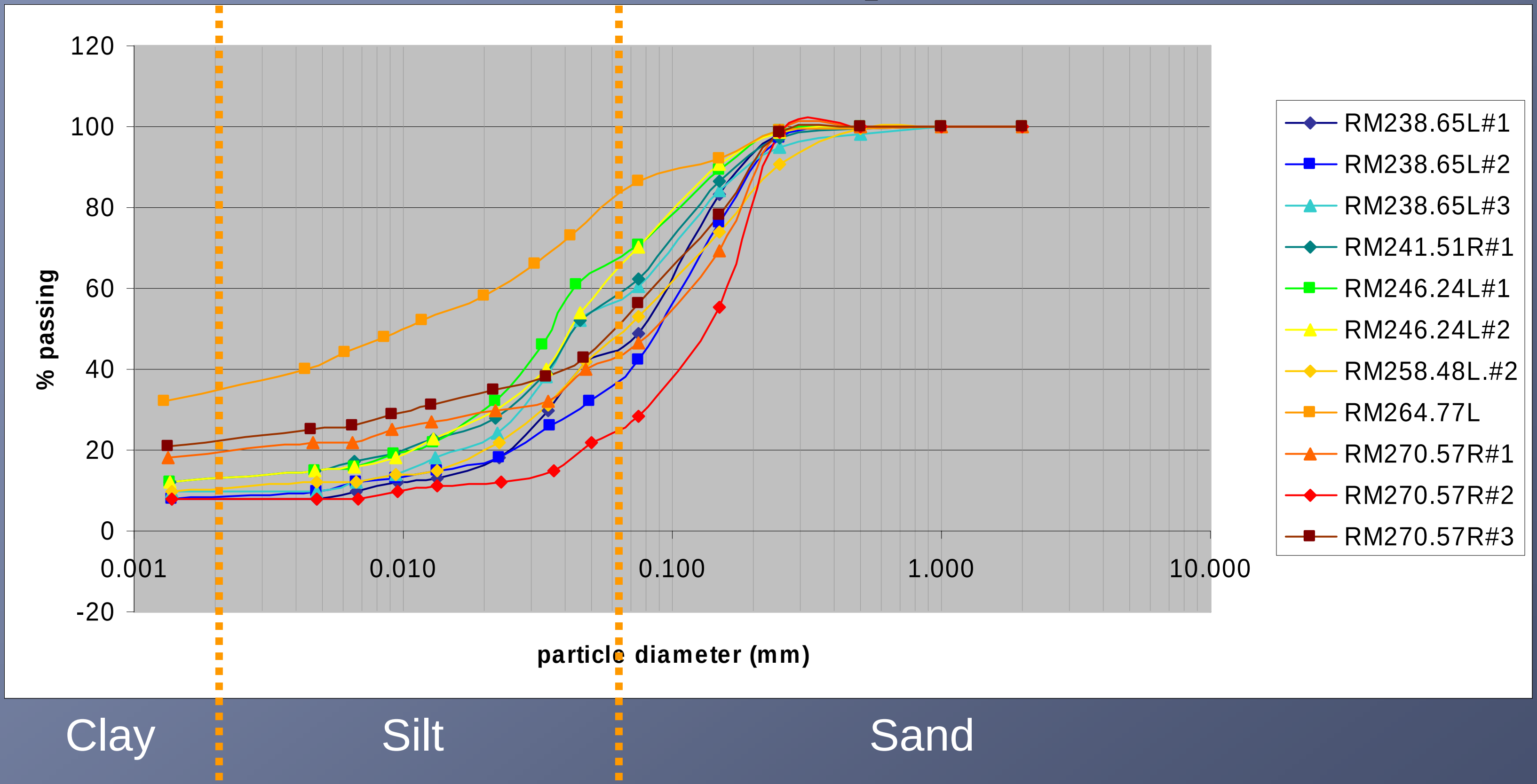


pure_expansion_from100s.avi

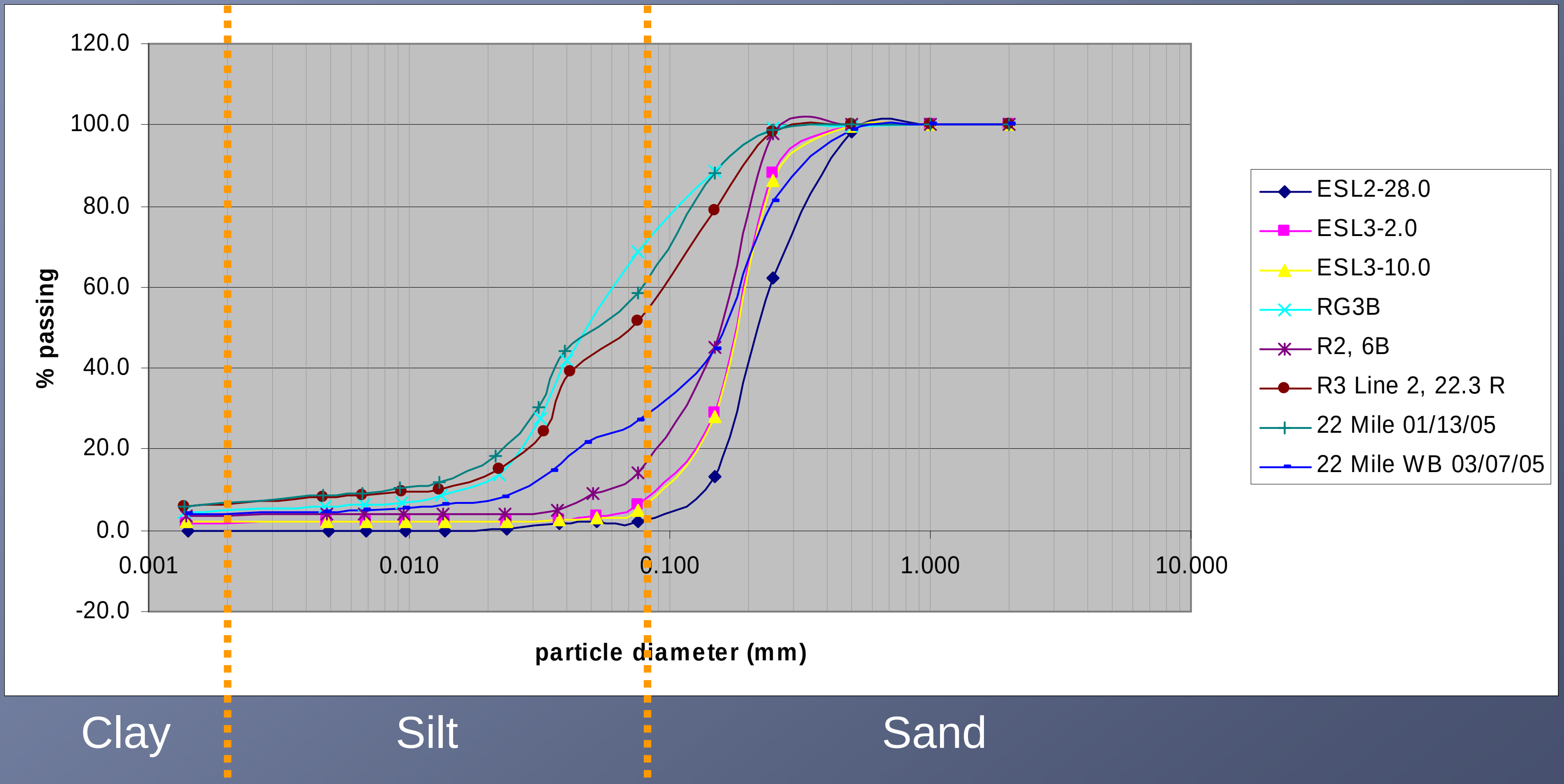
Cohesive Bar Sediments

Photo by David Topping

Particle Size Distribution
(PRE-flood Samples, collected in Feb 2004)

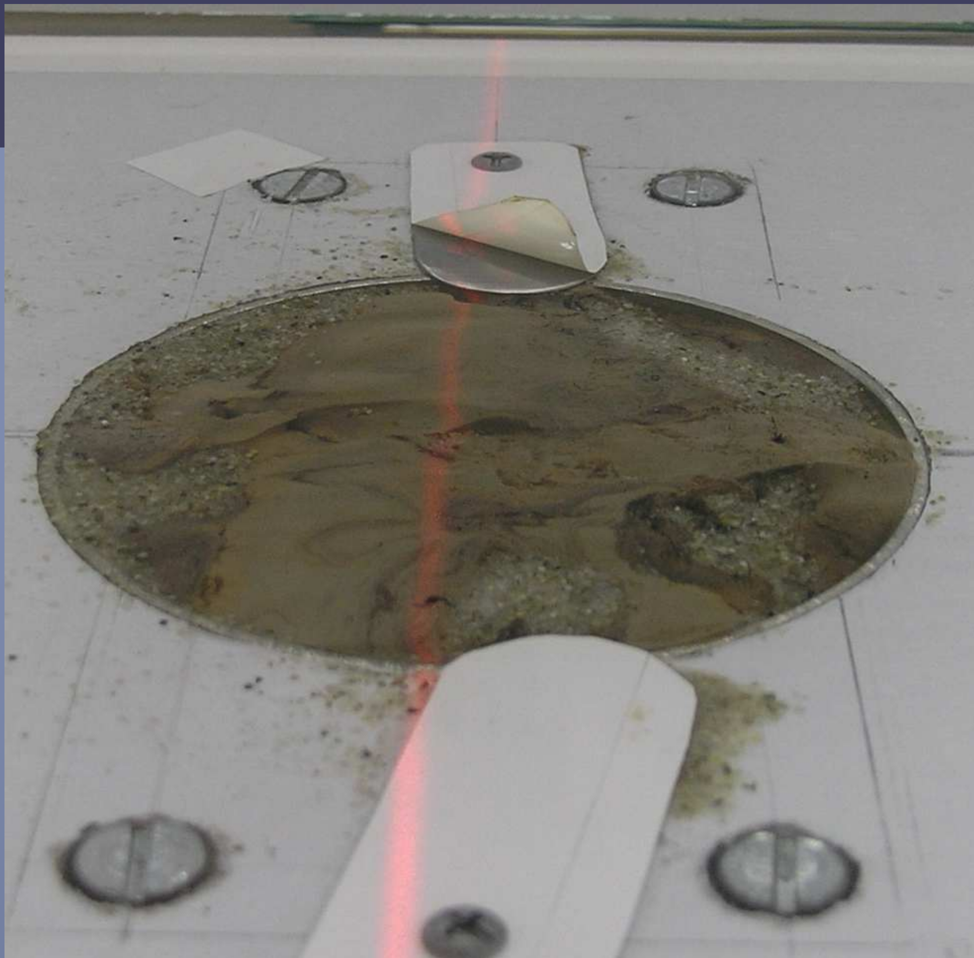


Particle Size Distribution
(POST-flood Samples, collected after Nov 2004)



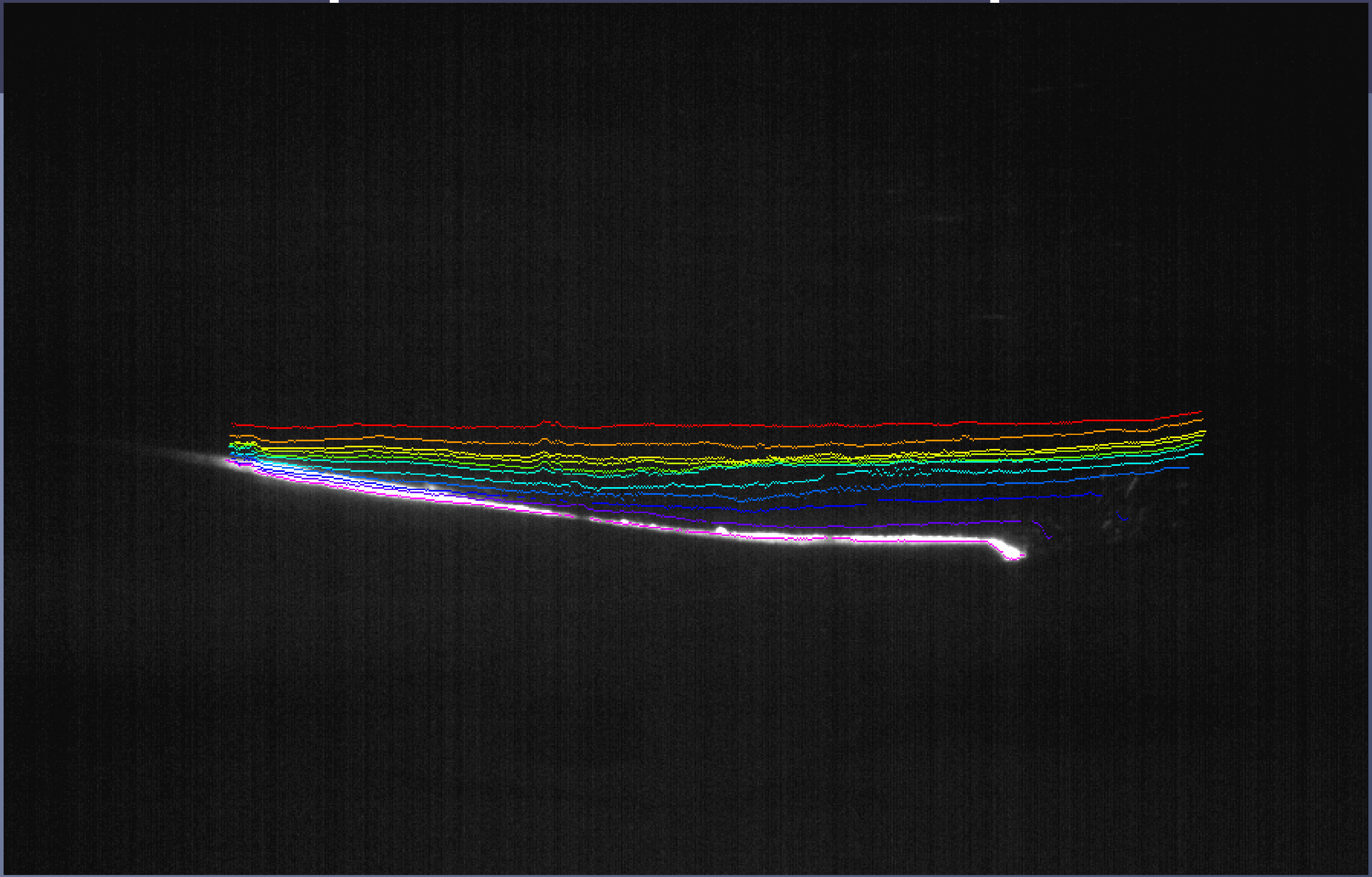
Mostly coarse materials

- Each sample was eroded at a range of shear stresses
- ADV used to measure near-bed velocity, thus boundary shear stress
- 1.3mm infrared laser sheet and digital photographs used to measure erosion with time



- Samples extruded from cylinder below false floor of the flume (diameter:10.1 cm, height: 7.7 cm)

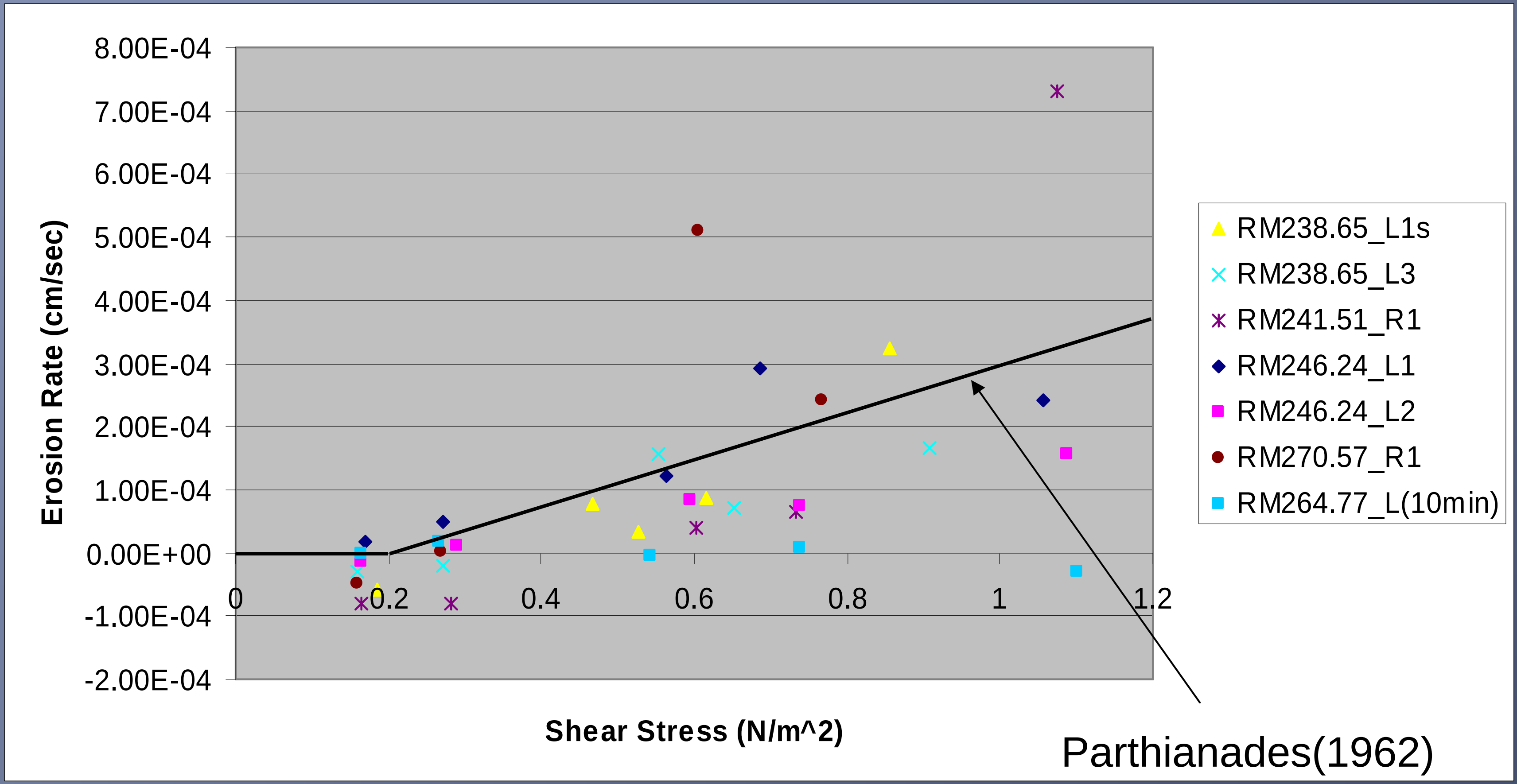
Example of Erosion profiles



Sample: RM270.57_R2 at Run 3: 0.626(N/m^2)

Erosion Rate vs. Shearing Stress

(cohesive samples)



Conclusions

- Beach erosion happens by coupled processes of groundwater flow, seepage erosion, and turbulent flow