An Engineering Perspective on Reservoir Sedimentation

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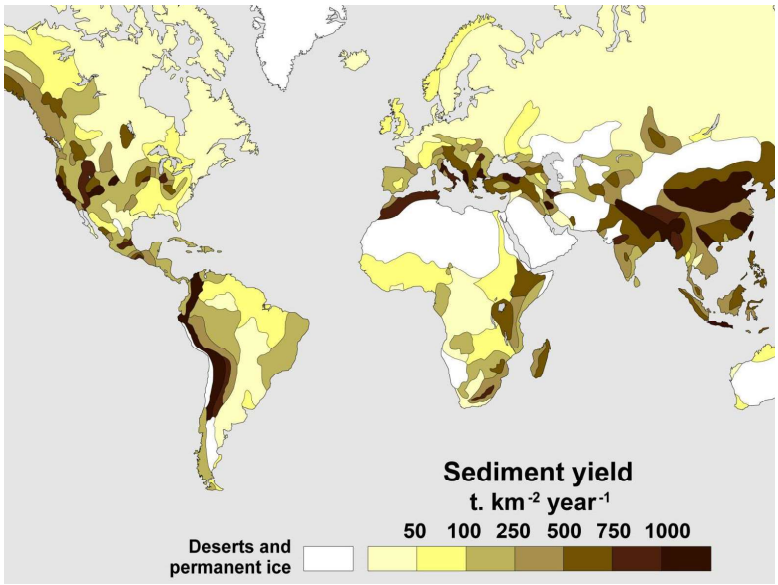
Reservoir Sedimentation

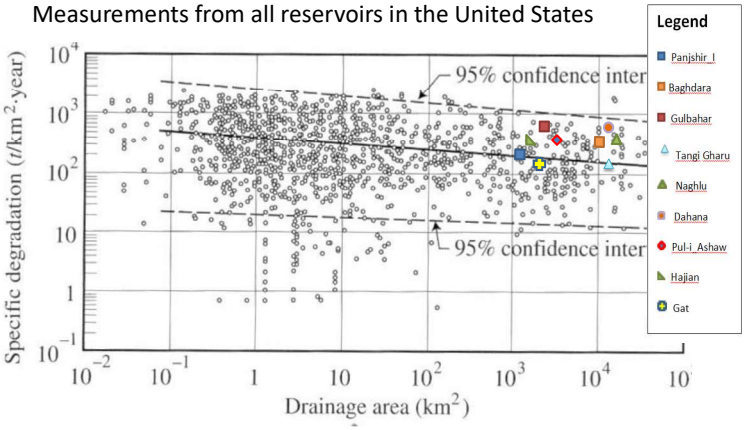
1. Sediment Sources and Yield
2. Dynamic Modeling
3. Density Currents
4. Dambreak Simulations
5. Multi-objective Decisions

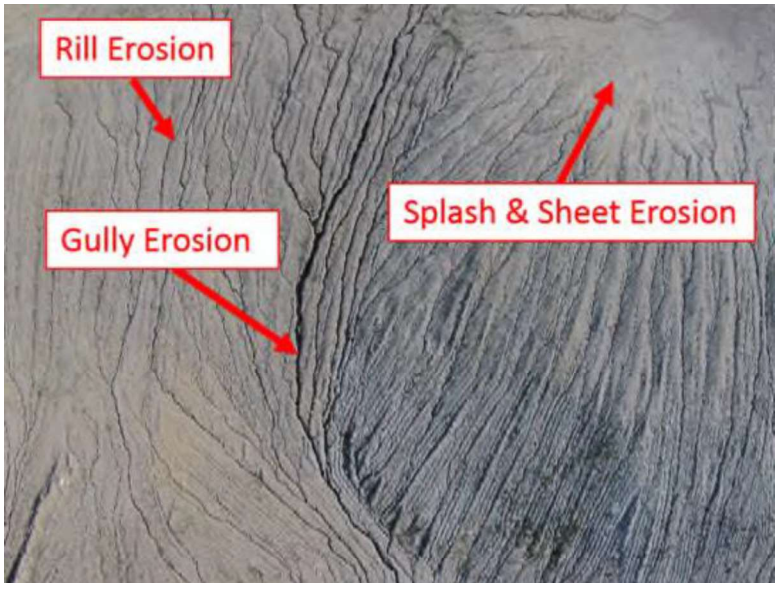


Sediment Yield...

- Kane and Julien (2007)

Measurements from all reservoirs in the United States

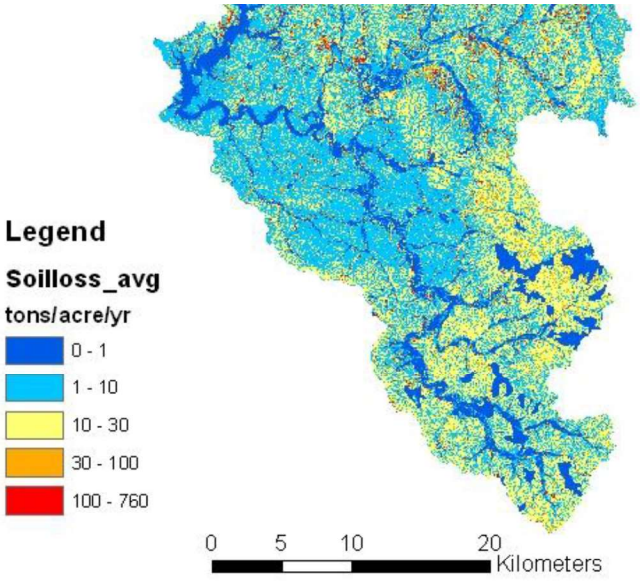




Revised Universal Soil-Loss Equation (RUSLE)

$$E = R K L S C P$$

- E: mean annual soil loss
- R : rainfall erosivity
- K : soil erodibility
- L : slope length
- S : slope steepness
- C : cropping management
- P : conservation practice



Upland Degradation Problems

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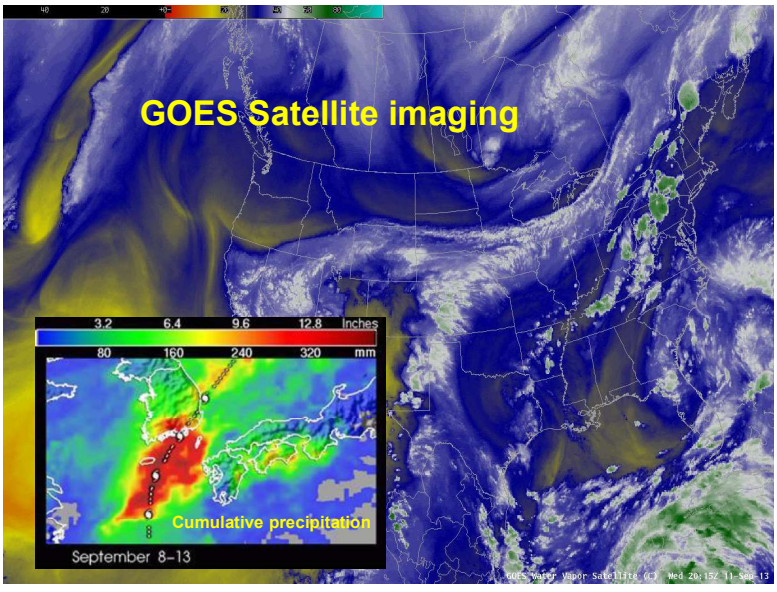
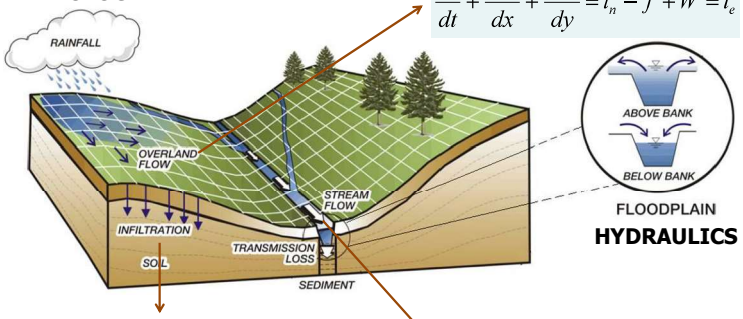


TREX: Two-dimensional Runoff Erosion and eXport

HYDROLOGY

$$\frac{\partial h}{dt} + \frac{\partial q_x}{dx} + \frac{\partial q_y}{dy} = i_n - f + \dot{W} = i_e$$



HYDRAULICS

$$f = K_h\left(1 + \frac{H_c(1 - S_e)\theta_e}{F}\right)$$

$$\frac{\partial A}{dt} + \frac{\partial Q}{dx} = q_l + \hat{W}$$

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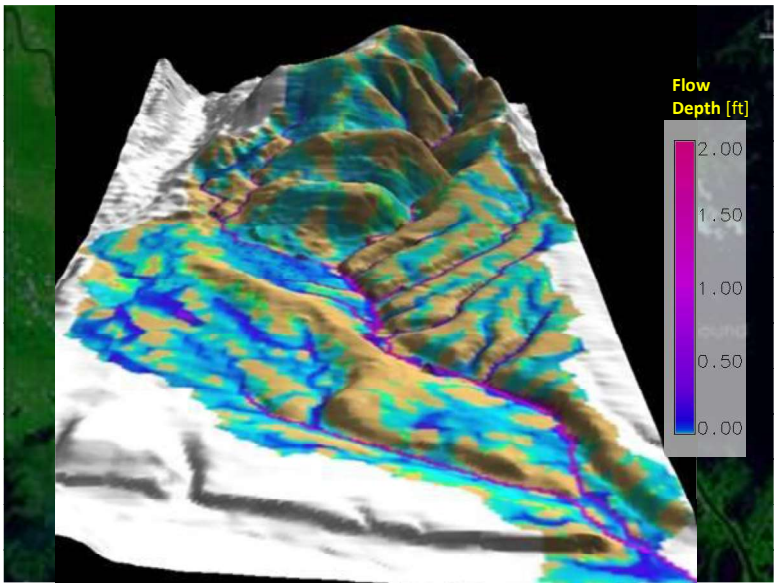
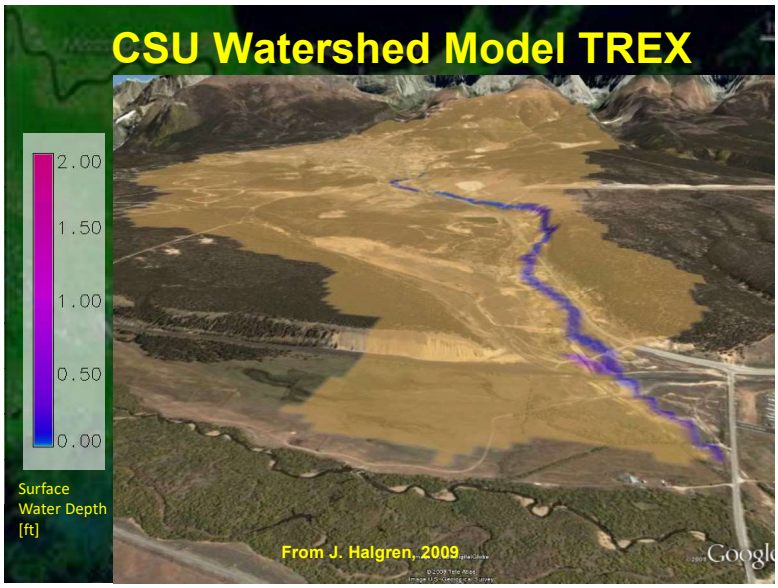
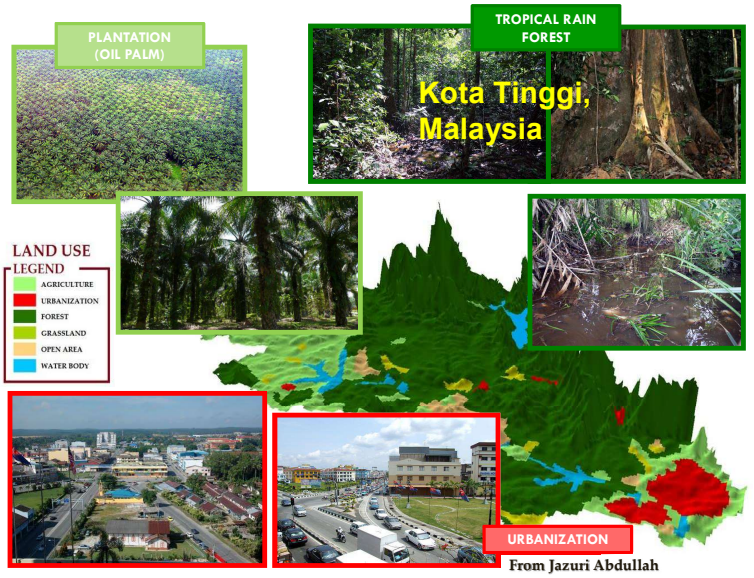
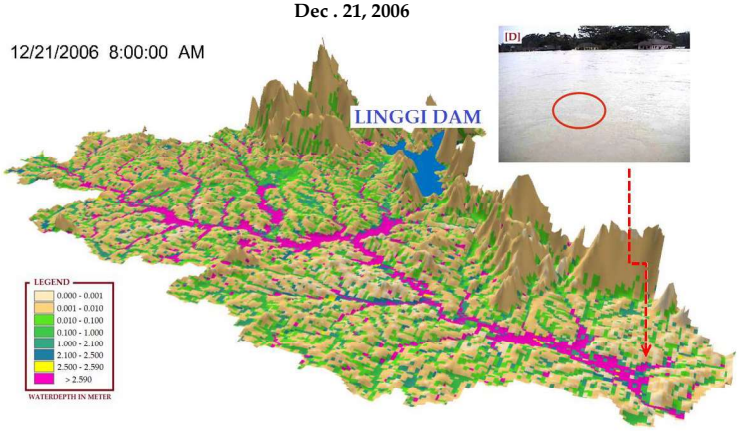




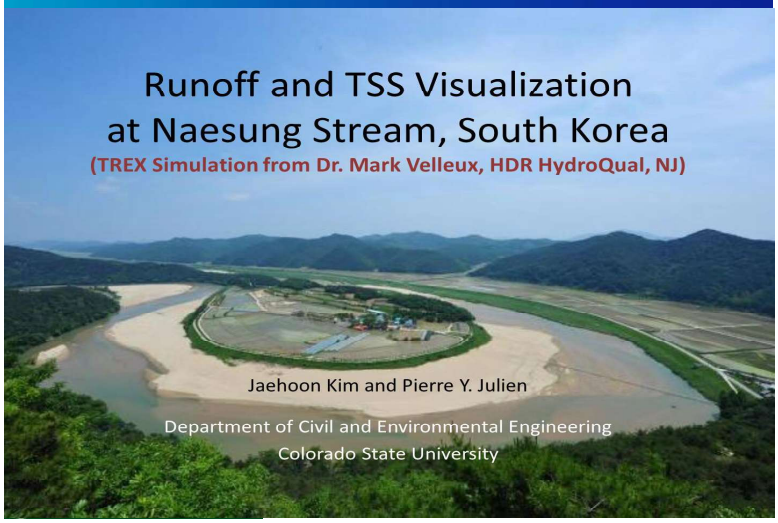


KOTA TINGGI FLOOD

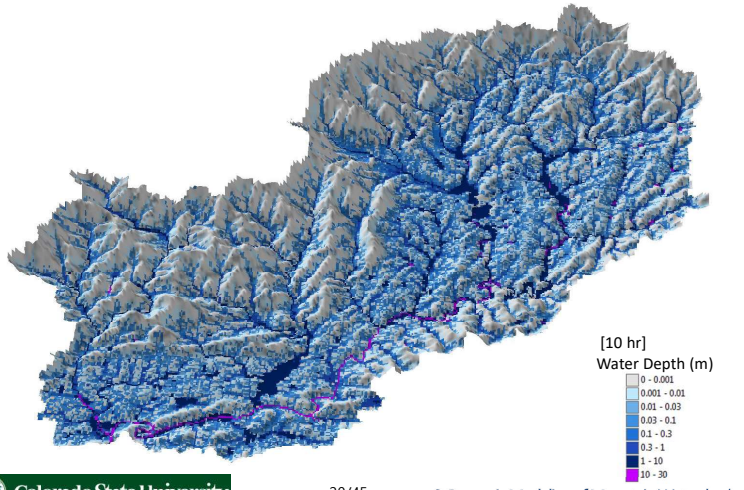
TREX Model simulation with 450 mm of rain in 4 days
Dec . 21, 2006



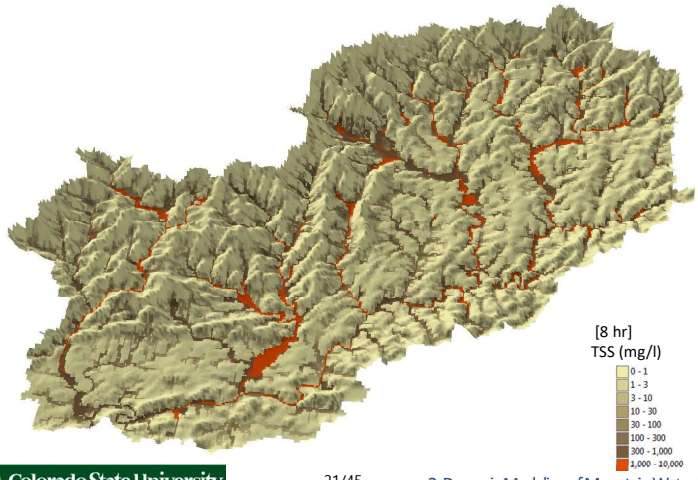
Runoff and TSS Visualization at Naesung Stream



Water Depth



Total Suspended Solids



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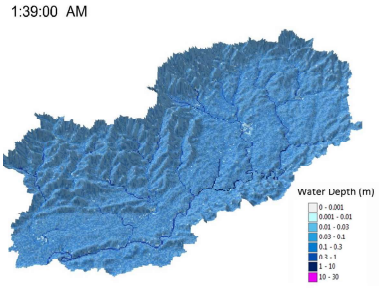

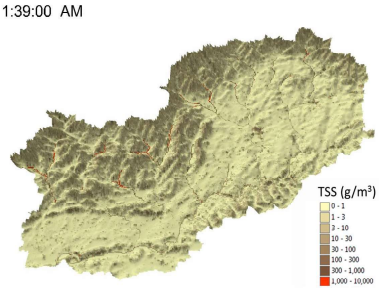

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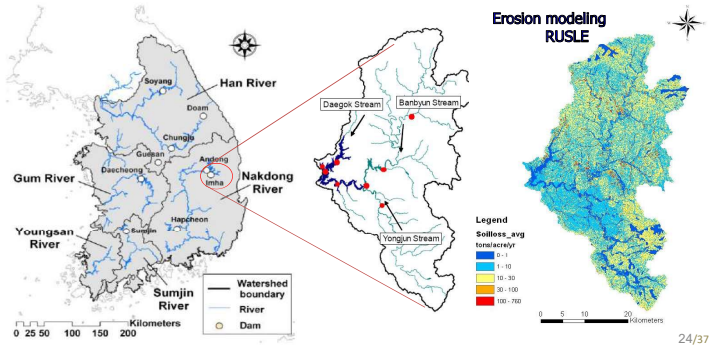
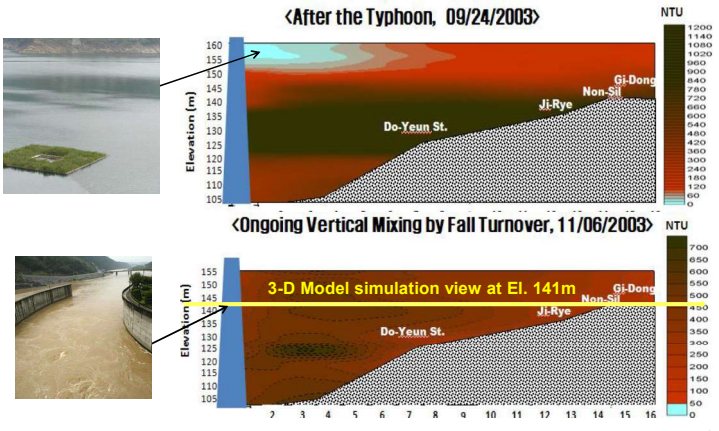
Example

Imha Reservoir has suffered from turbidity problems since 2002.

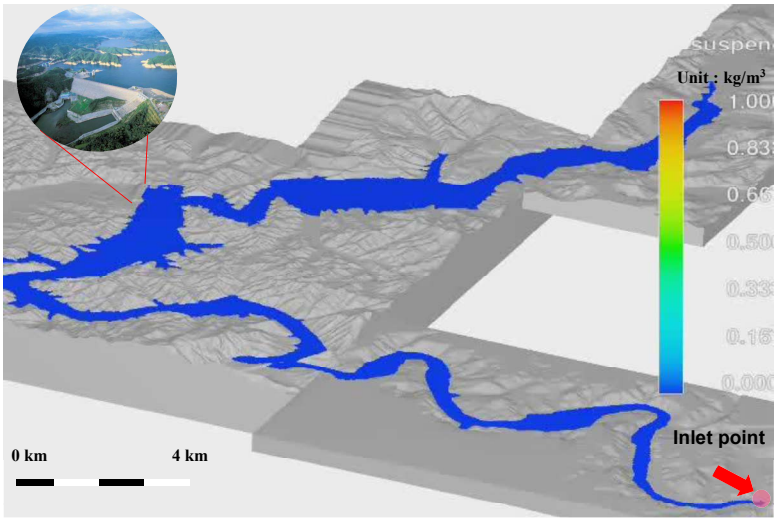
- Watershed area covers 1,361 km^2
- Three major tributaries

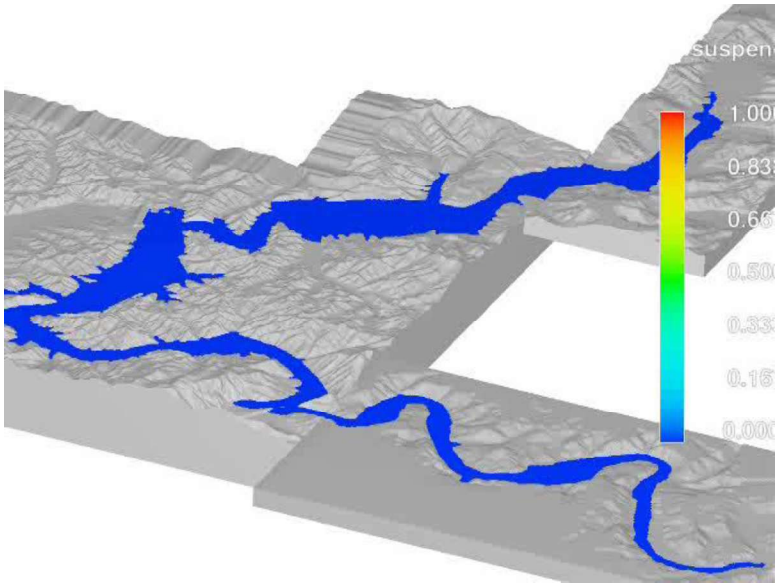


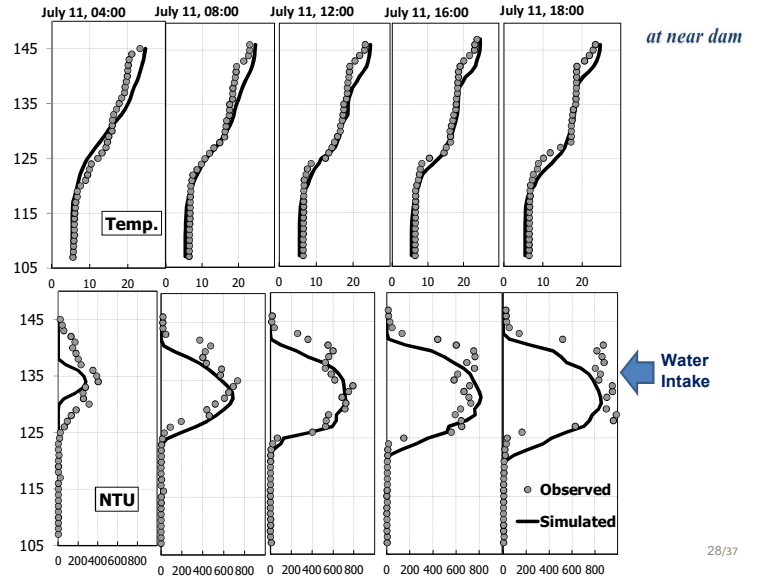
Turbidity Measurements



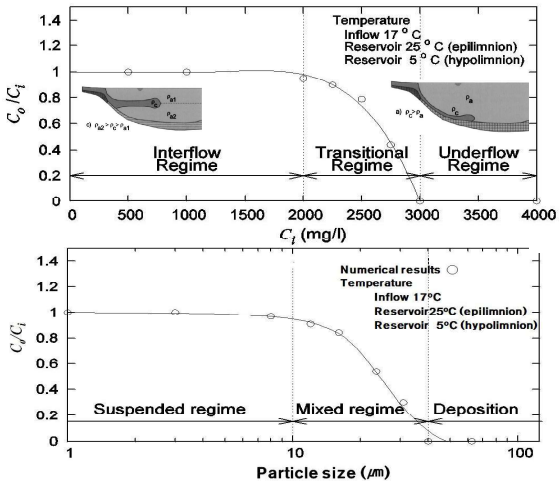
Numerical animation with bird's-eye viewpoint at EL. 141m







NEW Results on Density Currents!



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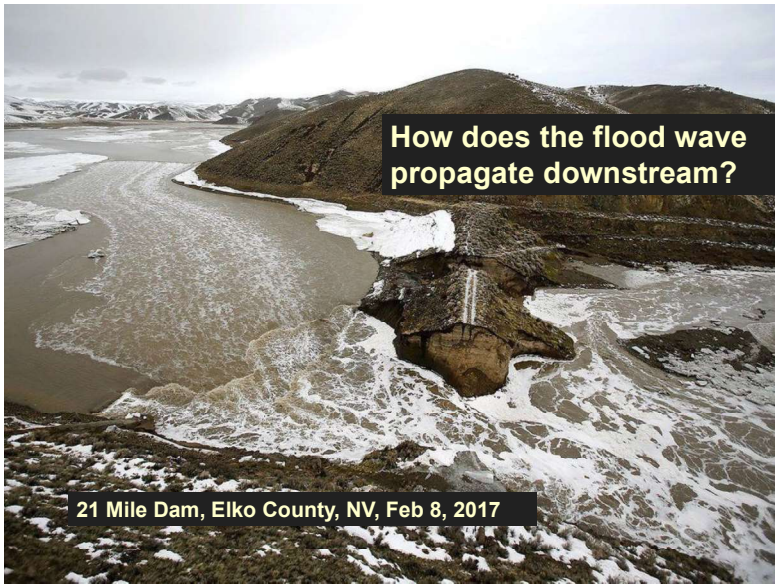
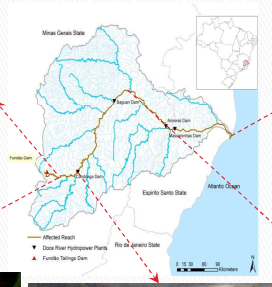


The Fundão Dam Collapse

Bento Rodrigues Town, 6 November 2015

Coast, 21 November 2015 C ≈1,500 mg/l

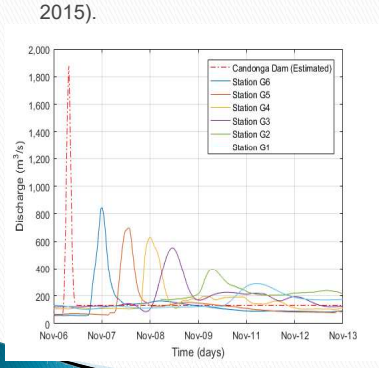


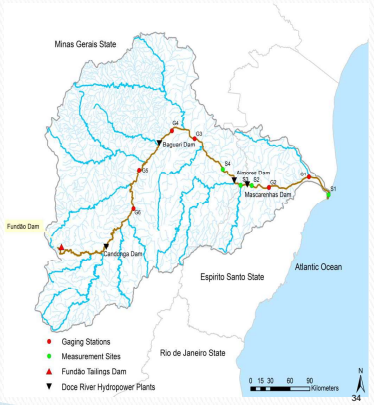
Gesteira Town 6 November 2015

Doce River at Governador Valadares City 11 November 2015, C ≈30,000 mg/l

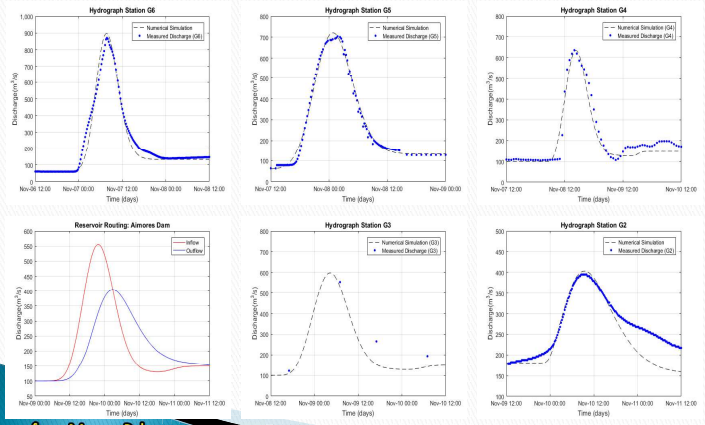
Hydrographs

Observed hydrographs in Doce River after the Fundão Dam break (ANA, 2015).





Floodwave Propagation Modeling



Sediment Routing NEW Development!

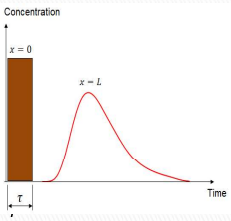
The one-dimensional advection-dispersion equation is applied on the evaluation of transport of suspended load in open channels (Fischer et al., 1979; Julien, 2010).

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} = K_d\frac{\partial^2 C}{\partial x^2} - kC$$

C is the concentration;
U is the flow averaged velocity;
κ_d is the longitudinal dispersion coefficient;
k is the settling rate.

Analytical solution for a constant spill in finite time interval is given by (Chapra, 2008):

$$C(x,t) = \frac{C_0}{2}\begin{cases} e^{\frac{Ux}{2K_d}(1-\Gamma)}\left[erfc\left(\frac{x-Ut\Gamma}{2\sqrt{K_d t}}\right) - erfc\left(\frac{x-U(t-\tau)\Gamma}{2\sqrt{K_d(t-\tau)}}\right)\right] \\ + e^{\frac{Ux}{2K_d}(1+\Gamma)}\left[erfc\left(\frac{x+Ut\Gamma}{2\sqrt{K_d t}}\right) - erfc\left(\frac{x+U(t-\tau)\Gamma}{2\sqrt{K_d(t-\tau)}}\right)\right] \end{cases}$$

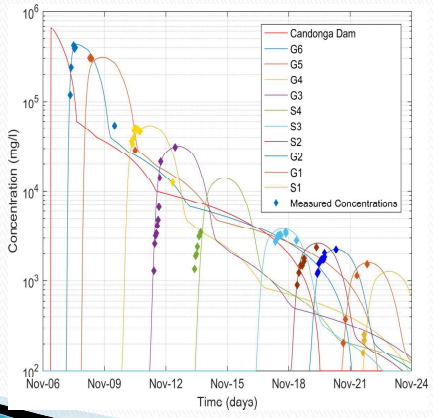


Where: $\Gamma = \sqrt{1+4\eta}$ and $\eta = \frac{kK_d}{U^2}$

The error function complement, *erfc*, is equal to:

$$erfc(b) = 1 - erf(b) = 1 - \frac{2}{\sqrt{\pi}}\int_0^b e^{-\beta}$$

Sediment Concentration Modeling



from Marcos Palu

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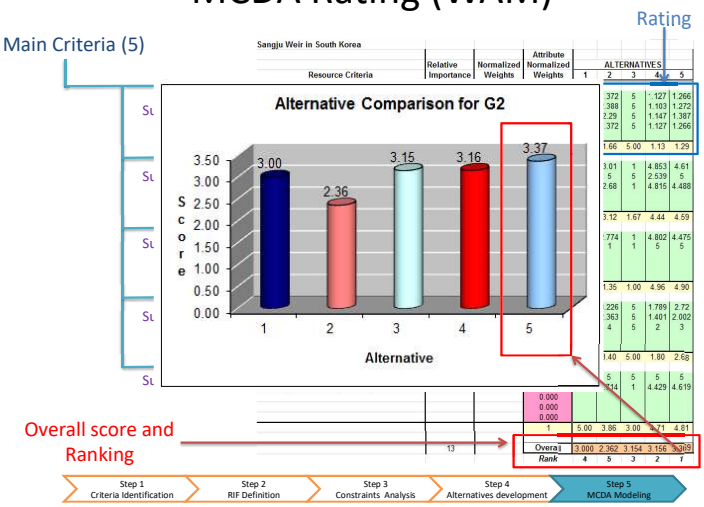
Sangju Weir, South Korea
from Hwayoung Kim, K-water

Other Issues besides sedimentation

- It is hard to change reservoir operation rules for sedimentation problems because we have many other issues to deal with.

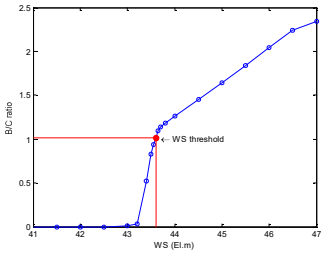
from H. Kim et al., ASCE, 2017

MCDA Rating (WAM)

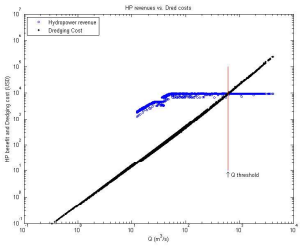


Hydraulic Thresholds

Operate the dam above
H threshold = EL. 43.6 m



Open the gates above
Q threshold = 620 m³/s



from H. Kim and Julien ASCE, 2018

Summary and Conclusions

1. Sediment Sources and Yield

Erosion mapping locates problem source areas

2. Dynamic Modeling

Dynamic models like TREX can simulate extreme floods

3. Density Currents

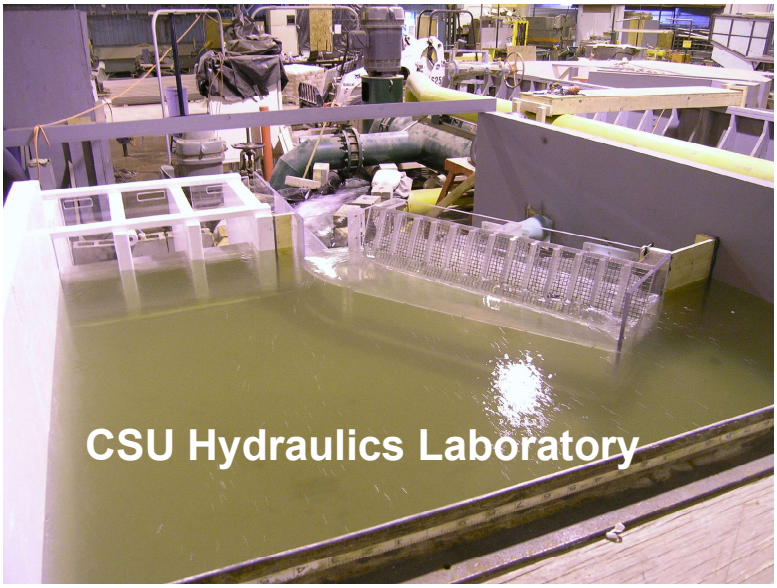
Turbidity problems from density currents can be modeled

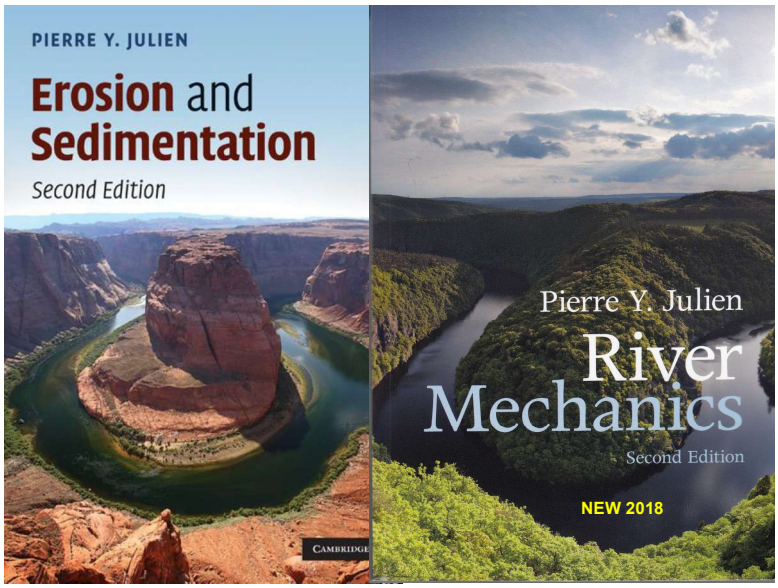
4. Dambreak Simulations

New models for flood and sediment wave propagation from dam break

5. Multi-objective Decisions

Base dam operations on hydraulic thresholds and MCDA





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Neil Andika, Indonesia
Un Ji, KICT, South Korea
Woochul Kang, KICT, South Korea
Apologies to those forgotten..

Terima Kasih atas Perhatian Anda!