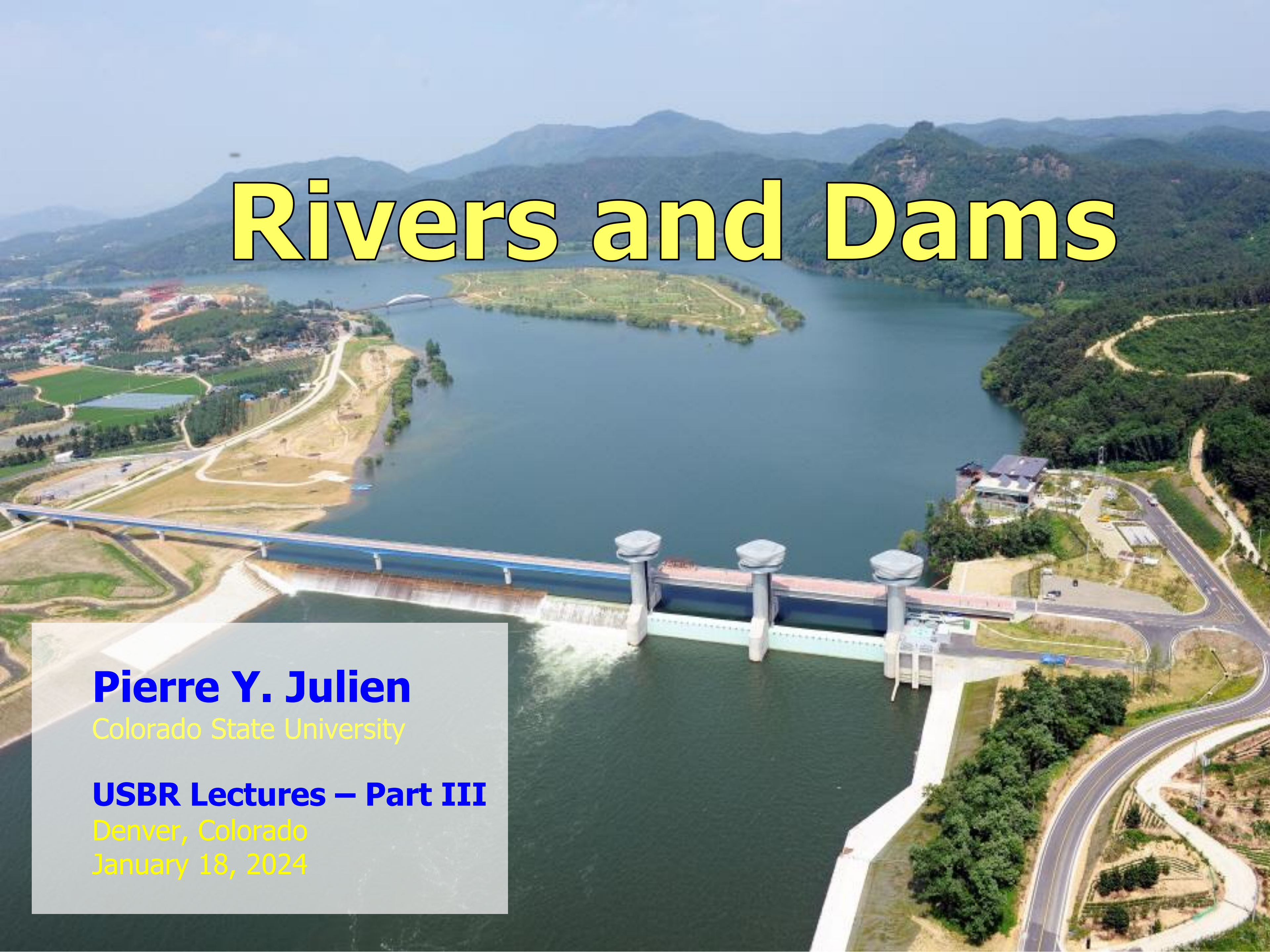
Rivers and Dams



Pierre Y. Julien
Colorado State University

USBR Lectures – Part III
Denver, Colorado
January 18, 2024

USBR Short Course

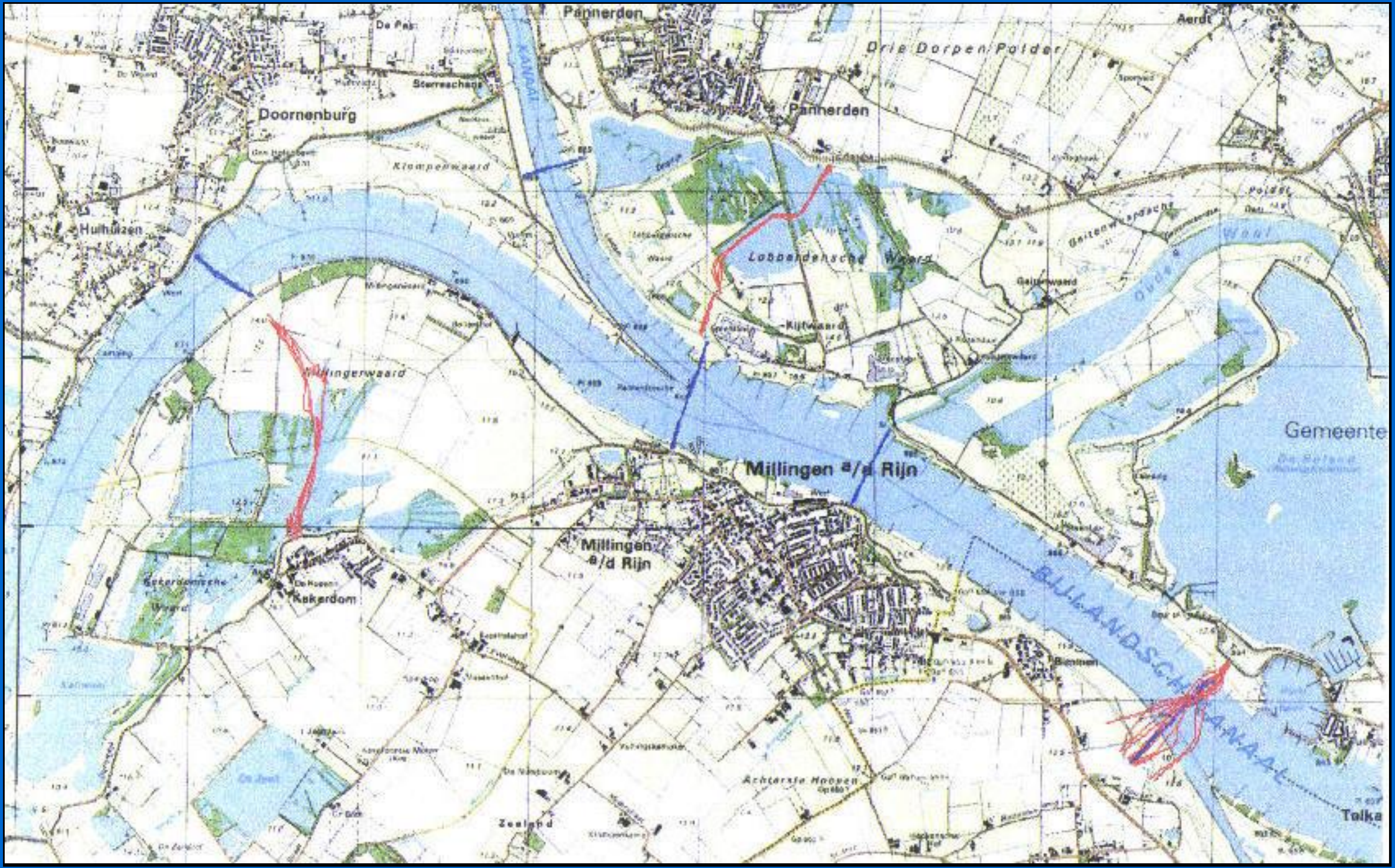
1. Watersheds and Climate
2. Sedimentation Engineering
3. Rivers and Dams
4. River Environment

Rivers and Dams

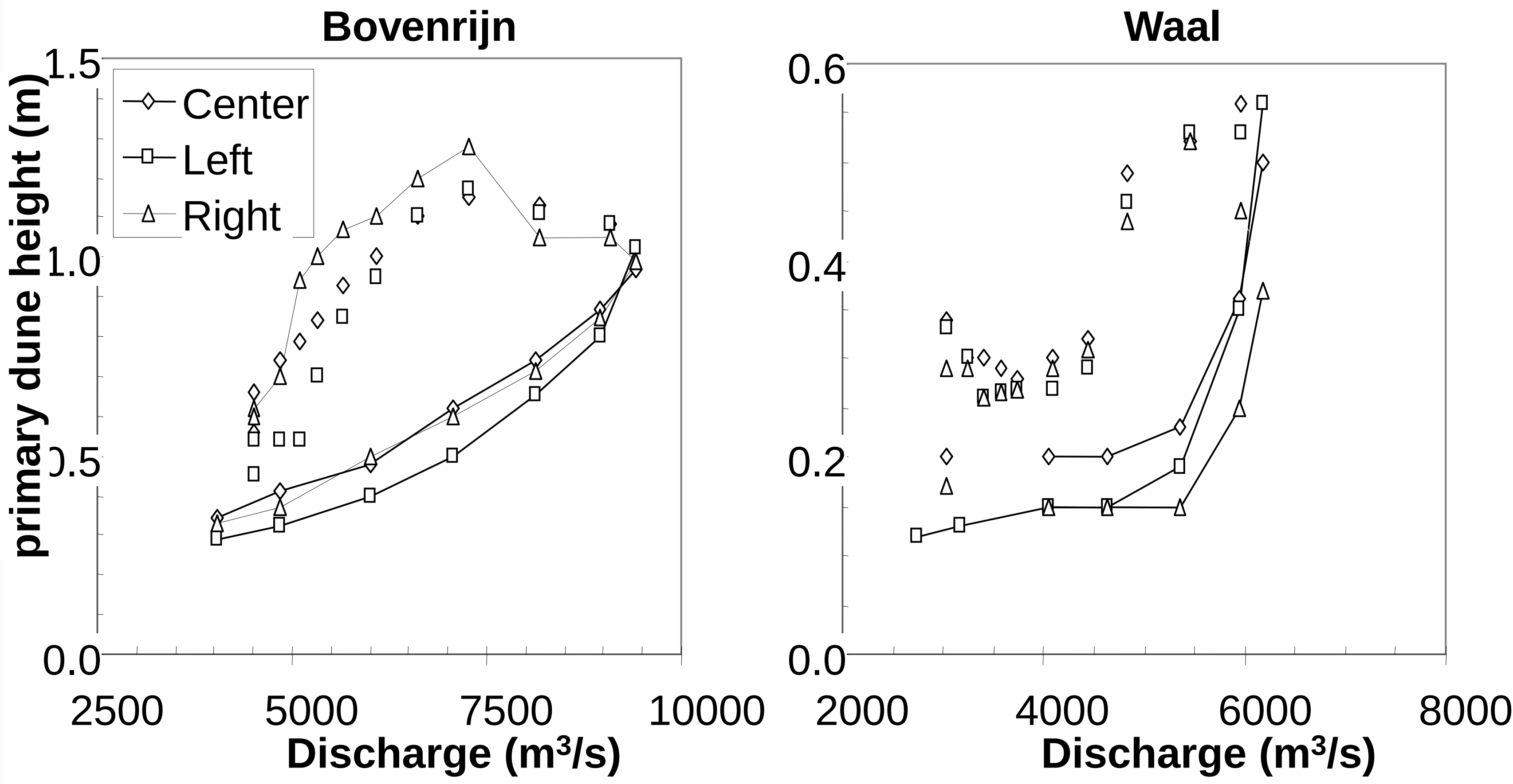
1. River Equilibrium
2. Aggradation
3. Degradation below Dams
4. Case Study Gupo Bridge
5. Case Study Dam Break

1a. Manning n

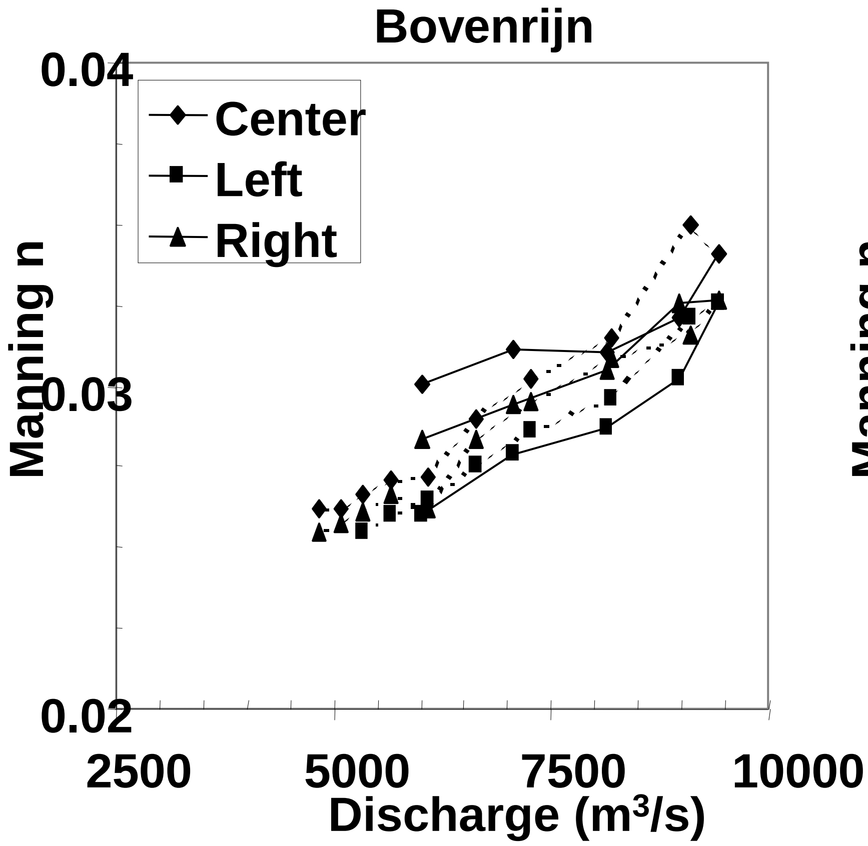
Rhine River flood in 1998

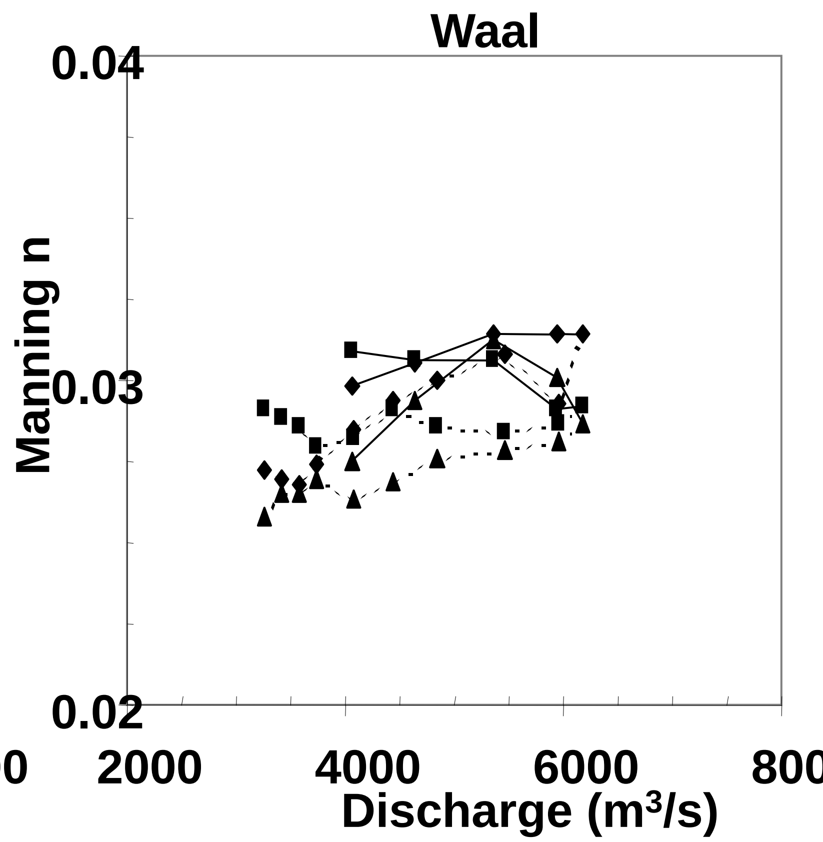


Primary dune height vs discharge



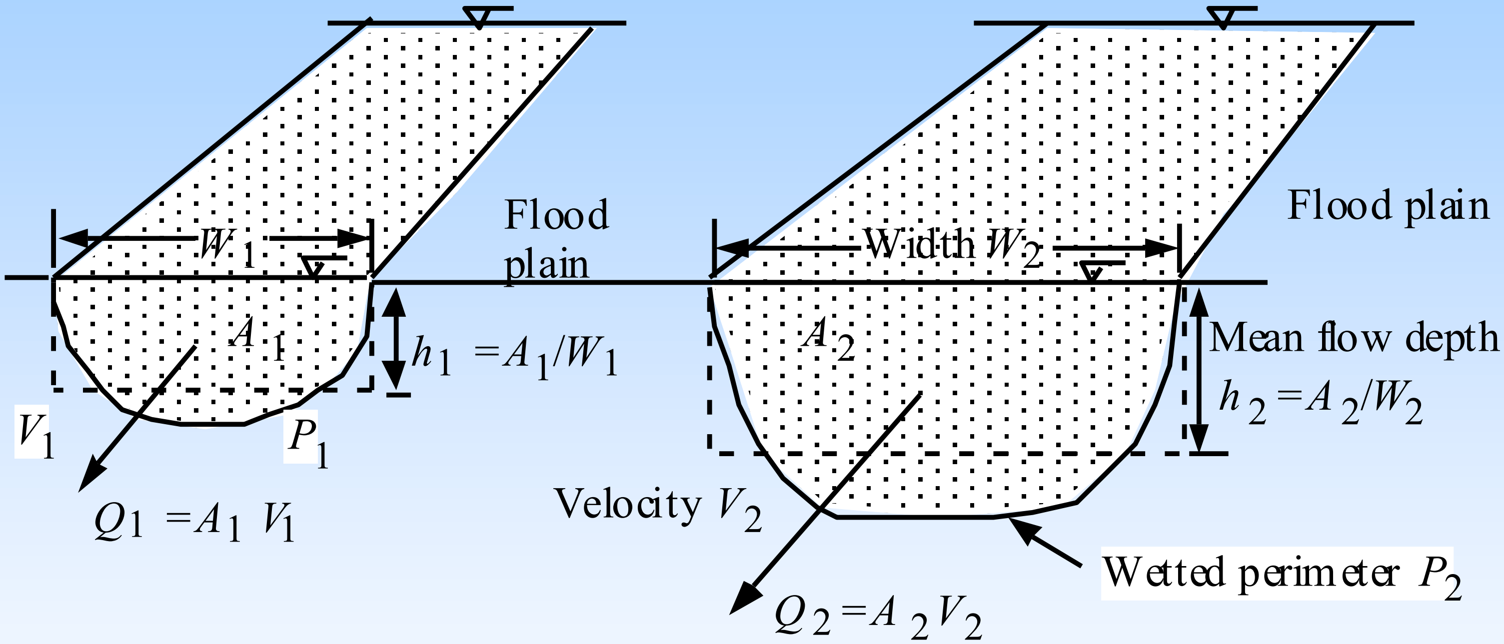
Manning n vs discharge





1b. Downstream Hydraulic Geometry

Downstream Hydraulic Geometry



Julien-Wargadalam (J-W) Equations

When the Manning-Strickler approximation is applicable, i.e. m = 1/6, a simplified form of Eqs. (10.19) is obtained in SI as

$$h \approx 0.133 Q^{0.4} \tau_*^{-0.2} \quad (10.20a) ♦$$

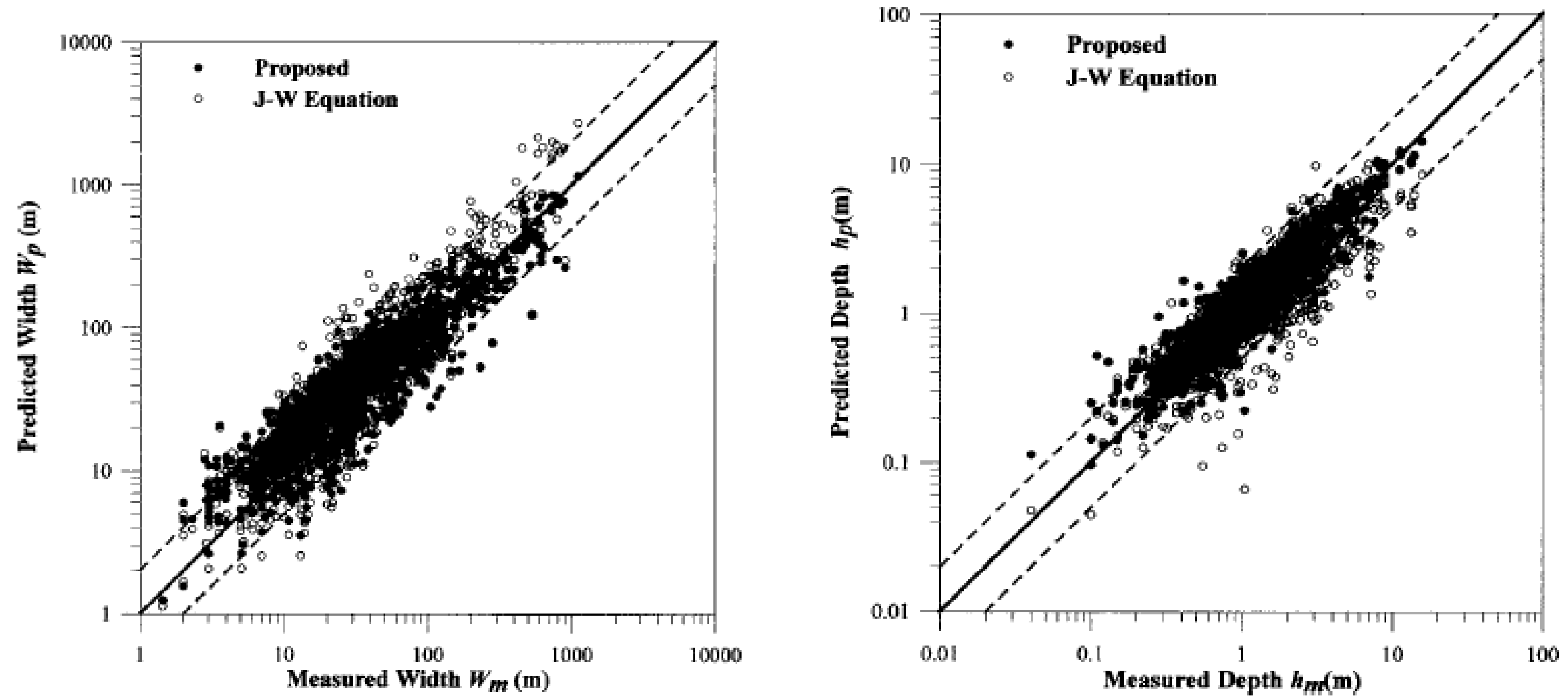
$$W \approx 0.512 Q^{0.53} d_s^{-0.33} \tau_*^{-0.27} \quad (10.20b) ♦$$

$$V \approx 14.7 Q^{0.07} d_s^{0.33} \tau_*^{0.47} \quad (10.20c) ♦$$

$$S \approx 12.4 Q^{-0.4} d_s \tau_*^{1.2} \quad (10.20d) ♦$$

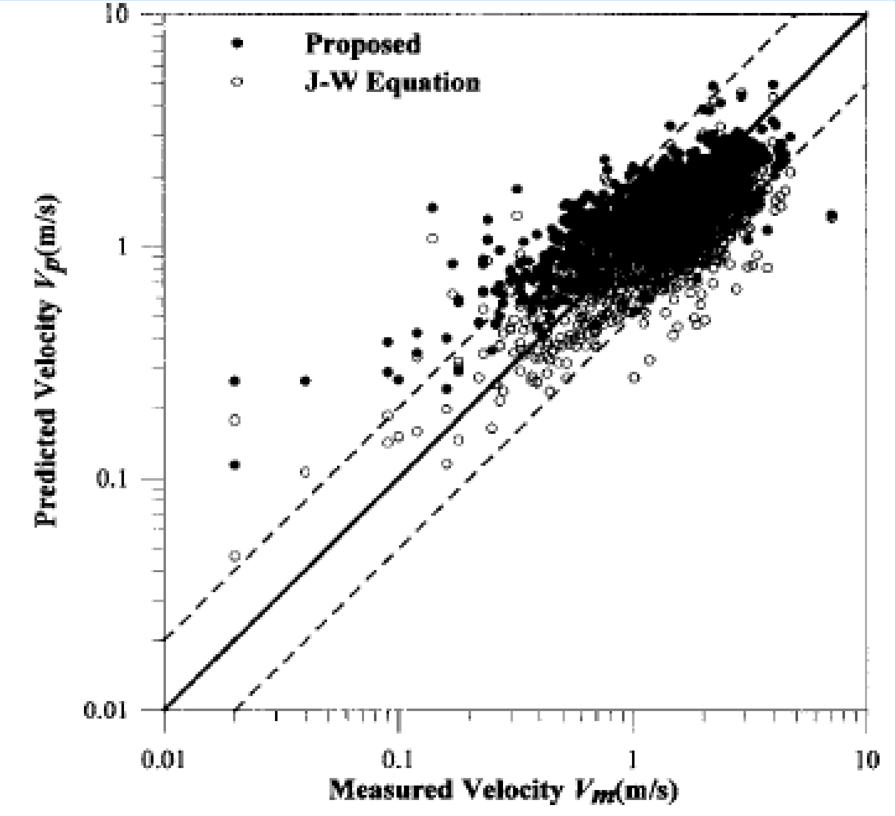
The hydraulic geometry of stable channels is obtained from Eqs. (10.20) when $\tau_* \cong 0.047$. Higher sediment transport rates require higher velocity and slope, and reduced width and depth.

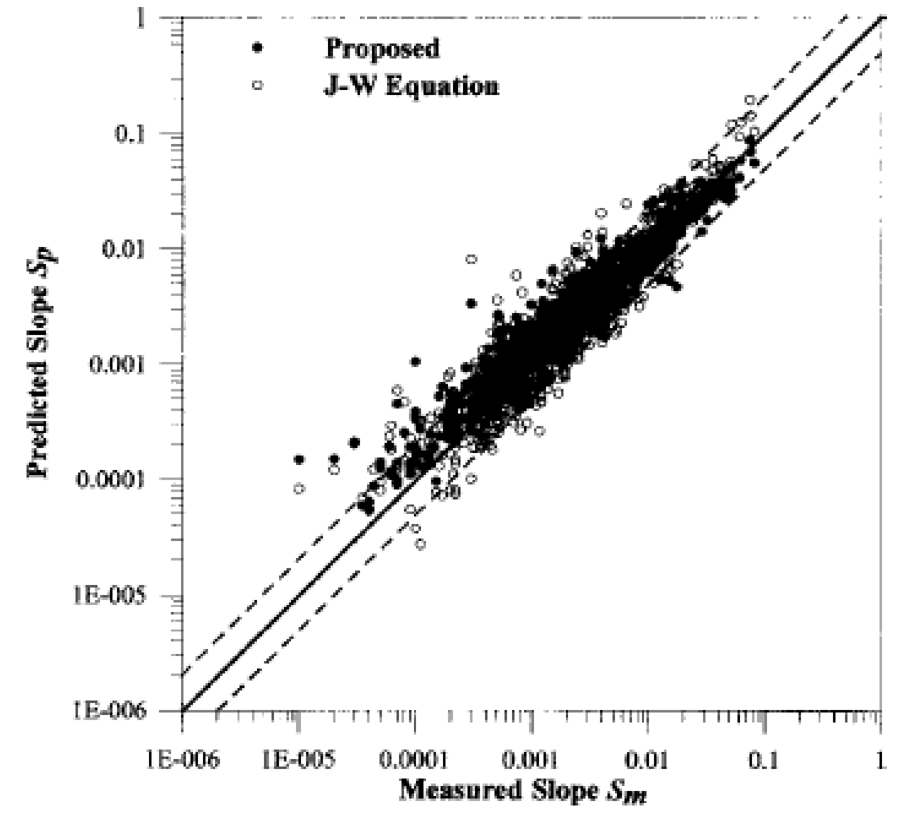
Bankfull width and depth



from Julien and Wargadalam (ASCE-JHE, 1996)

Bankfull velocity and slope





from Julien and Wargadalam (ASCE-JHE, 1996)

1c. Meandering

Sediment Transport in Sharp Bends

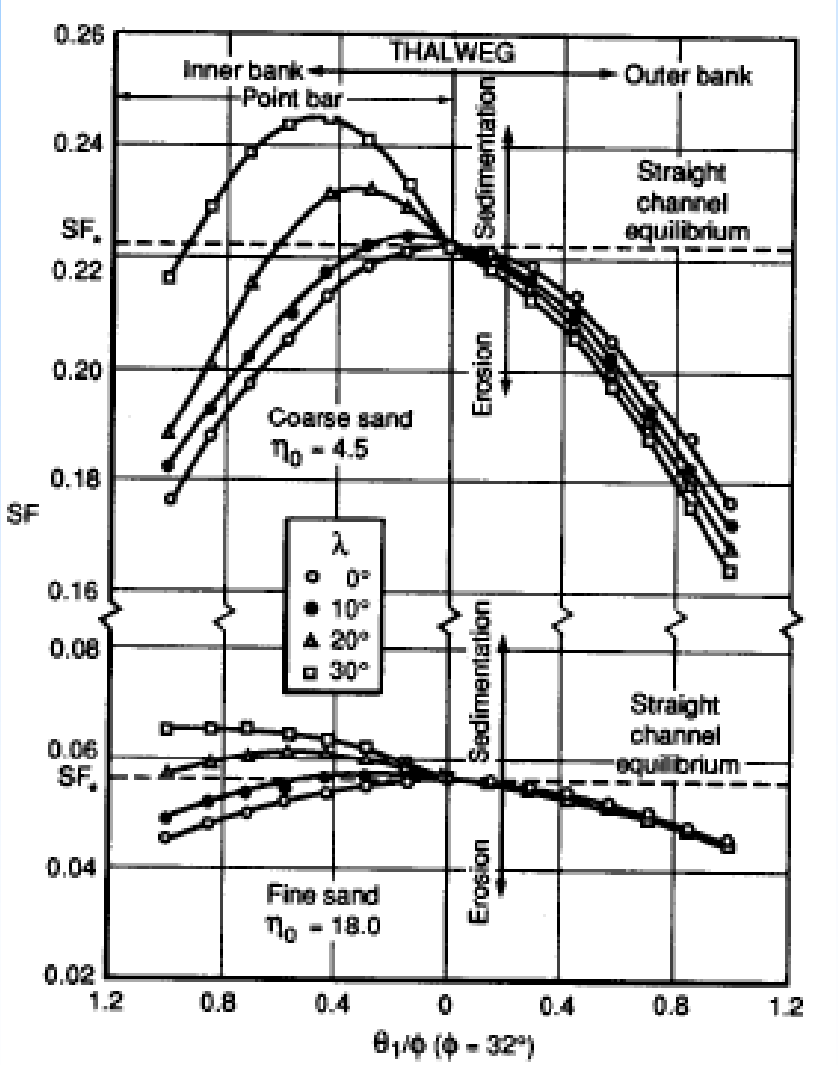
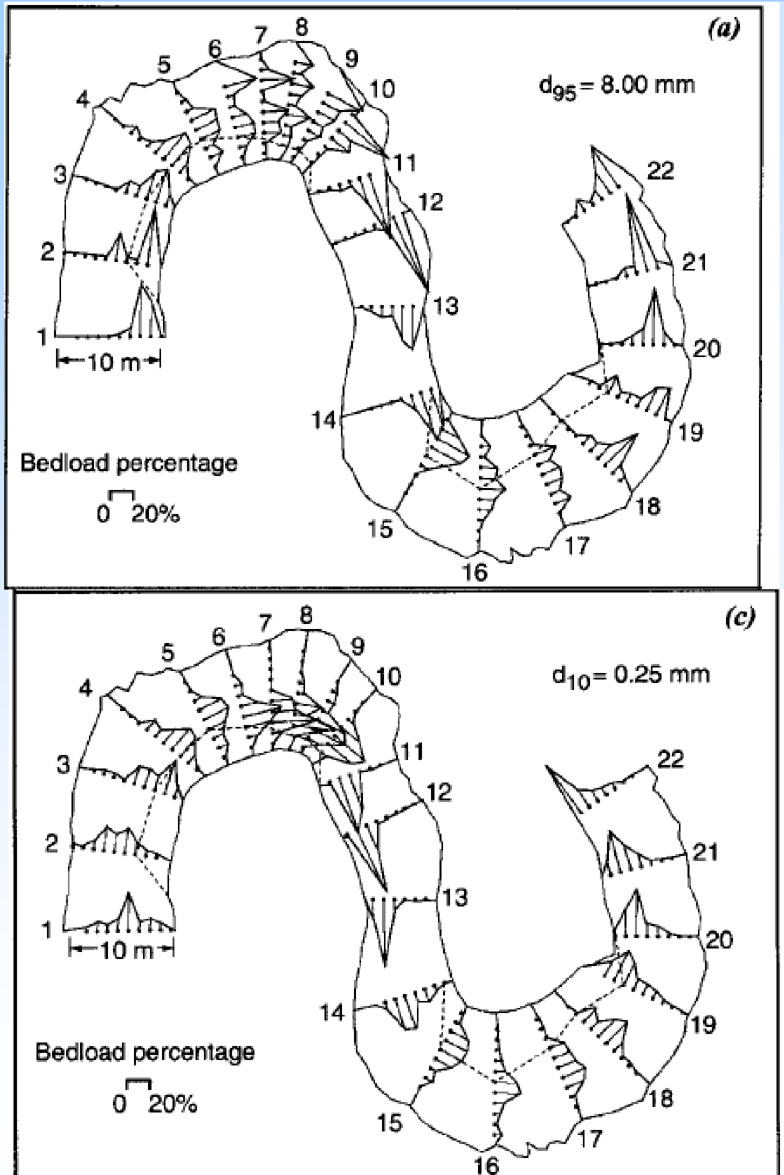


Fig. 3. Relation between *SF* and θ_1/ϕ (*M/N* = 1).

Laboratory experiments show that fine sand can deposit where coarse sand cannot, i.e. point bars

from Kawai and Julien (JHR-IAHR, 1996)

Sediment Transport in Sharp Bends



Field measurements in the sharp bends of the Fall River, Colorado demonstrate that particles of different sizes move in different directions.

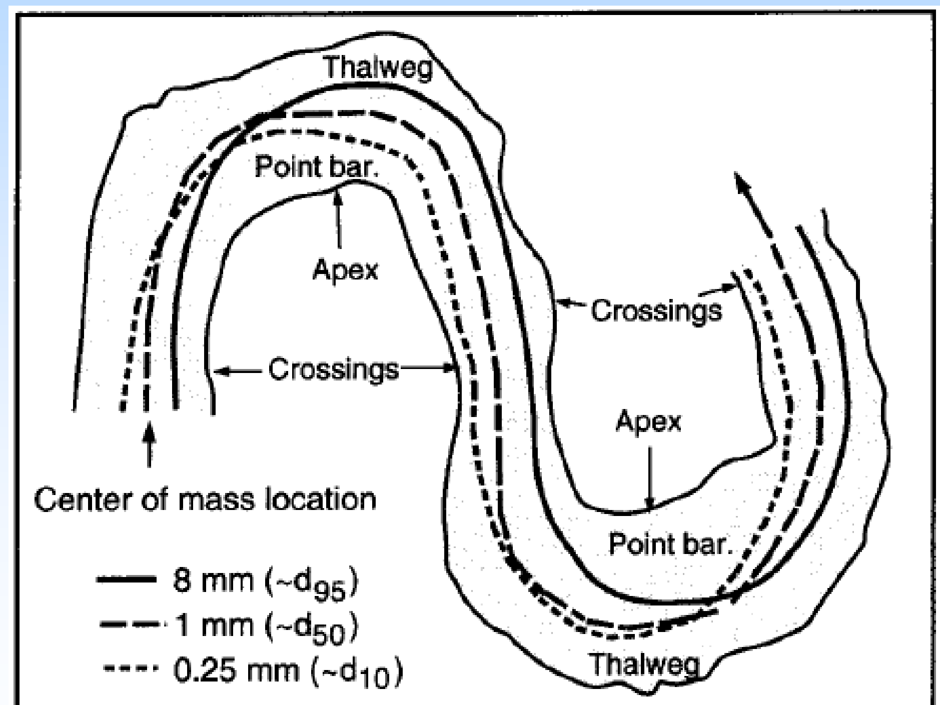
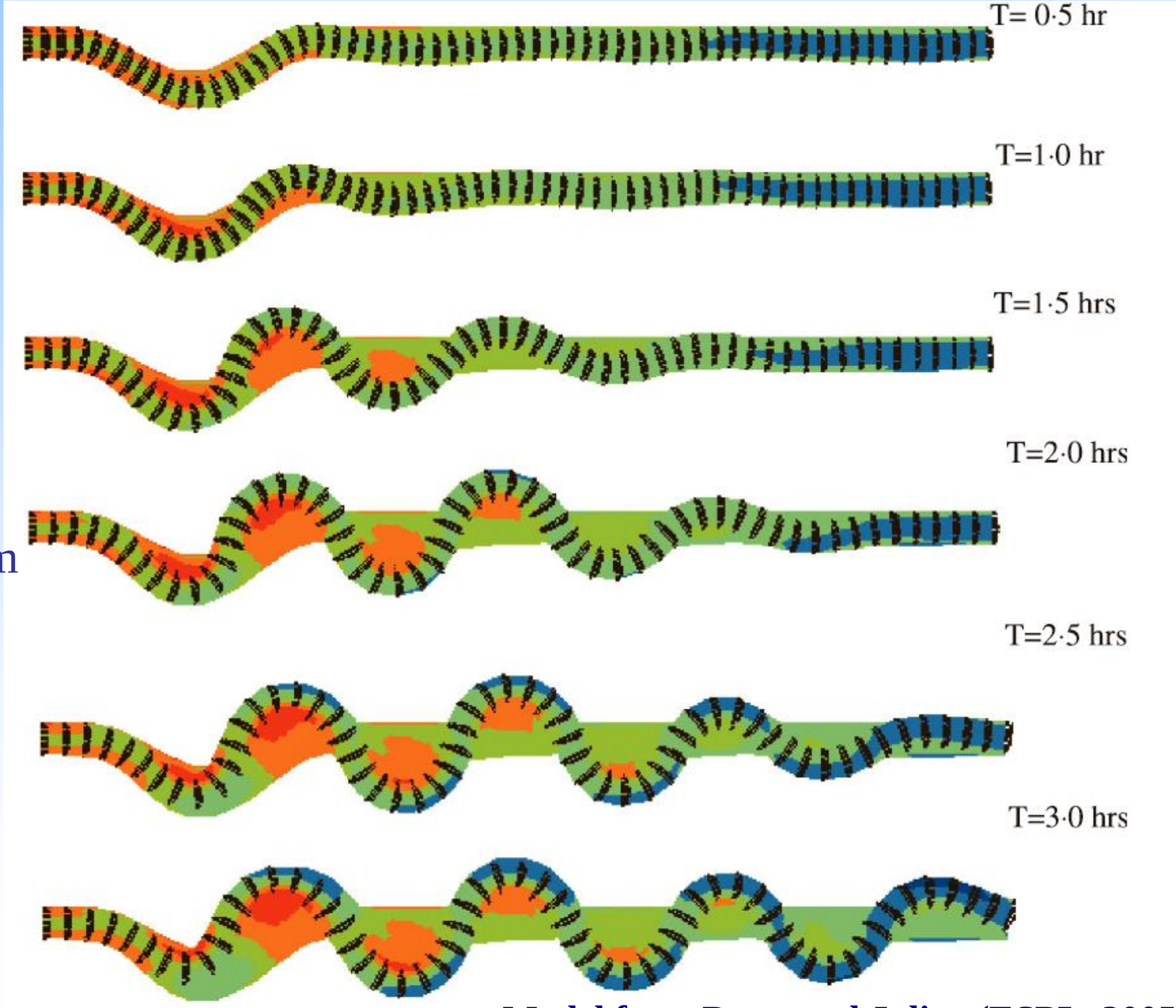


Fig. 5 Center of mass curves for three bedload size fractions

from Julien and Anthony (JHR-IAHR, 2002)

Meandering Simulations

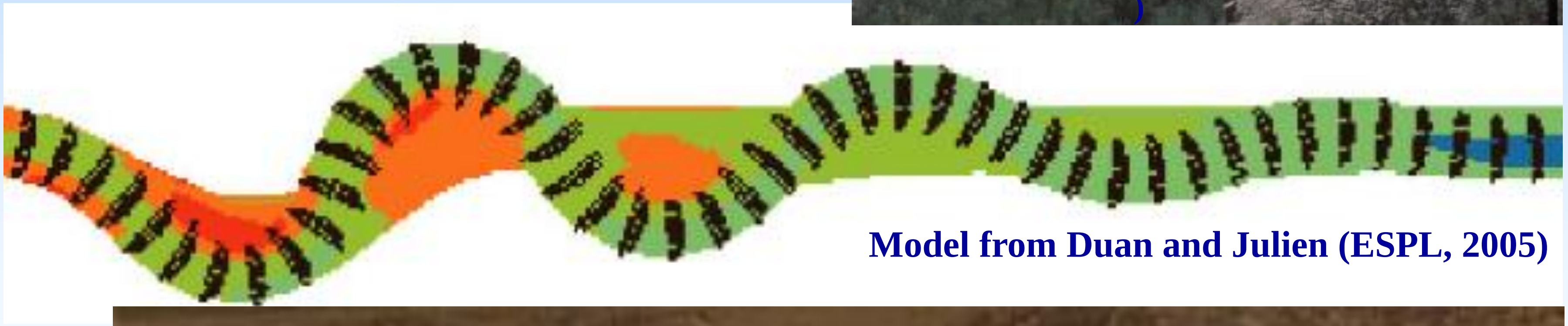
Initial Conditions
- sine-generated
- deflection angle 30°
- discharge 2.1 *l*/s
- width 0.4 m
- length 13.2 m
- sediment size 0.45 mm



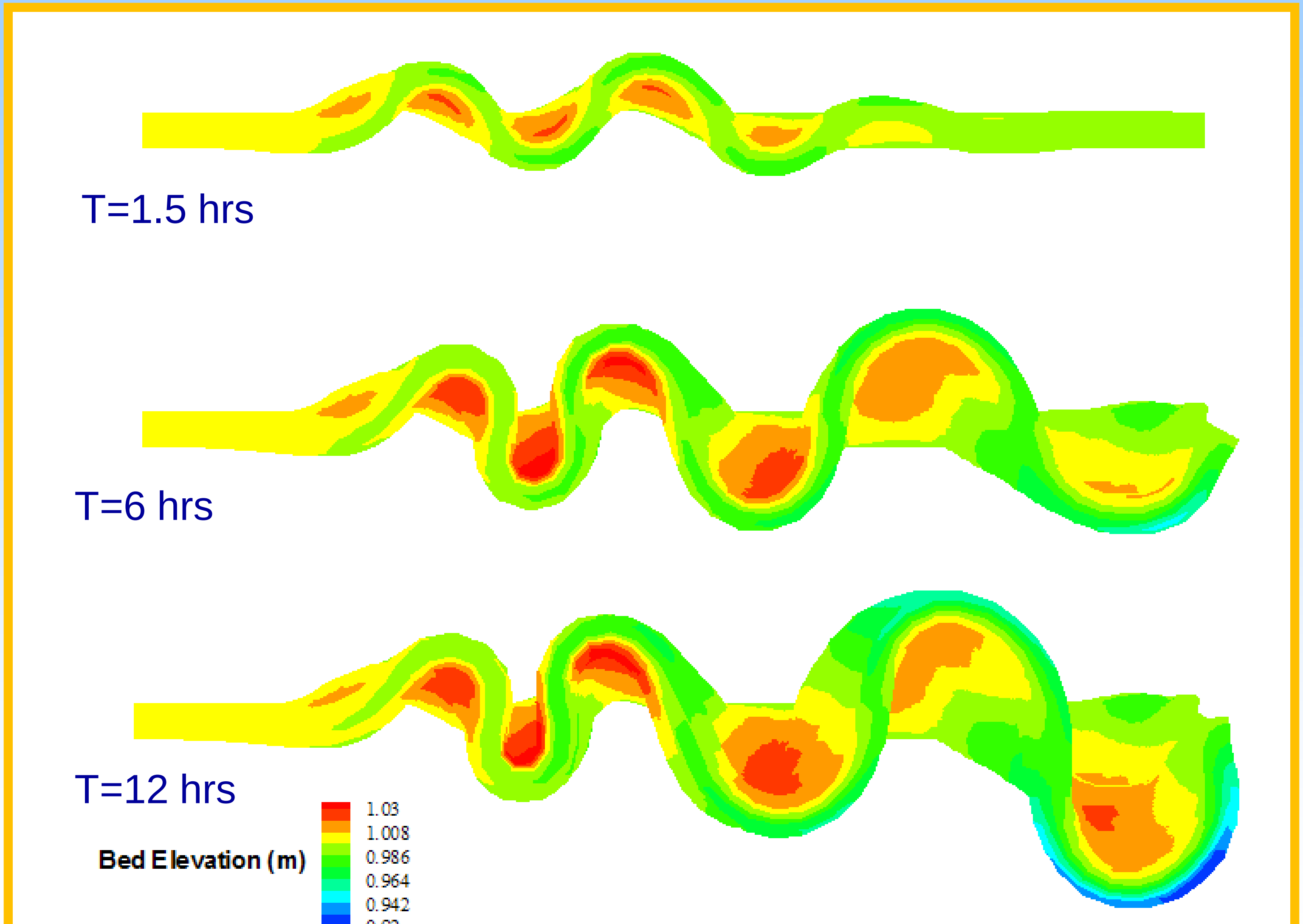
Model from Duan and Julien (ESPL, 2005)

Meandering Evolution

Example starting from a straight channel on the Rio Puerco, New Mexico



Meandering Simulations



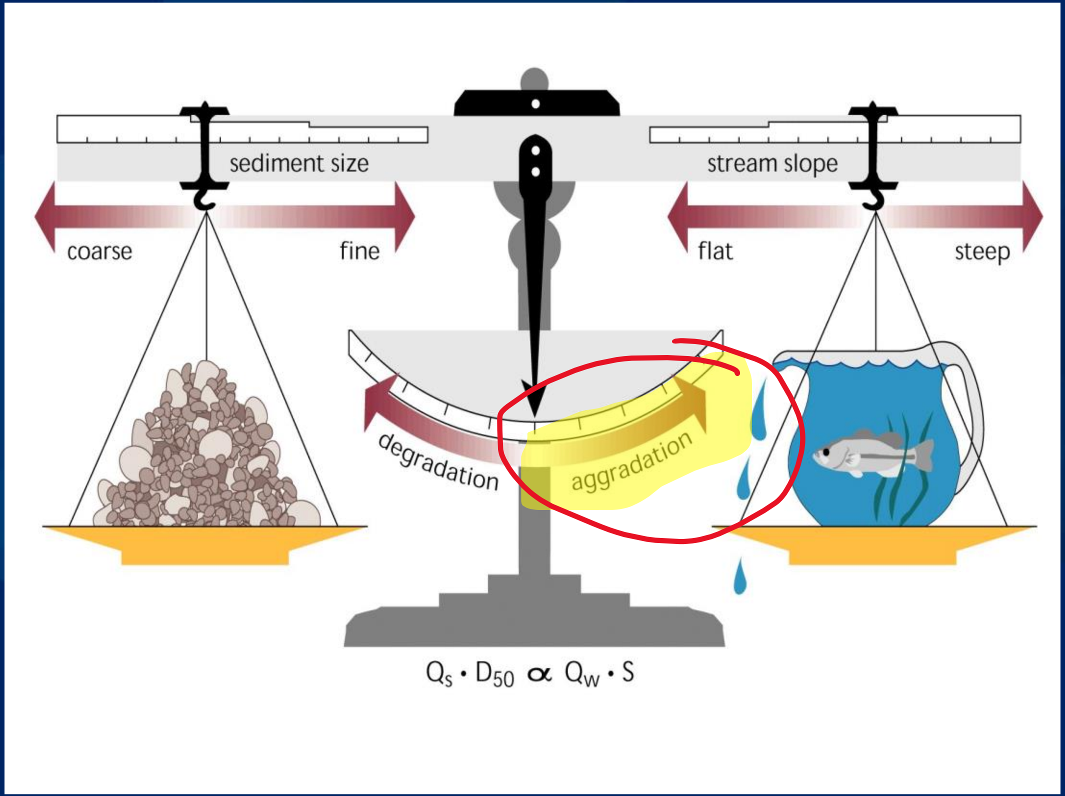
from Duan and Julien (J. Hydrol., 2010)

Lateral Migration in a Meandering Channel

Rivers and Dams

1. River Equilibrium
2. **Aggradation**
3. Degradation below Dams
4. Case Study Gupo Bridge
5. Case Study Dam Break

2a. Meandering to Braiding (sediment overload)



Natural Chute Cutoffs

- Often in response to an increase in sediment load

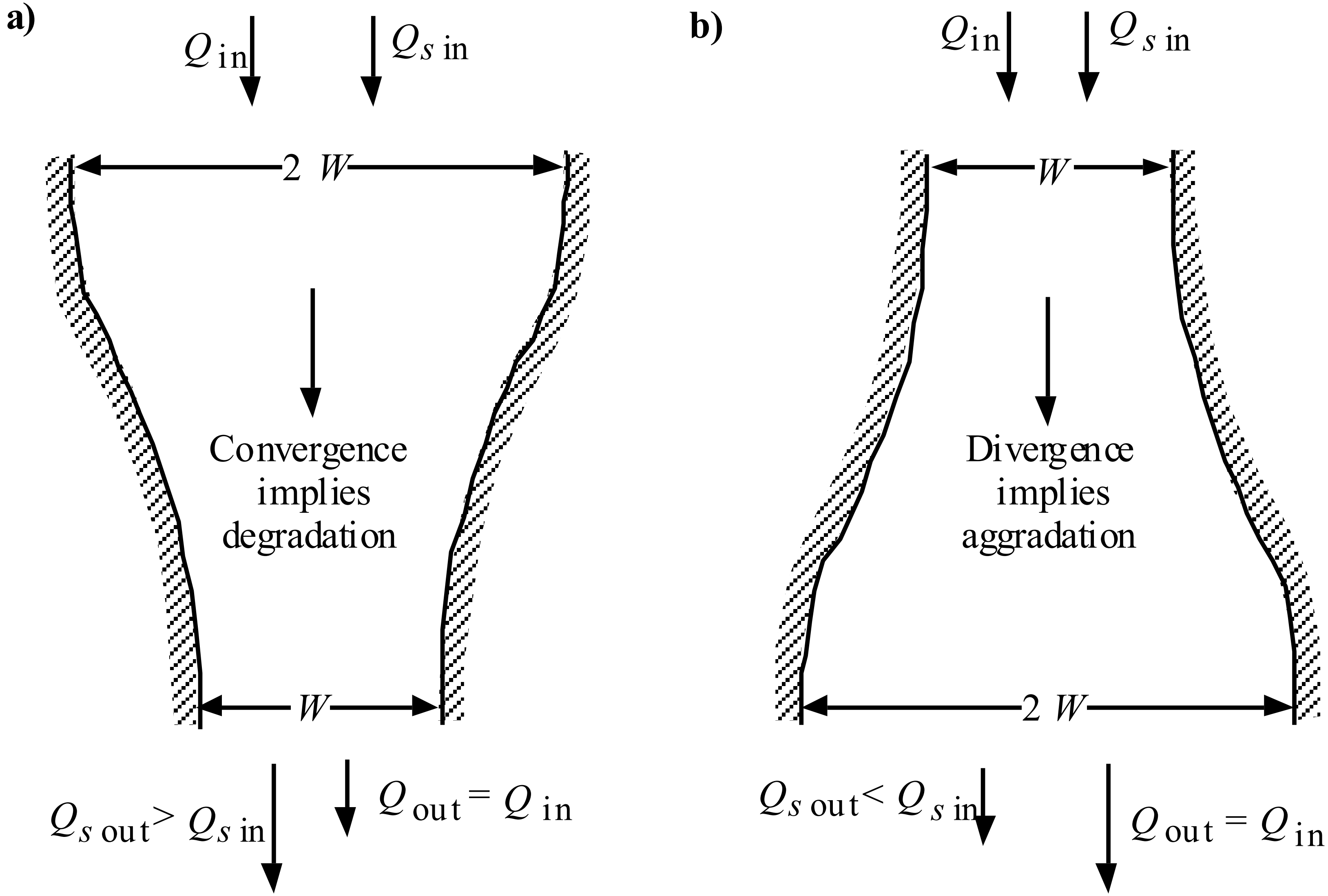
- Chute cutoffs on Williams River, AK

(Photo by N.D. Smith)

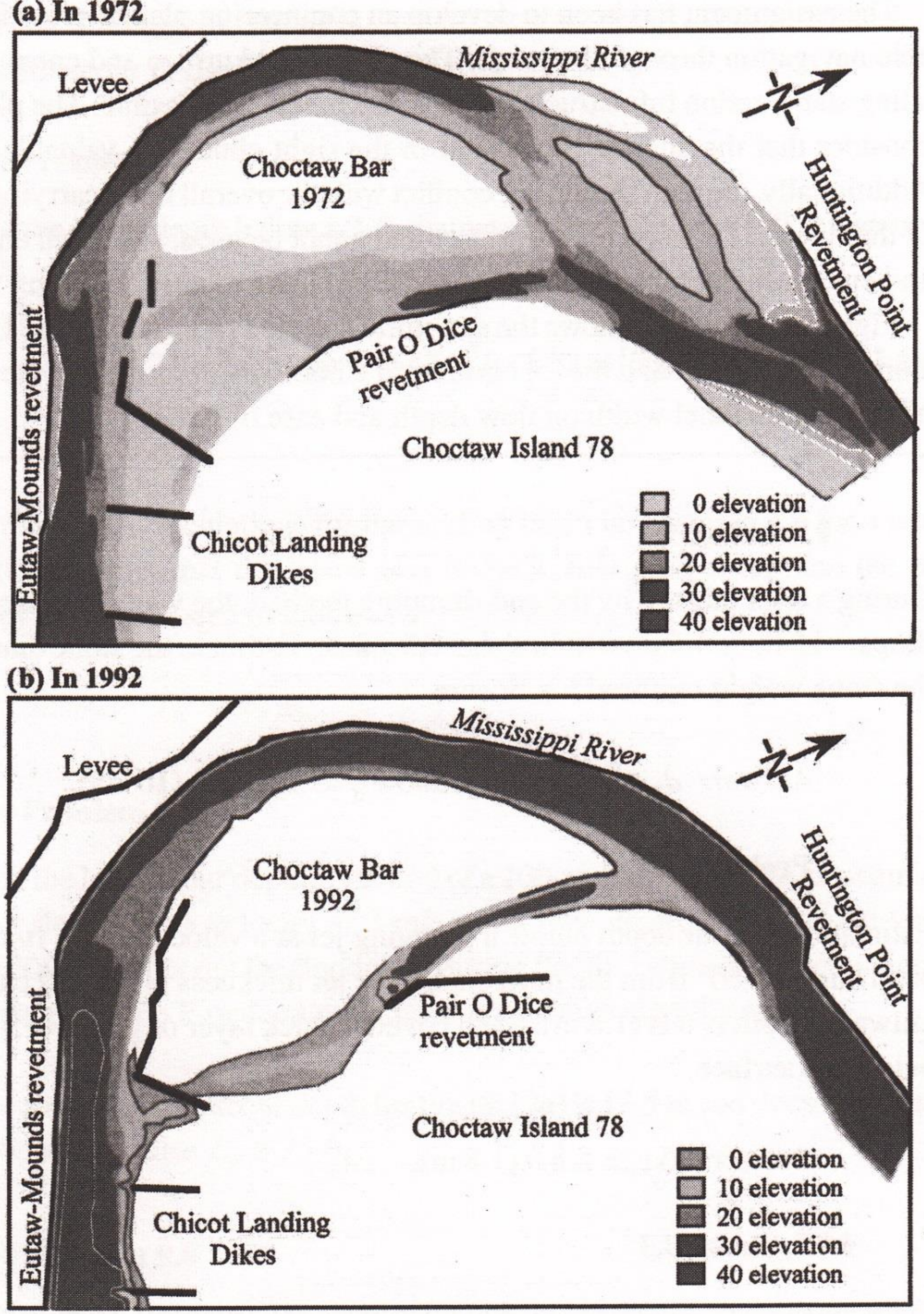
Oxbow Lake


Riverbed rising forces
river overbank

2b. Channel width variability

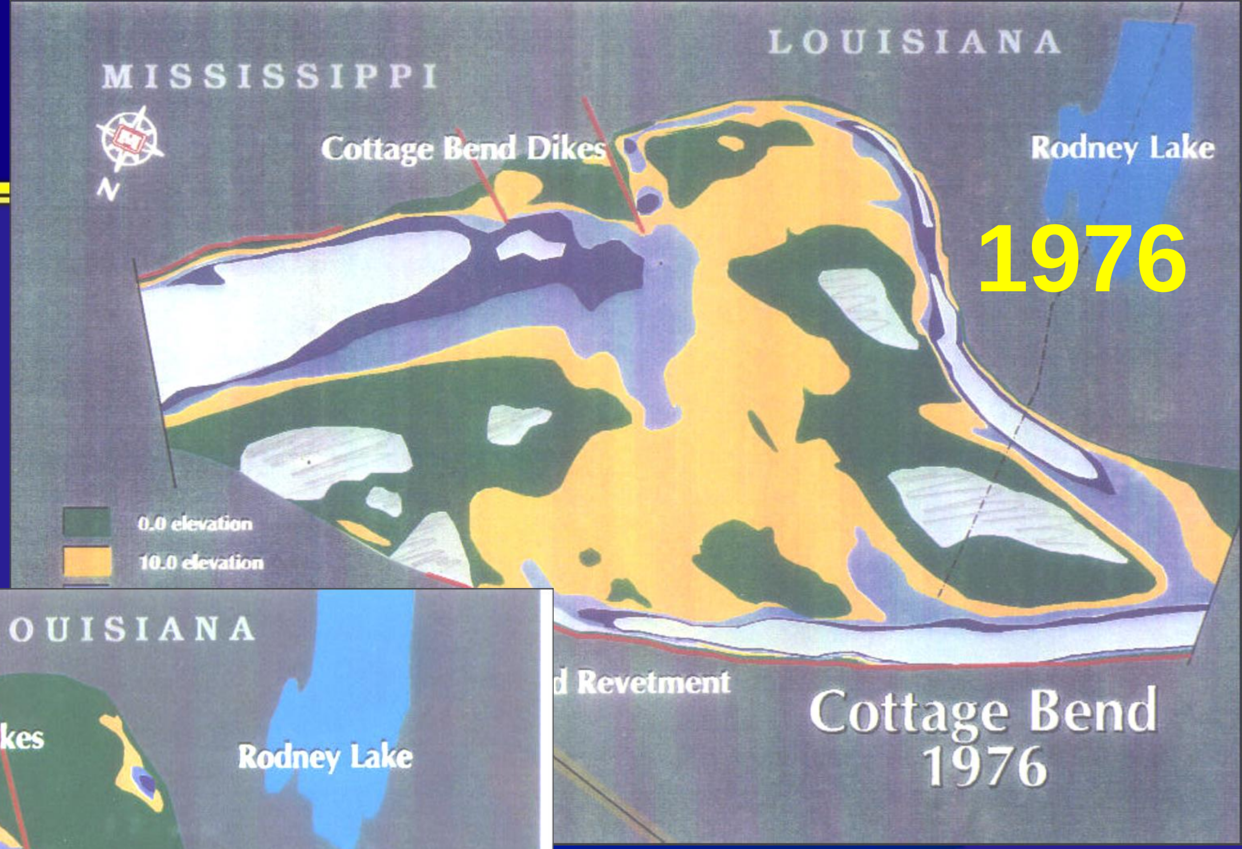

a)
Q_{in}
$Q_{s\ in}$
2 W
Convergence
implies
degradation
W
$Q_{s\ out} > Q_{s\ in}$
$Q_{out} = Q_{in}$
b)
Q_{in}
$Q_{s\ in}$
W
Divergence
implies
aggradation
2 W
$Q_{s\ out} < Q_{s\ in}$
$Q_{out} = Q_{in}$

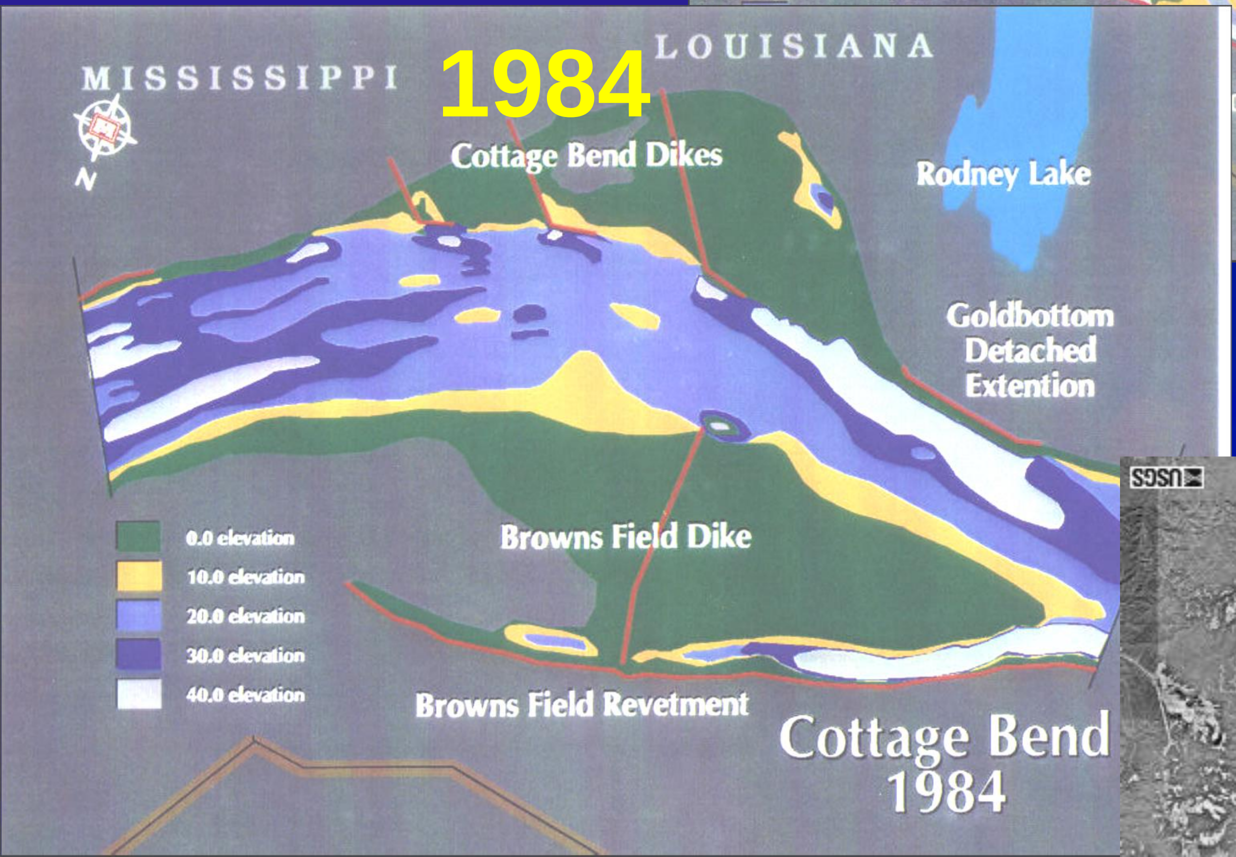
Dykes



From Julien River Mechanics CUP 2018

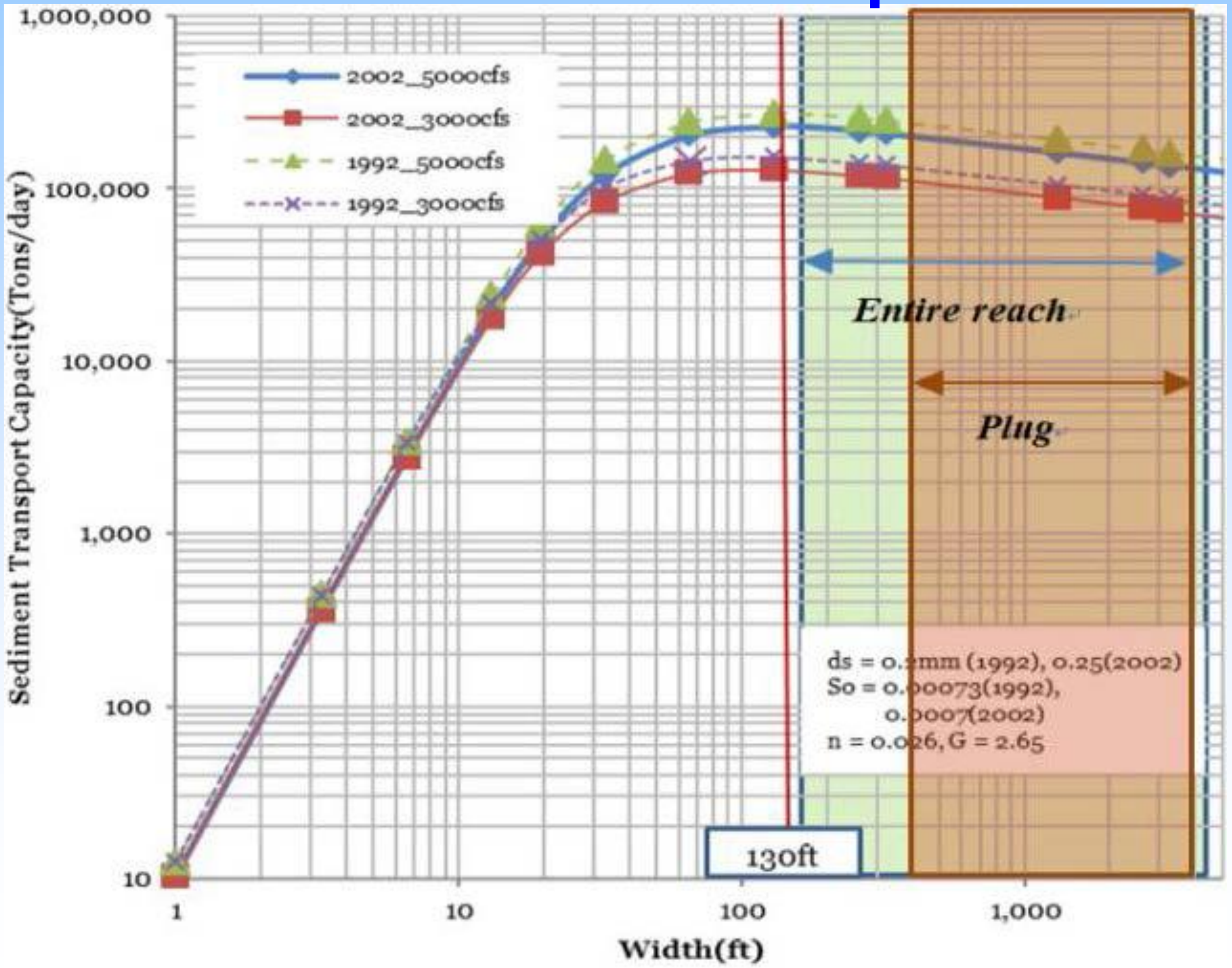
Cottage Bend



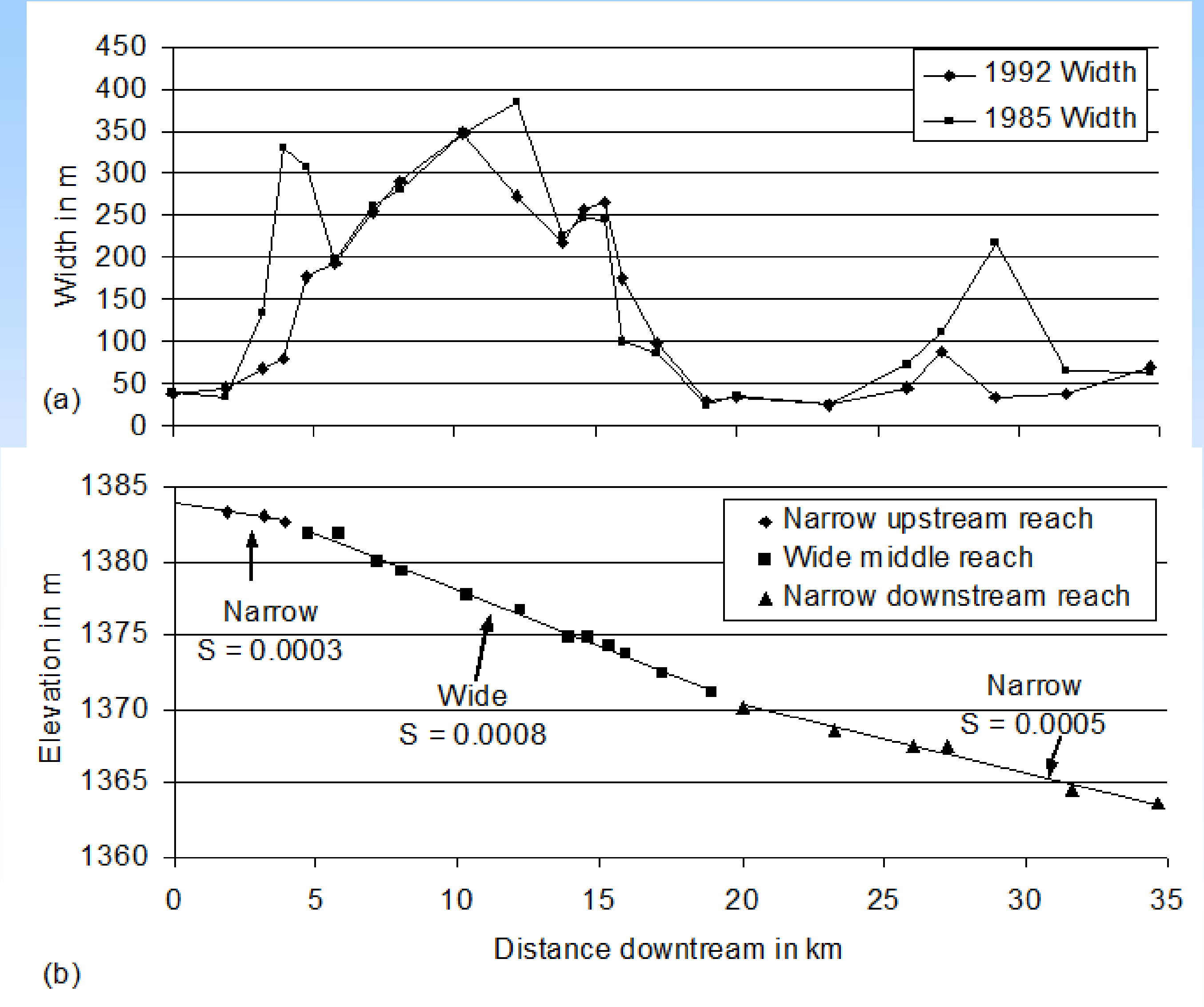


2c. Width-slope trade-offs

Relationship between channel width and sediment transport



Wider reaches are steeper!



From Leon et al. ASCE-JHE 135(4), 2009

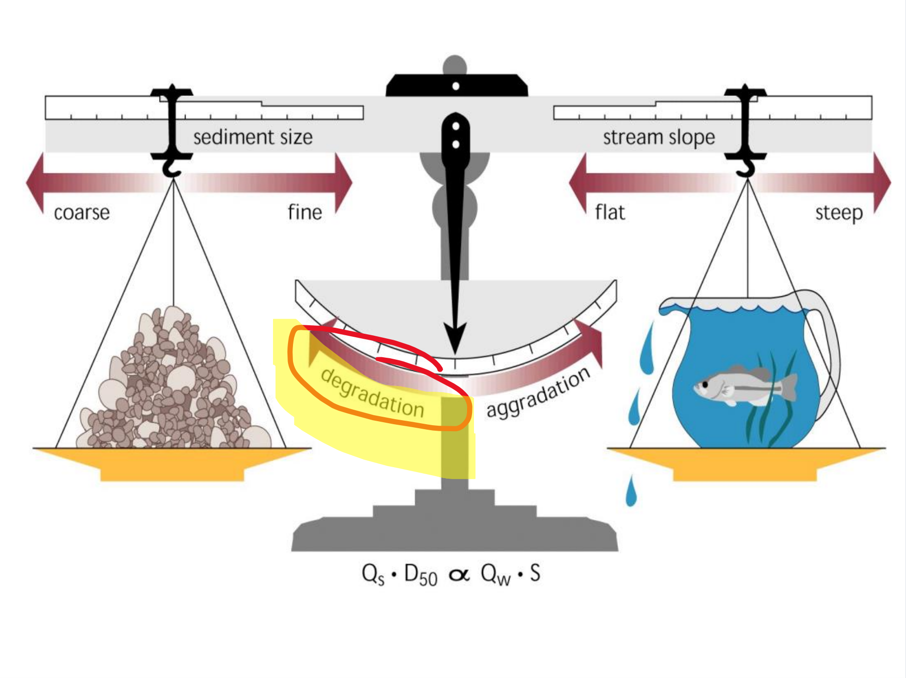
Rivers and Dams

1. River Equilibrium
2. Aggradation
3. **Degradation below Dams**
4. Case Study Gupo Bridge
5. Case Study Dam Break

3a. Degradation Problems

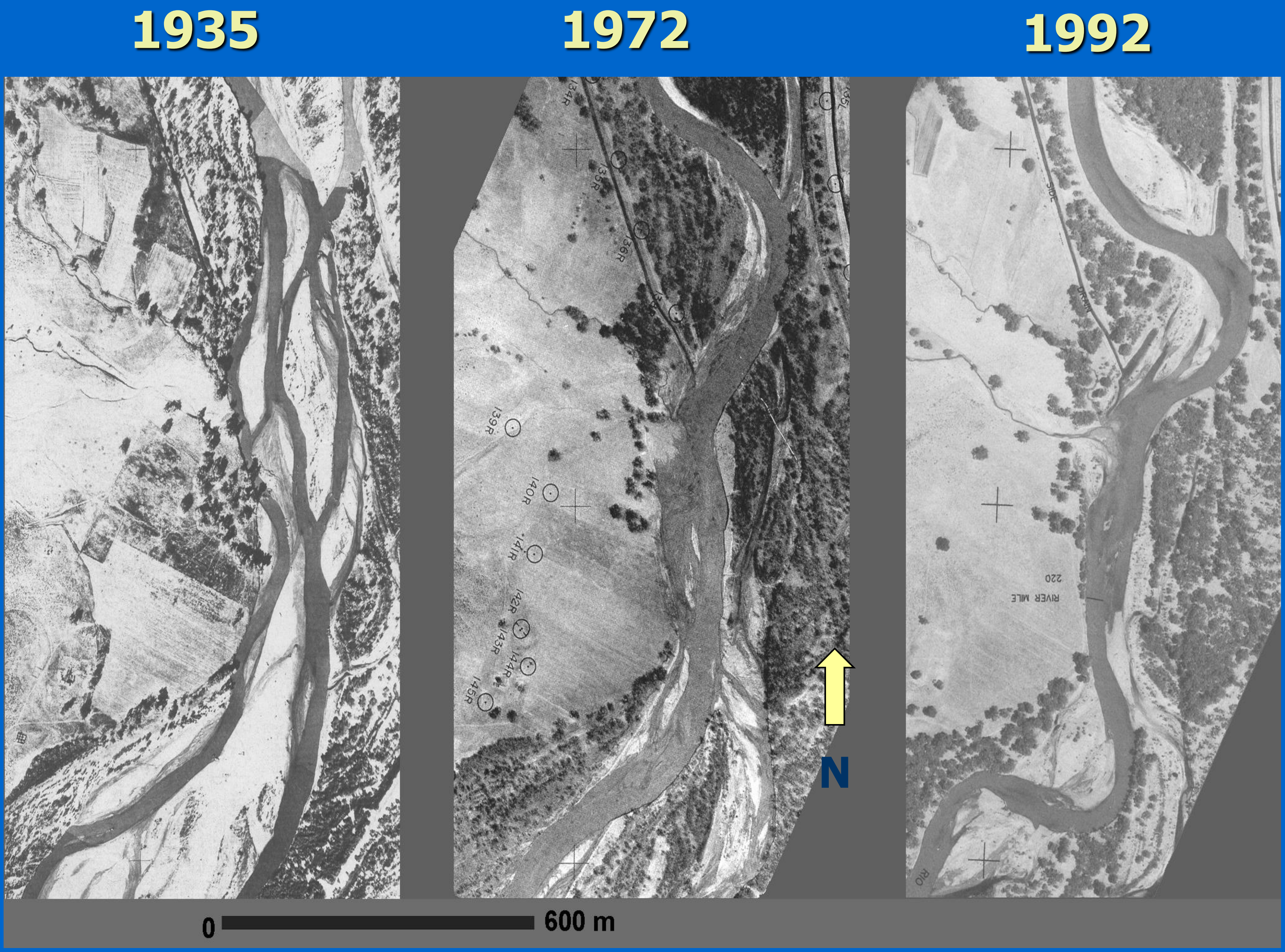



3b. Braiding to meandering (sediment starved)

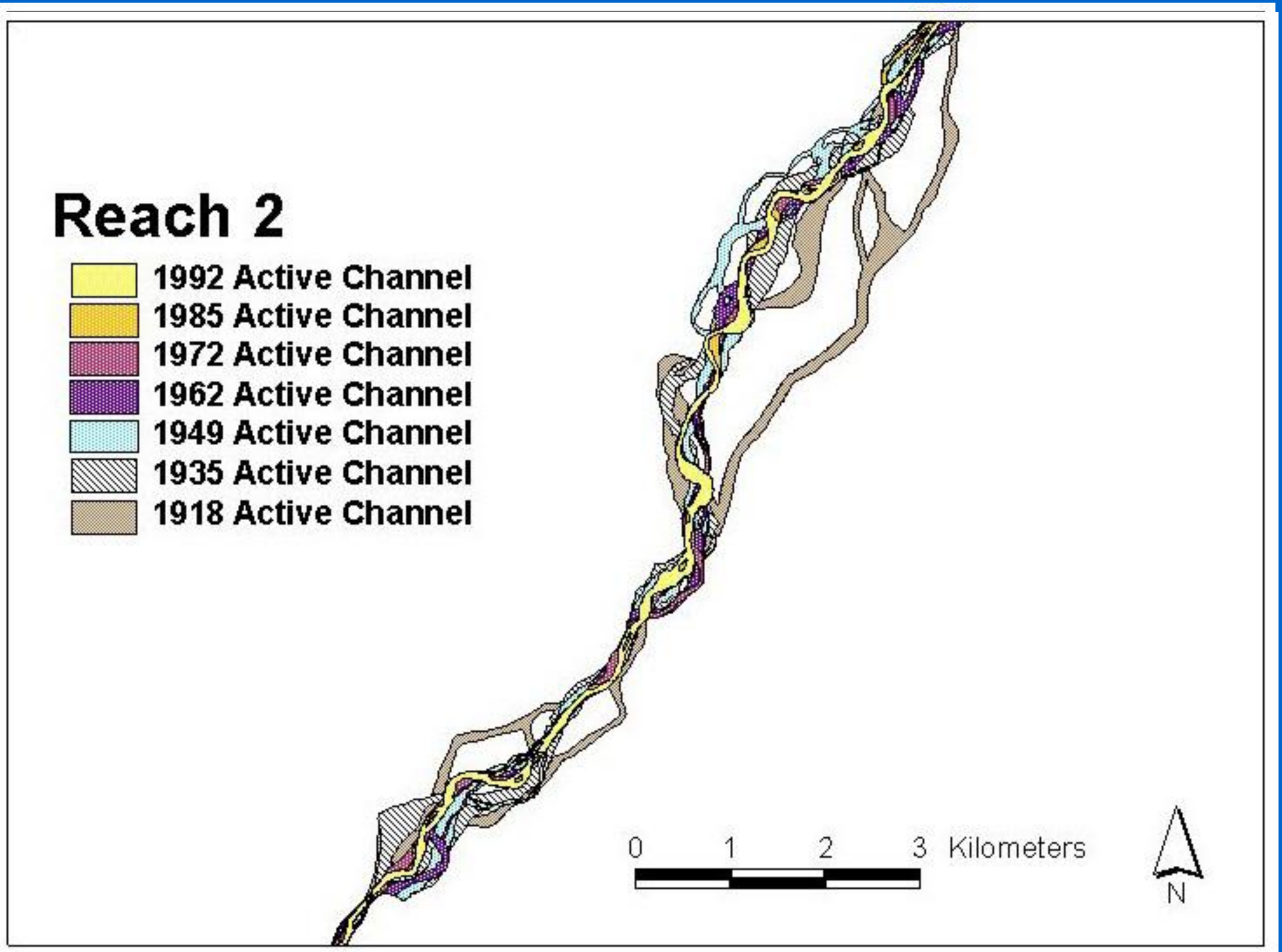



Cochiti
Dam
Rio Grande
Santa Fe River
N
USGS

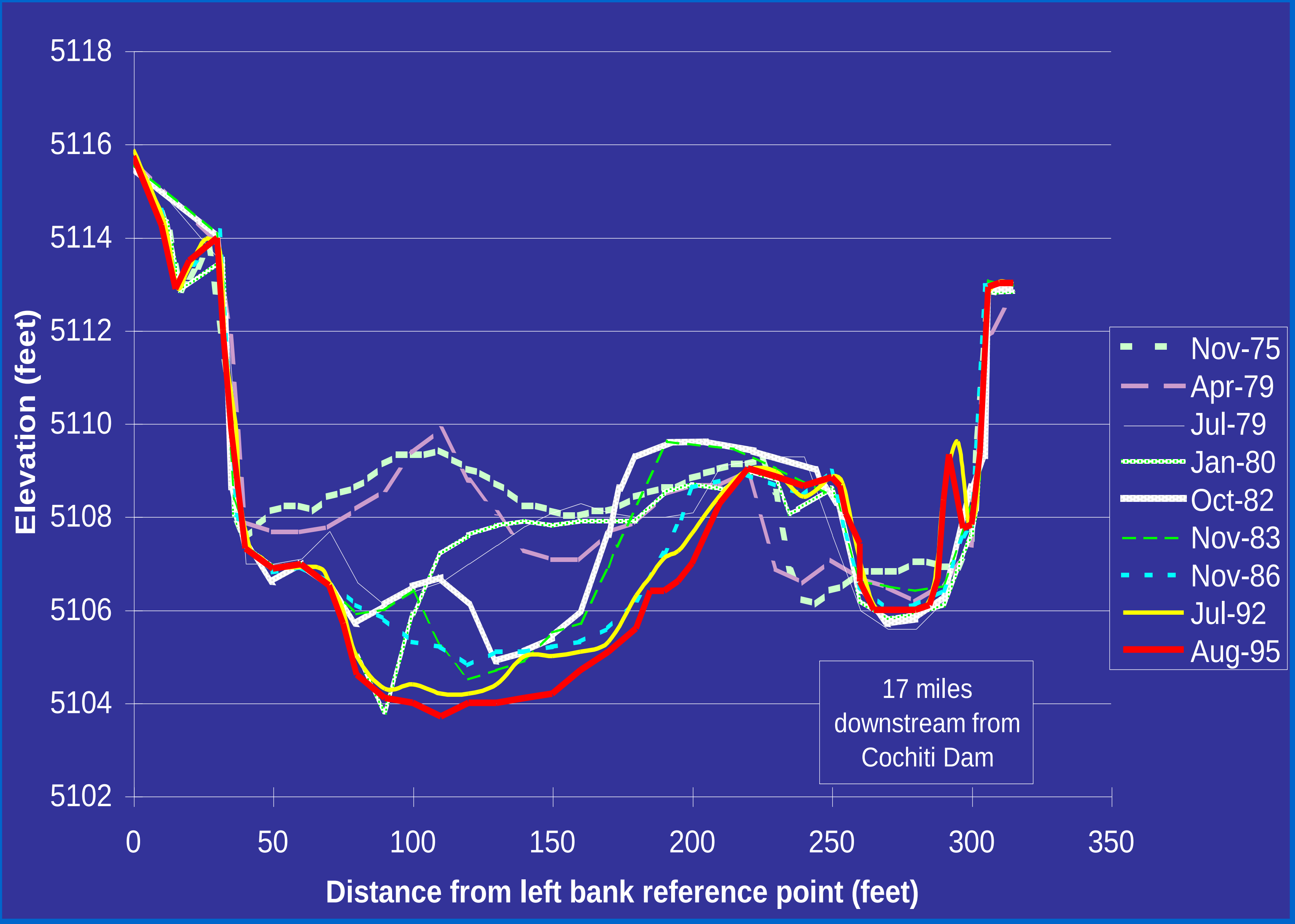
Planform geometry



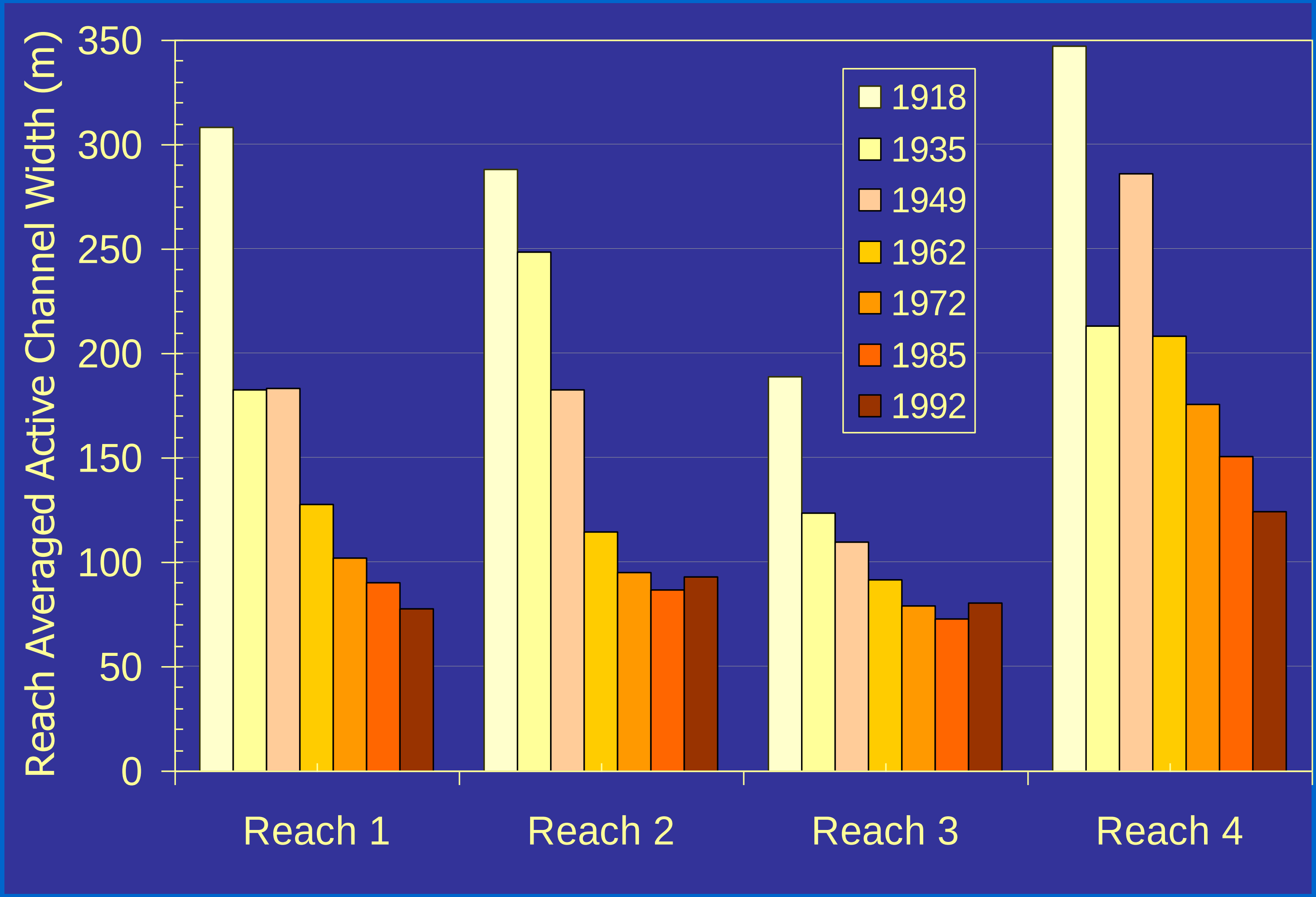
Lateral Adjustments



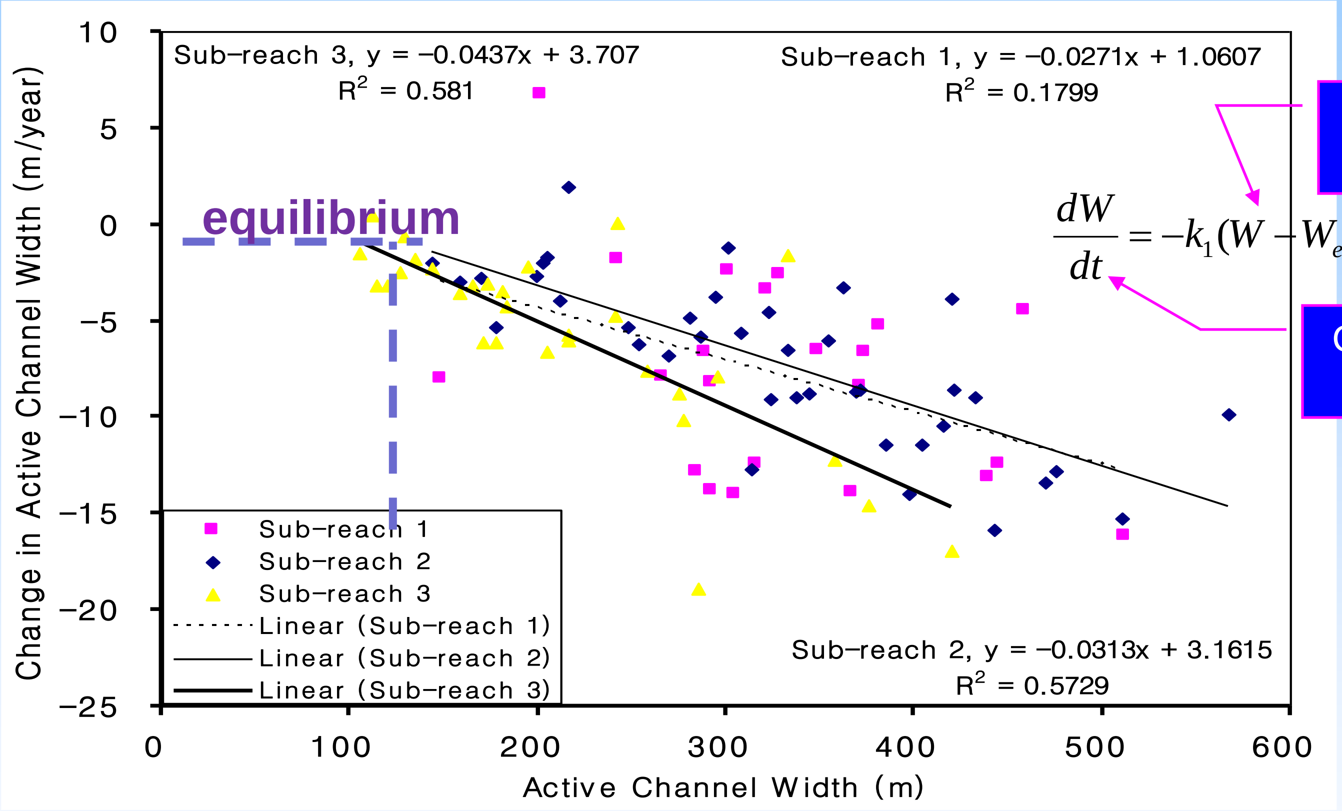
Cross section CO-18



Active channel width



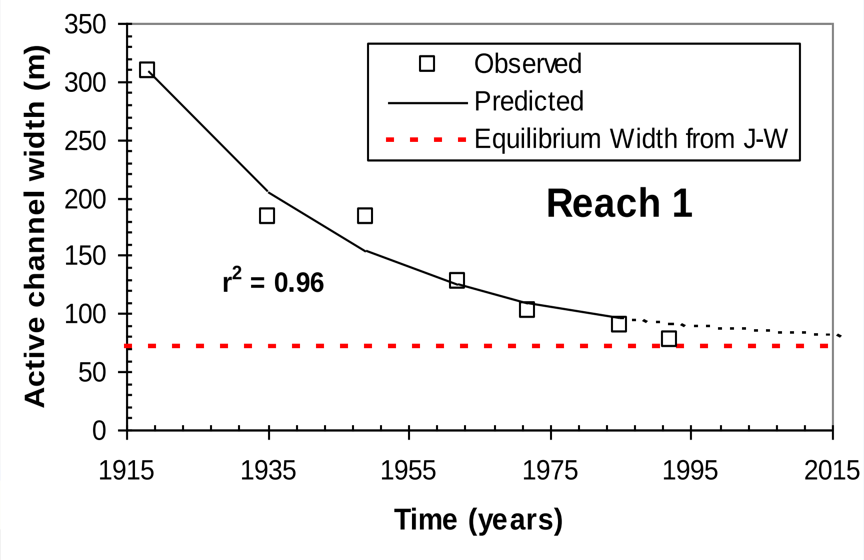
Changes in active channel width Rio Grande, NM (after Richard et al., 2005)

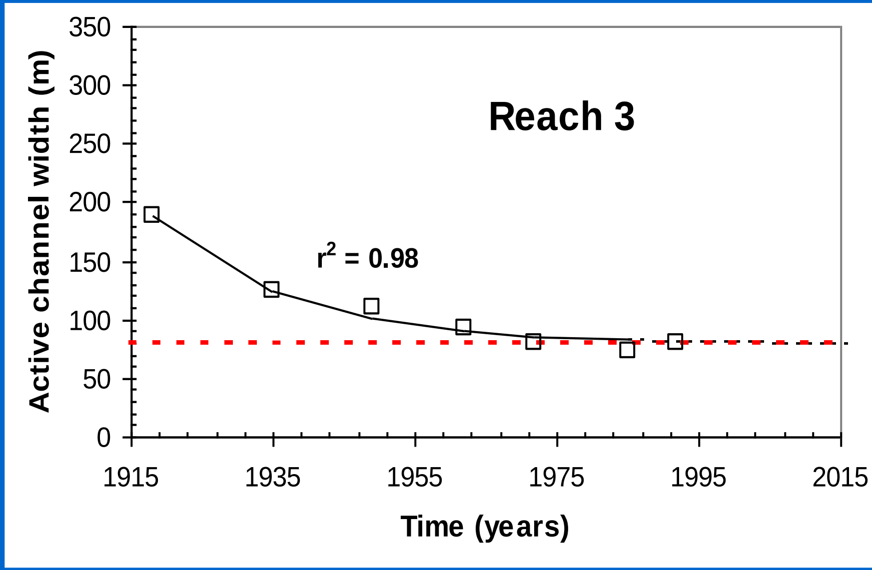


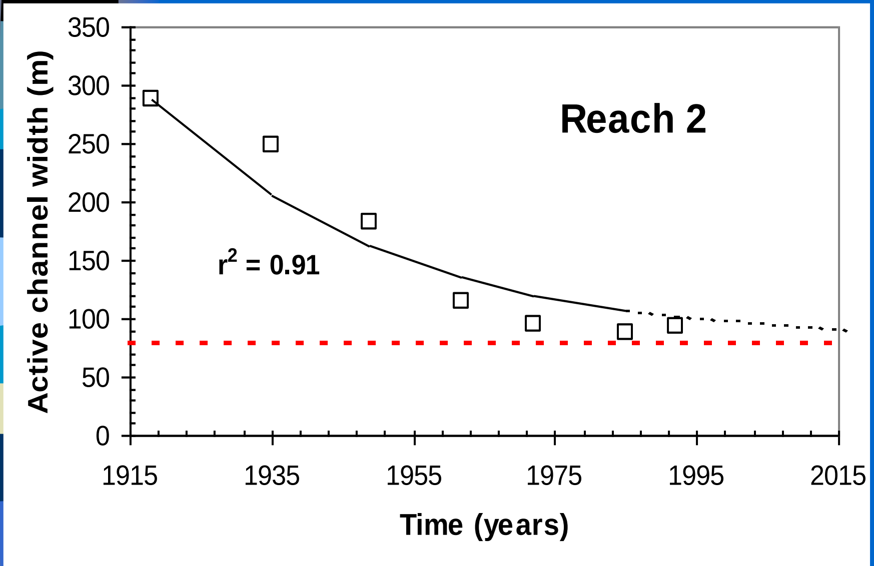
$$\frac{dW}{dt} = -k\left(W - W_e\right)$$

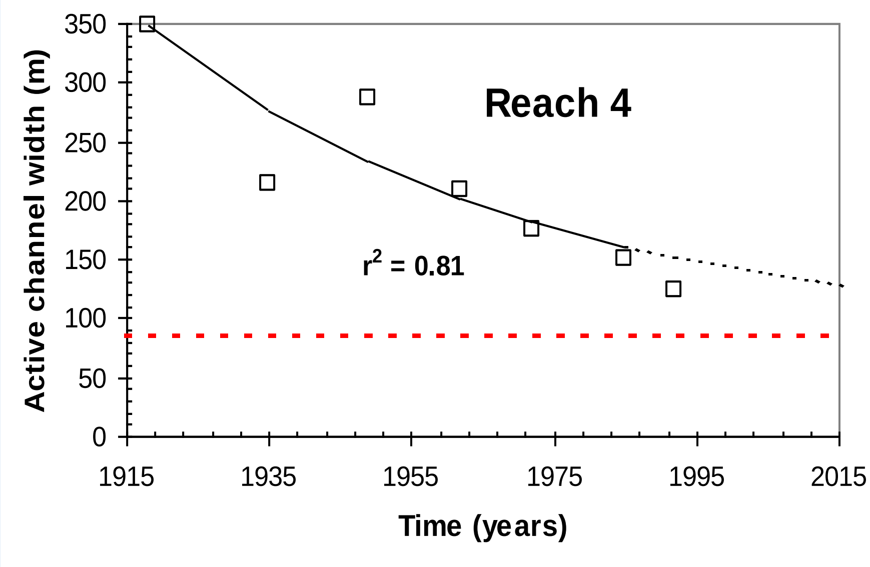
$$W = W_e + \left(W_o - W_e\right)\cdot e^{-kt}$$

Exponential Model Results

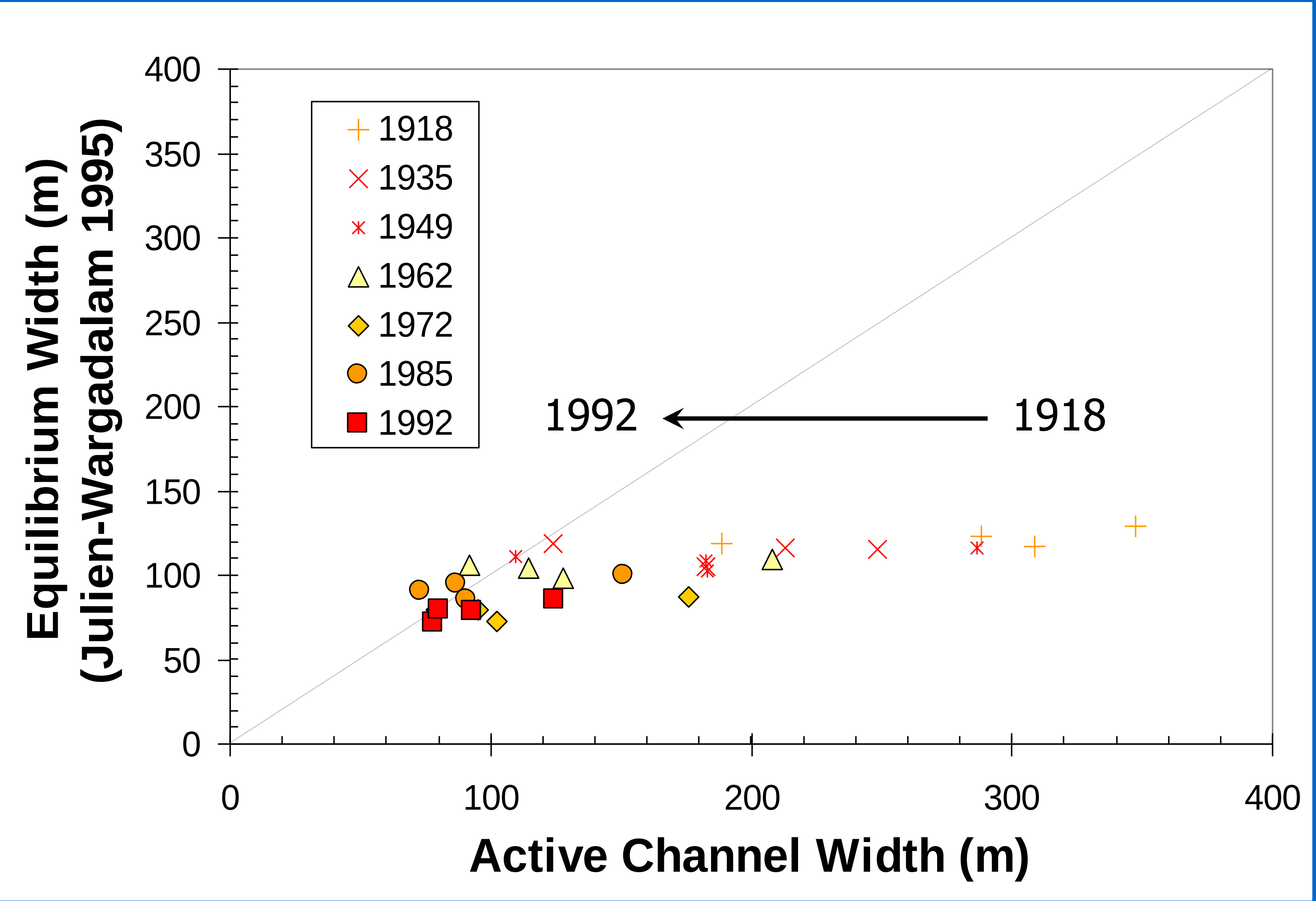








Hydraulic Geometry Equations
(Julien & Wargadalam 1995)

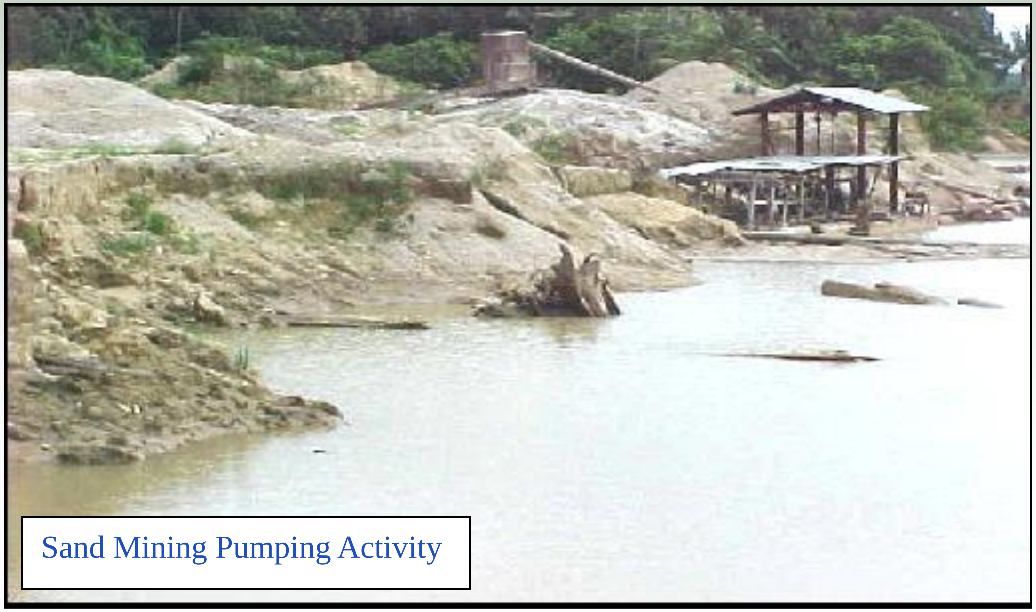


3c. River Problems in Estuaries

Sand and Gravel Mining

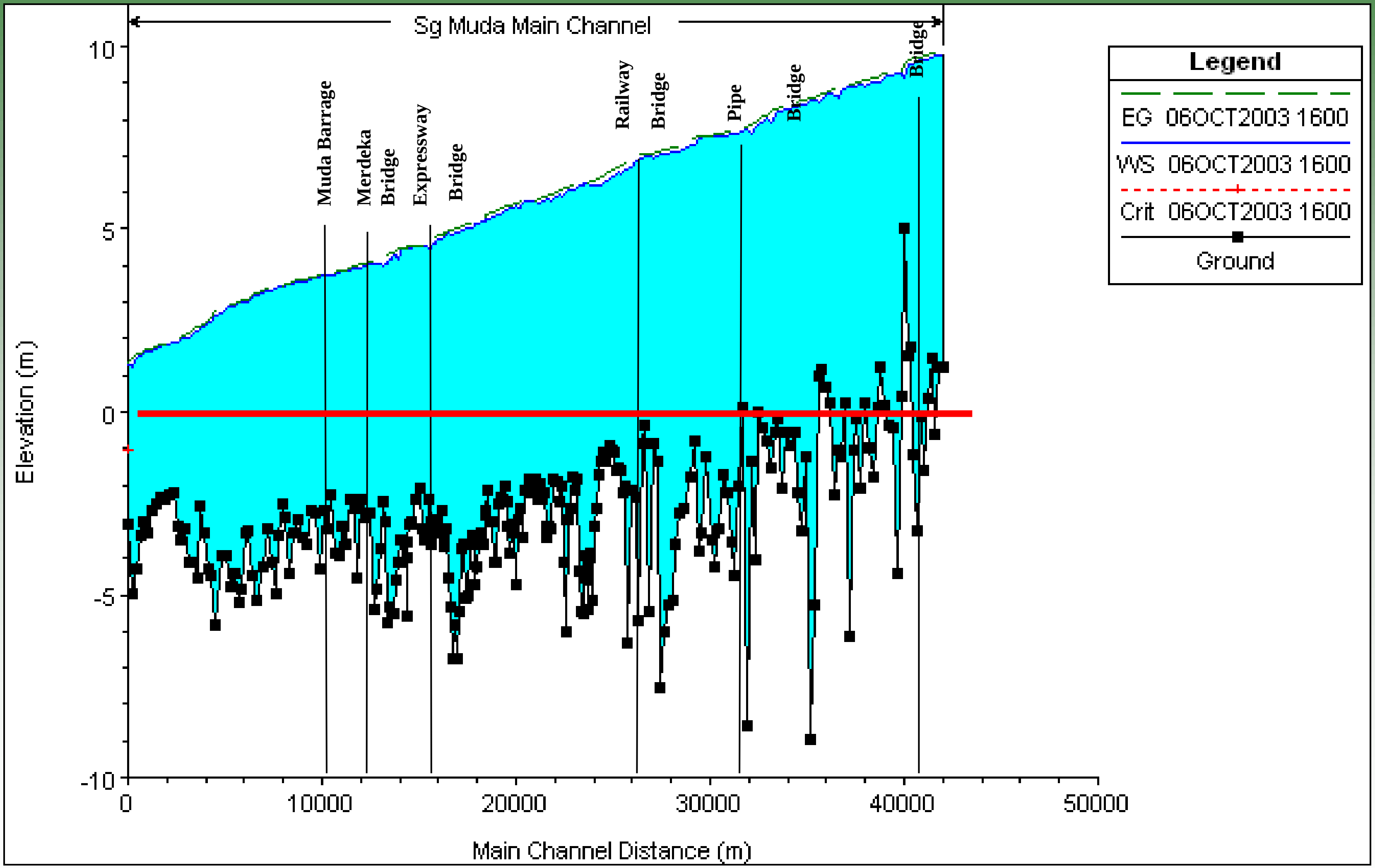

Kampong Kubang Bedengong


Kampong Lubok Segintah


Sand Mining Pumping Activity

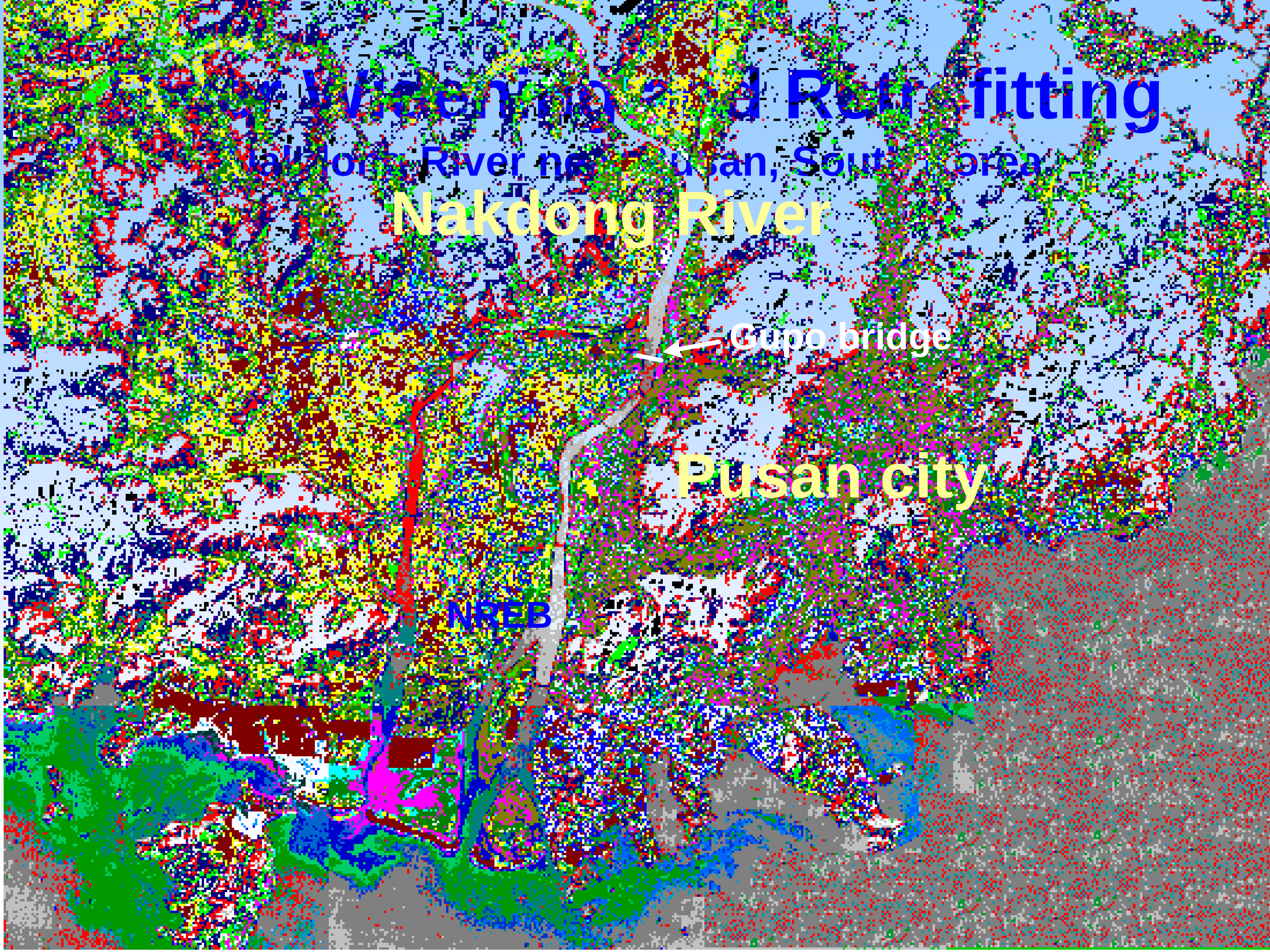
River Sand Mining

Longitudinal Flood Profile for Sg Muda ($Q=1340m^3/s$)

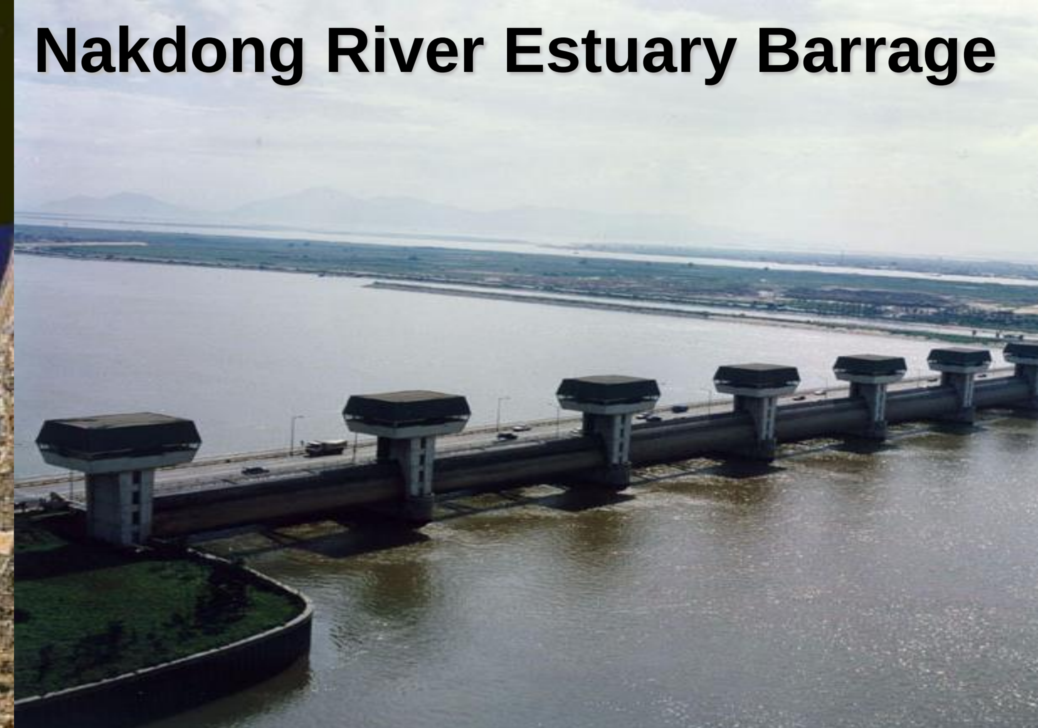


River Widening and Retrofitting

Nakdong River near Pusan, South Korea



Nakdong River Estuary Barrage

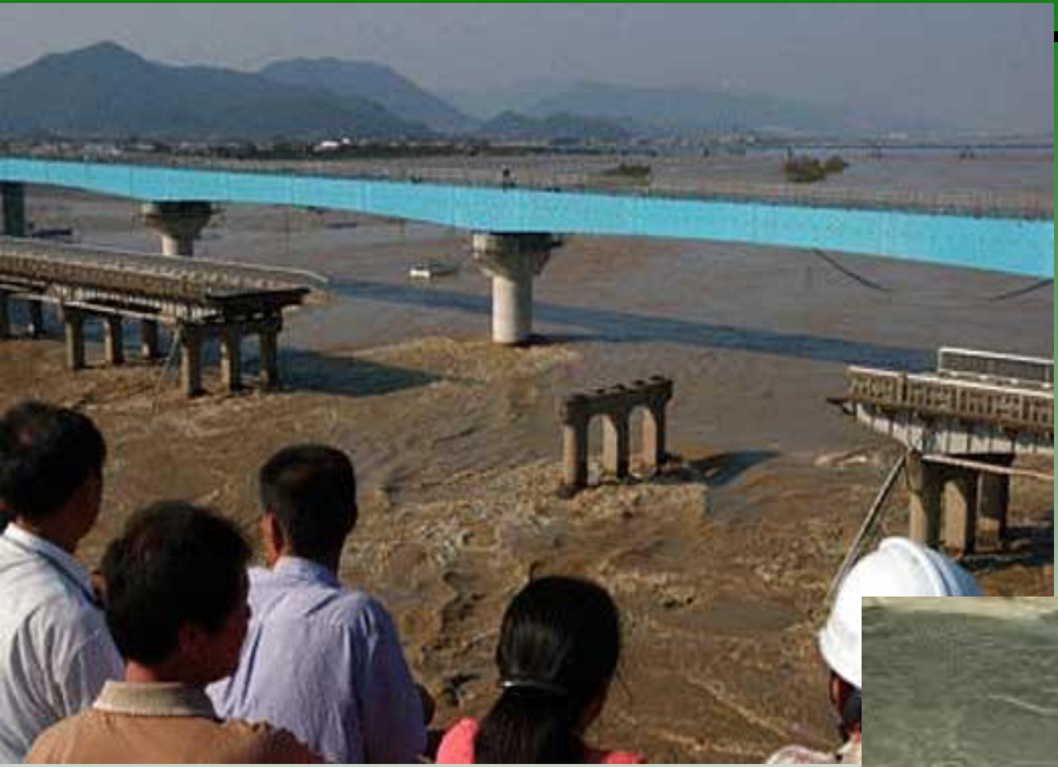


•*from Ji et al. ASCE-JHE, Nov. 2011*

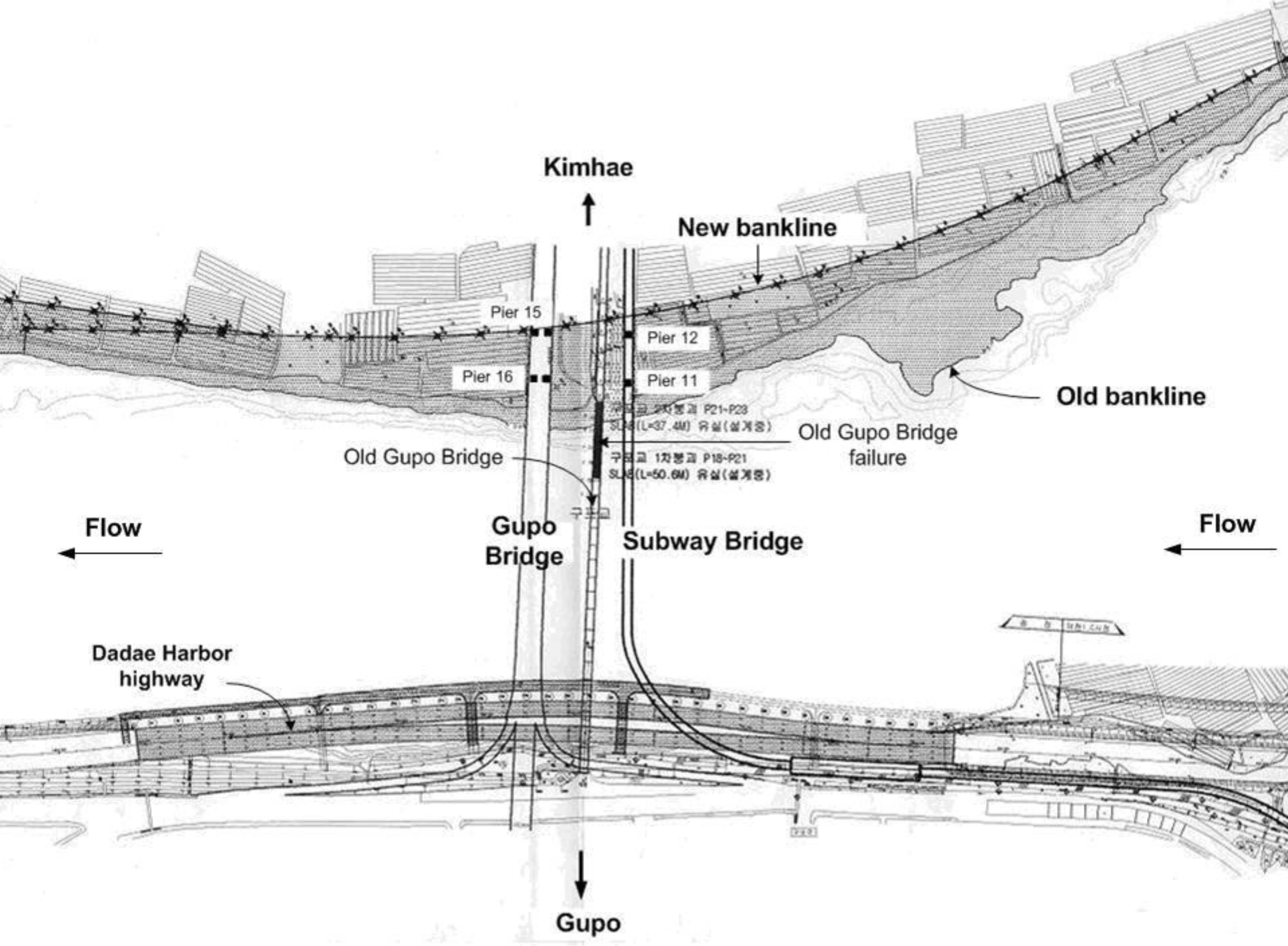
Rivers and Dams

1. River Equilibrium
2. Aggradation
3. Degradation below Dams
4. **Case Study Gupo Bridge**
5. Case Study Dam Break

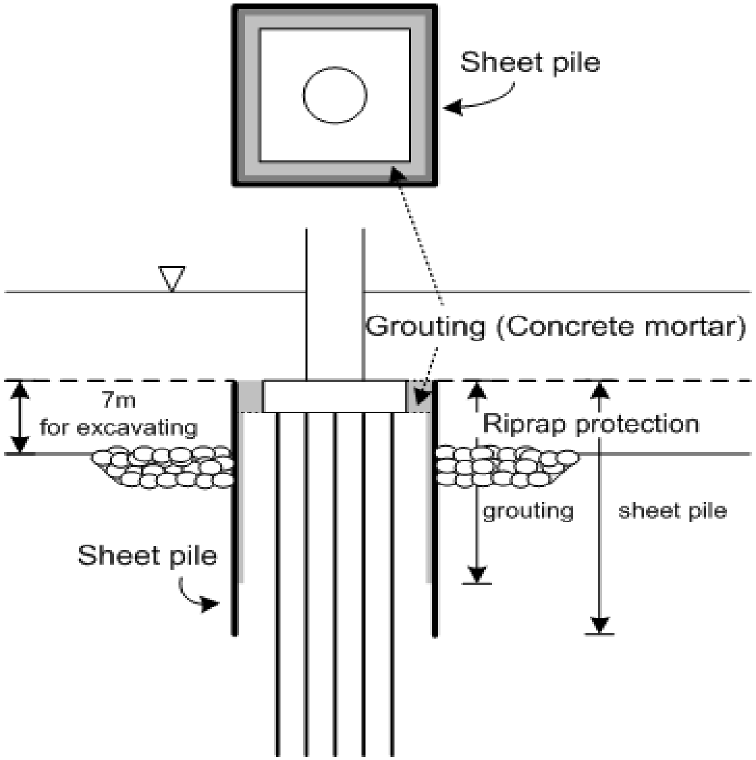
Case-Study: Gupo Bridge during Typhoon Maemi in 2003



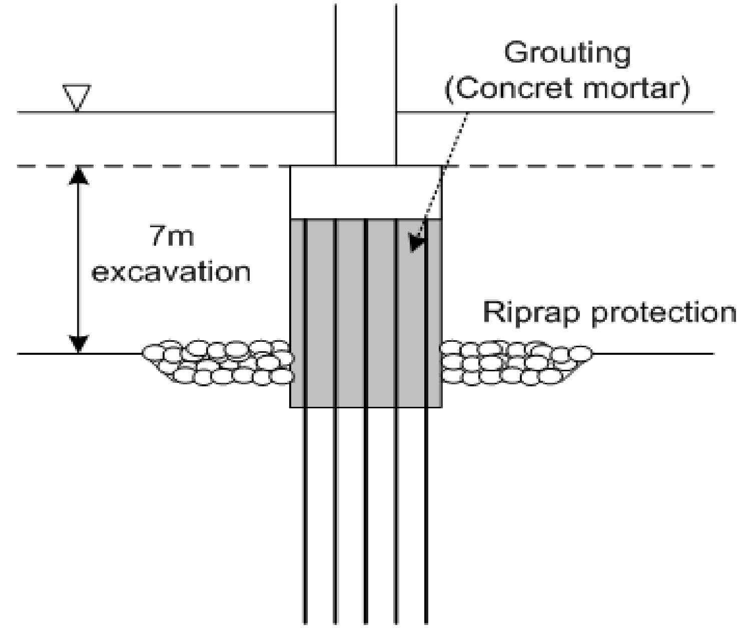

P10


Kimhae
New bankline
Pier 15
Pier 12
Pier 16
Pier 11
Old bankline
Old Gupo Bridge
Old Gupo Bridge failure
Flow
Gupo Bridge
Subway Bridge
Flow
Dadae Harbor highway
Gupo

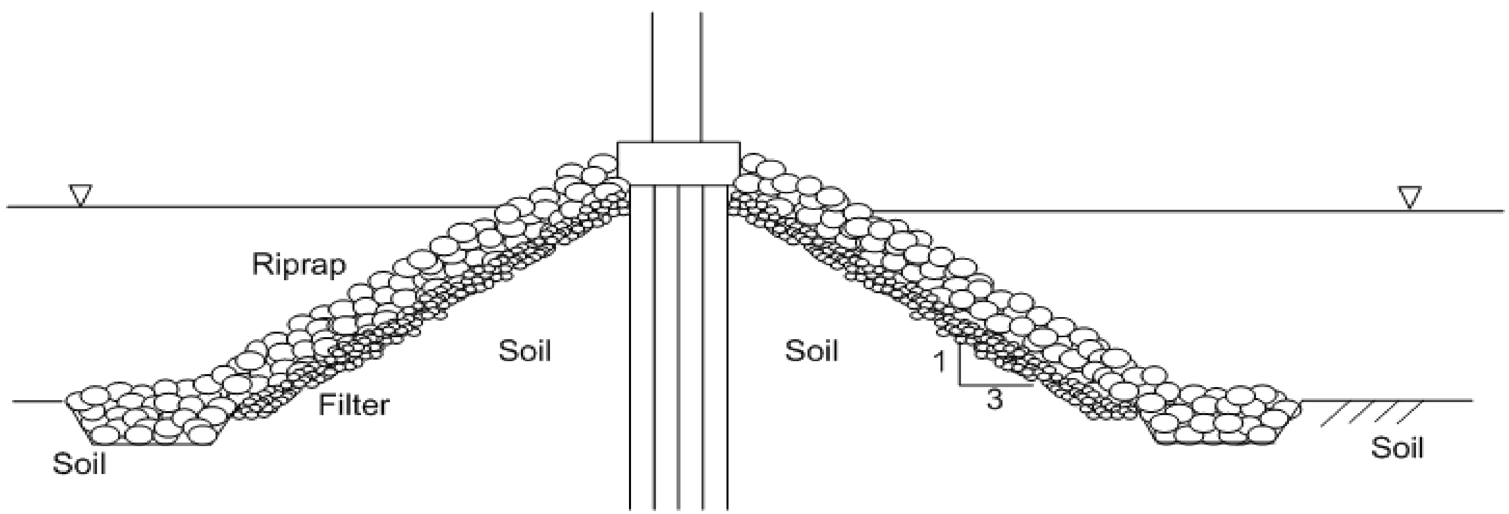

P15



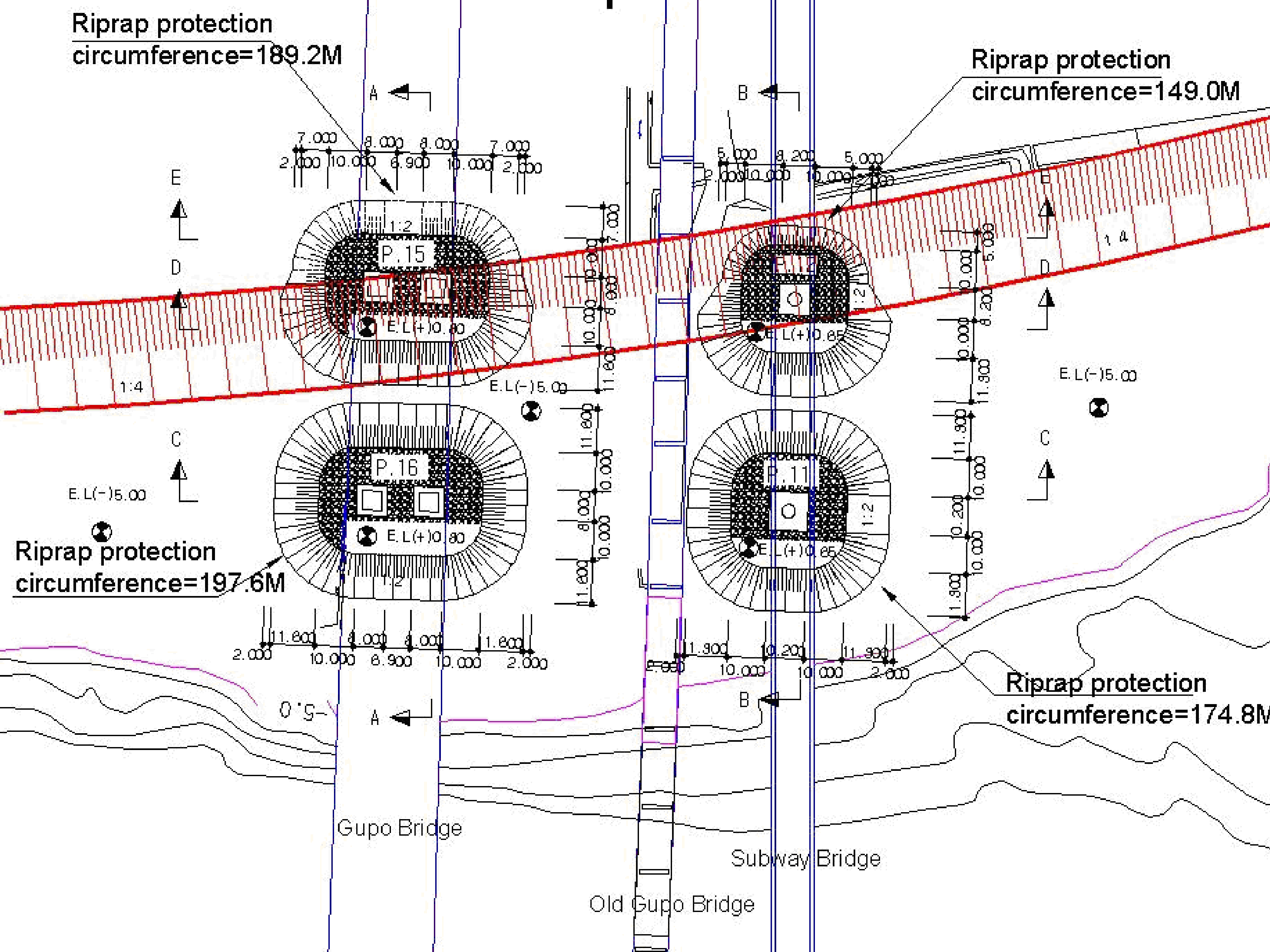
Alternative plan I



Alternative plan II



Alternative plan III



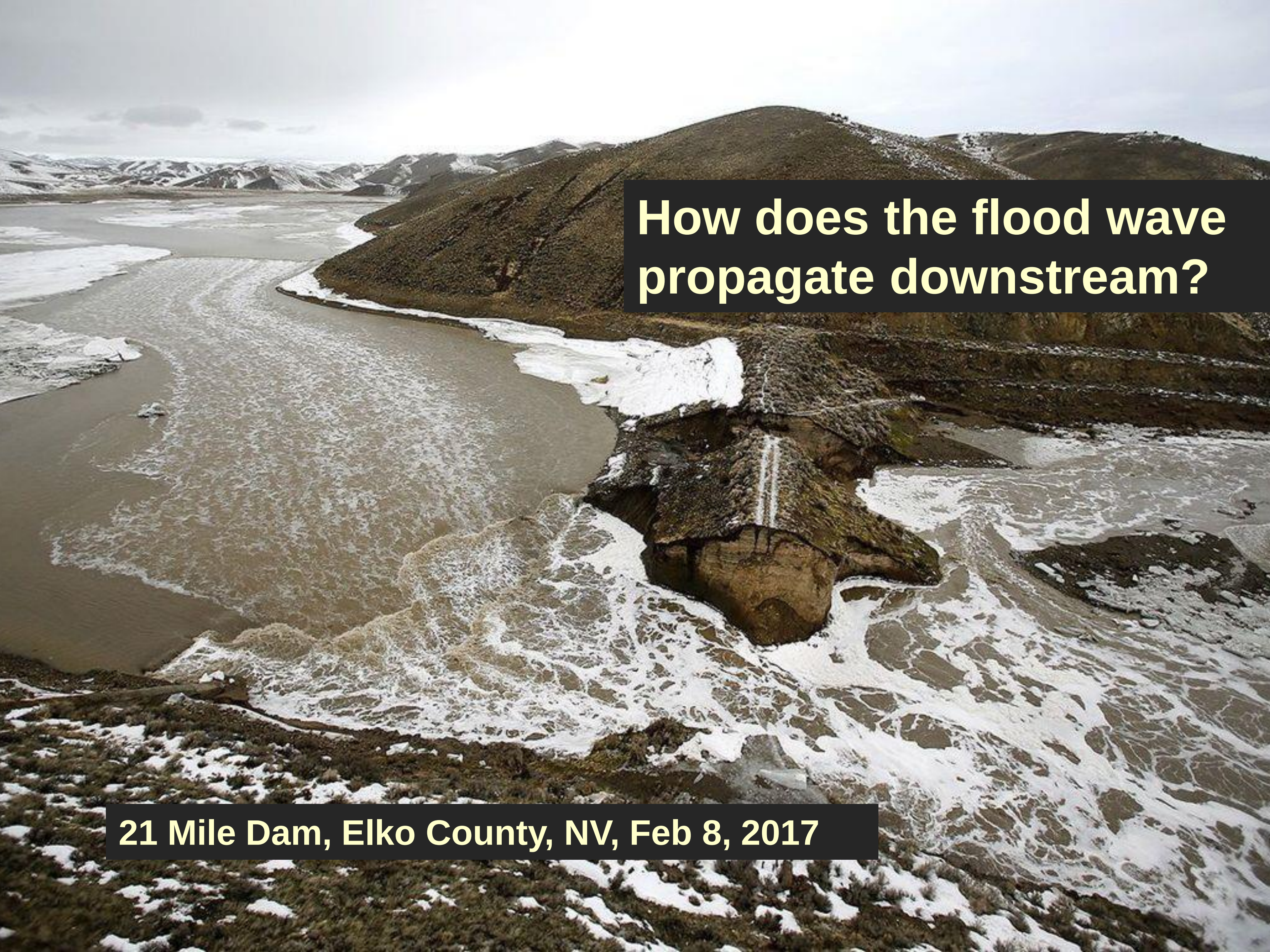
Riprap protection
circumference=189.2M
Riprap protection
circumference=149.0M
P.15
P.16
P.11
E.L(+)0.80
E.L(+)0.85
E.L(-)5.00
Riprap protection
circumference=197.6M
Riprap protection
circumference=174.8M
Gupo Bridge
Subway Bridge
Old Gupo Bridge

Figure 14. Gupo and Subway Bridge Piers before and after retrofitting construction

Rivers and Dams

1. River Equilibrium
2. Aggradation
3. Degradation below Dams
4. Case Study Gupo Bridge
5. Case Study Dam Break

How does the flood wave propagate downstream?

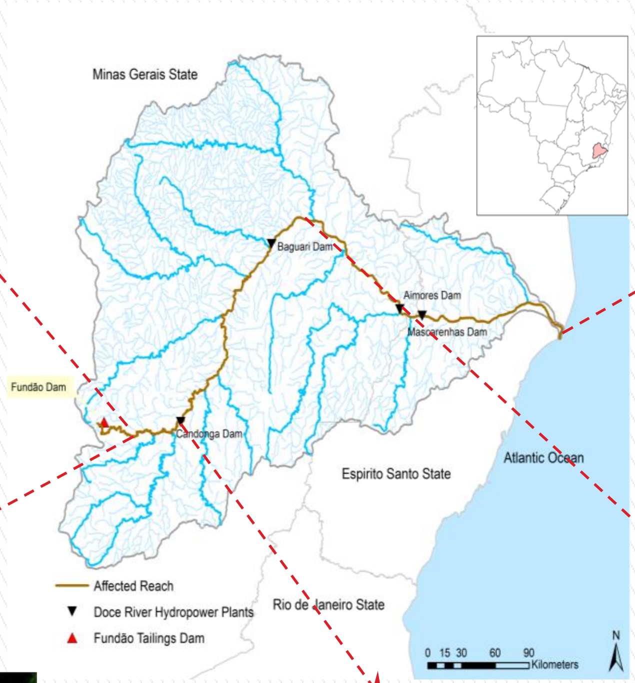


21 Mile Dam, Elko County, NV, Feb 8, 2017


25/01/2019 12:28:2
AM1 - Barragem
AO V

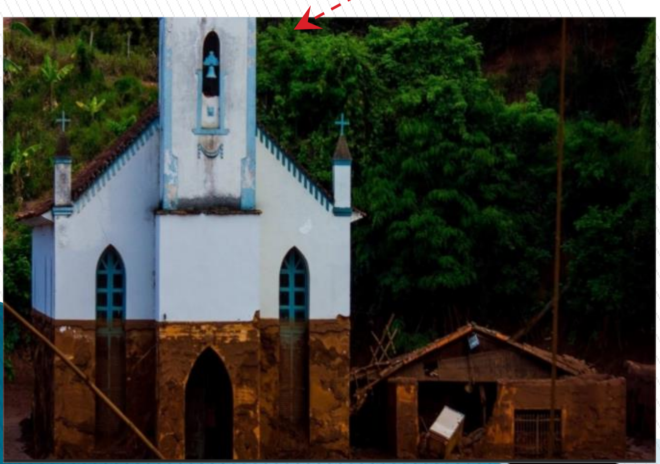
The Fundão Dam Collapse

Bento Rodrigues Town, 6 November 2015



Coast, 21 November 2015
C ≈1,500 mg/l

Gesteira Town 6 November 2015

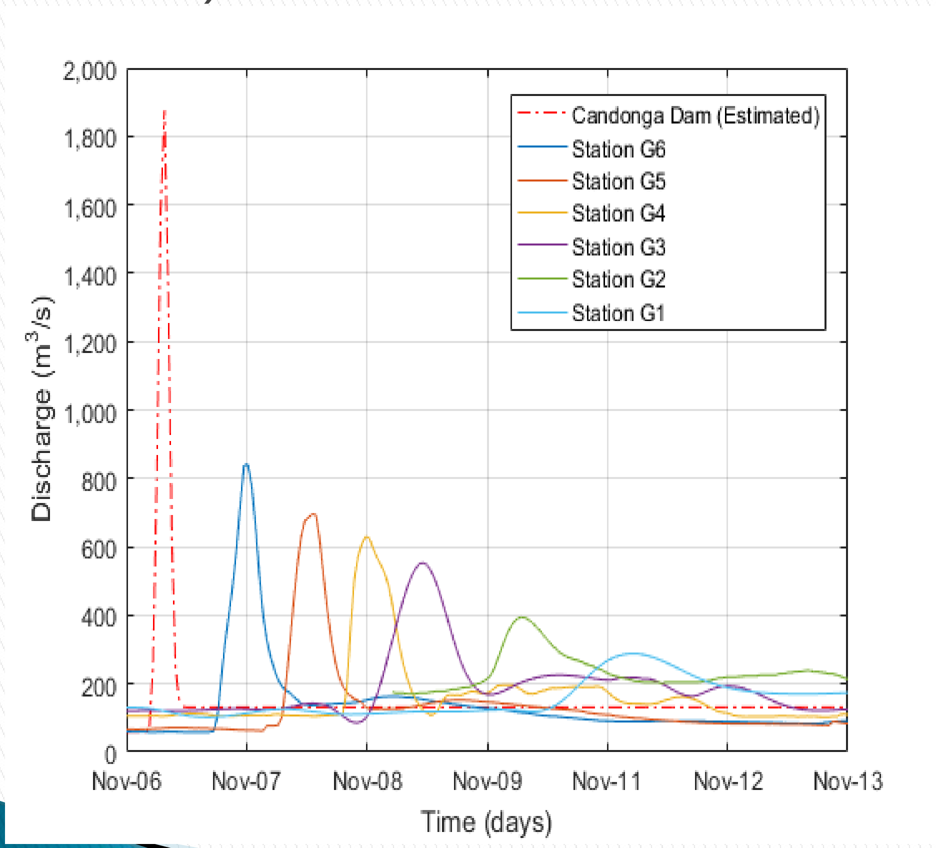


from Marcos Palu (2018)

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

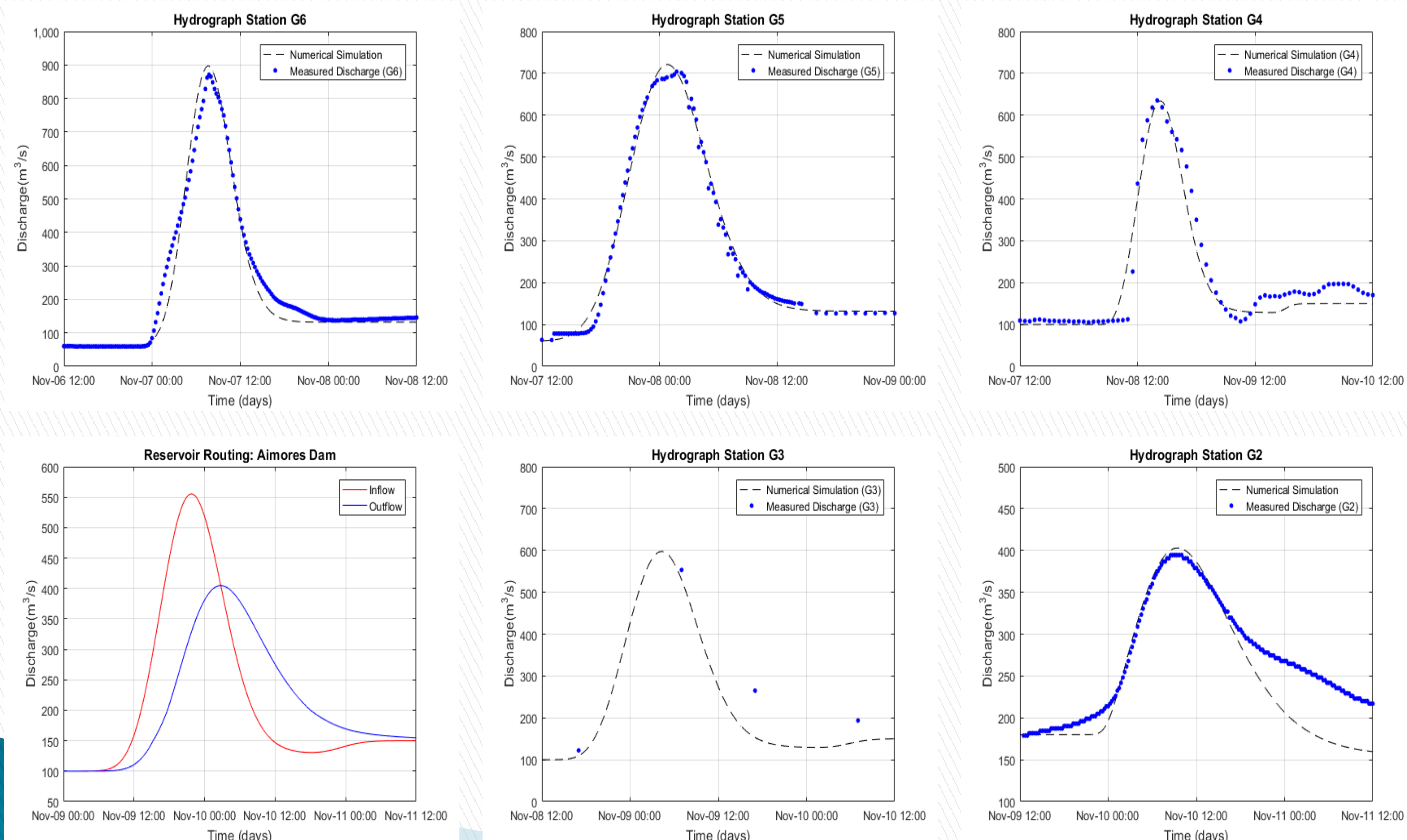
Hydrographs

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



from Marcos Palu

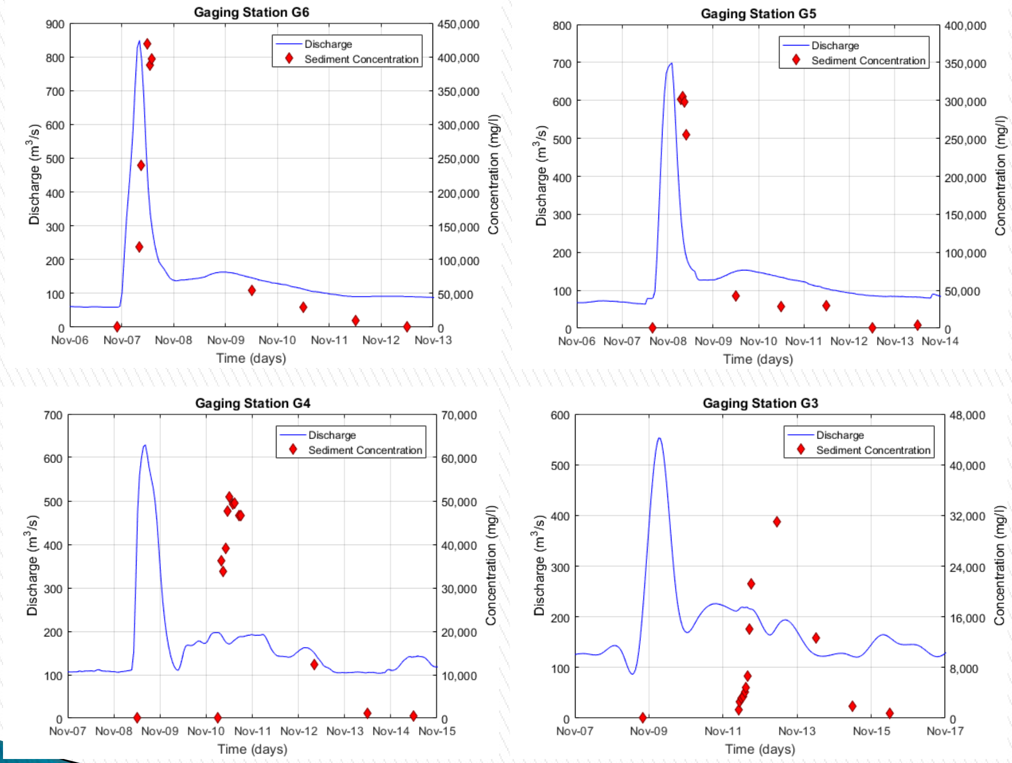
Floodwave Propagation Modeling

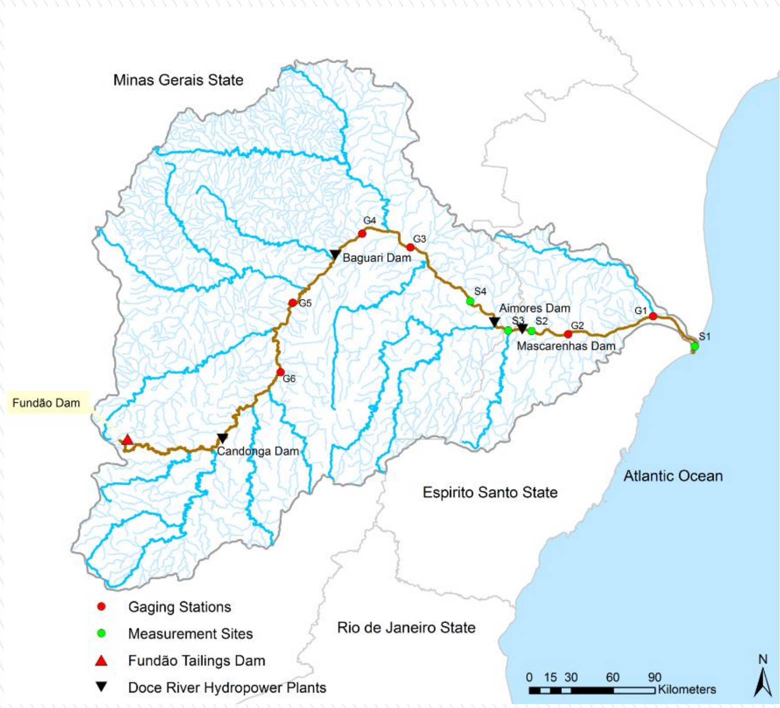


from Marcos Palu and Julien ASCE-JHE (2020)

Sediment Concentration Measurements

Observed suspended sediment concentration (CPRM & ANA, 2015)





Sediment Routing
NEW Development!

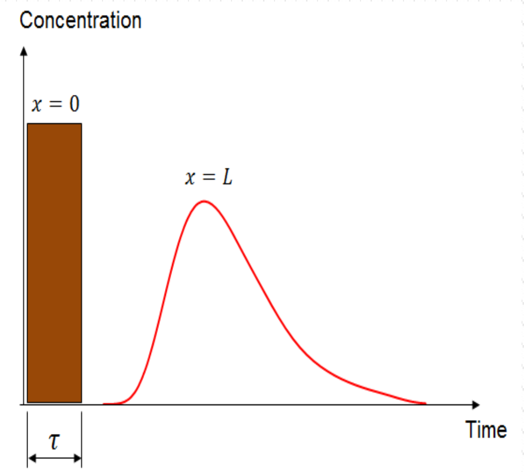
The one-dimensional advection-dispersion equation with settling is applied on the evaluation of transport of suspended load in open channels (Fischer et al., 1979; Julien, 2010).

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

C is the concentration;
U is the flow averaged velocity;
K_d is the longitudinal dispersion coefficient;
$k = \omega/h$ is the settling rate.

Analytical solution for a constant spill of finite duration τ is:

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



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

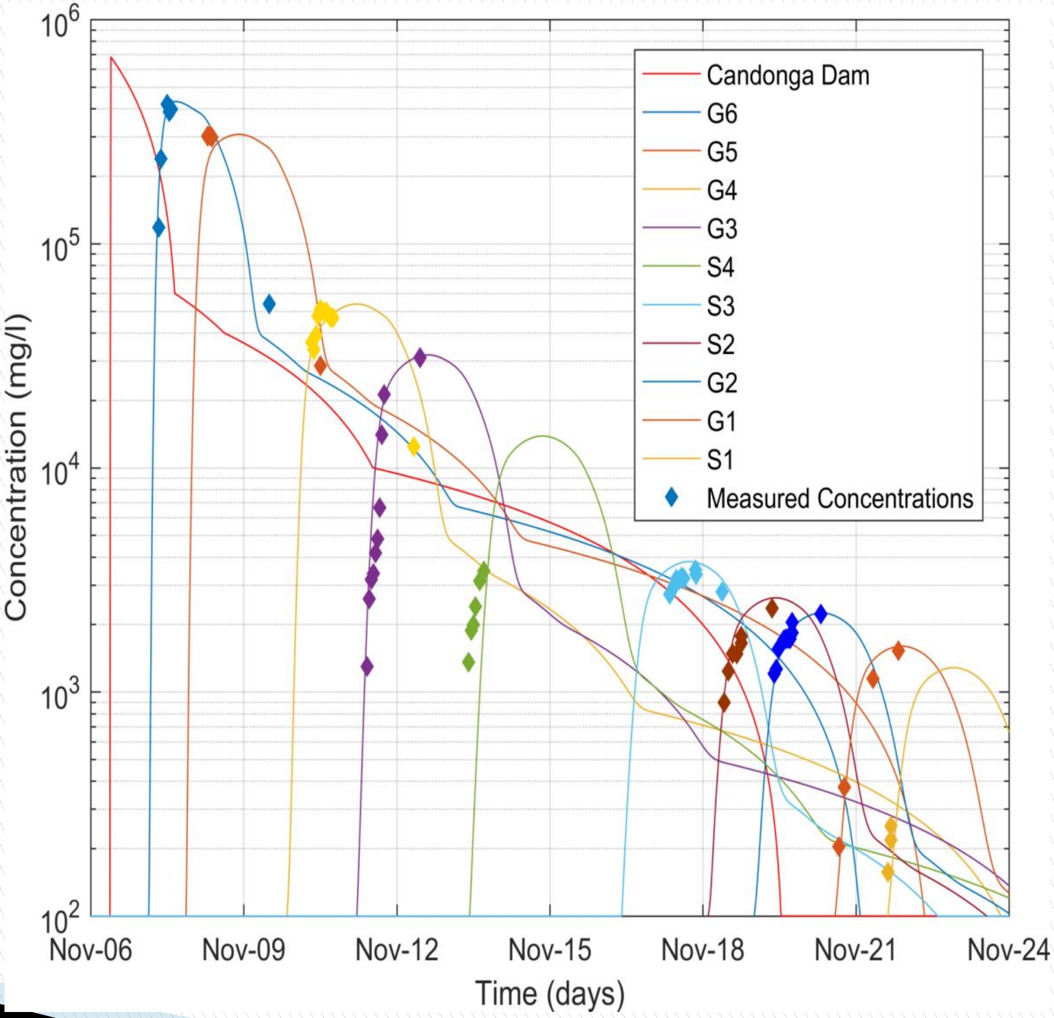
The complementary error function *erfc* is equal to:

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

erfc.precise in Xcel

from Palu and Julien ASCE-JHE (2018)

Sediment Concentration Modeling



from Palu and Julien ASCE-JHE (2018)

Summary and Conclusions

1. River Equilibrium

Rivers can reach equilibrium after several years.

2. Aggradation

Aggradation forces out-of-banks rivers and braiding.

3. Degradation below Dams

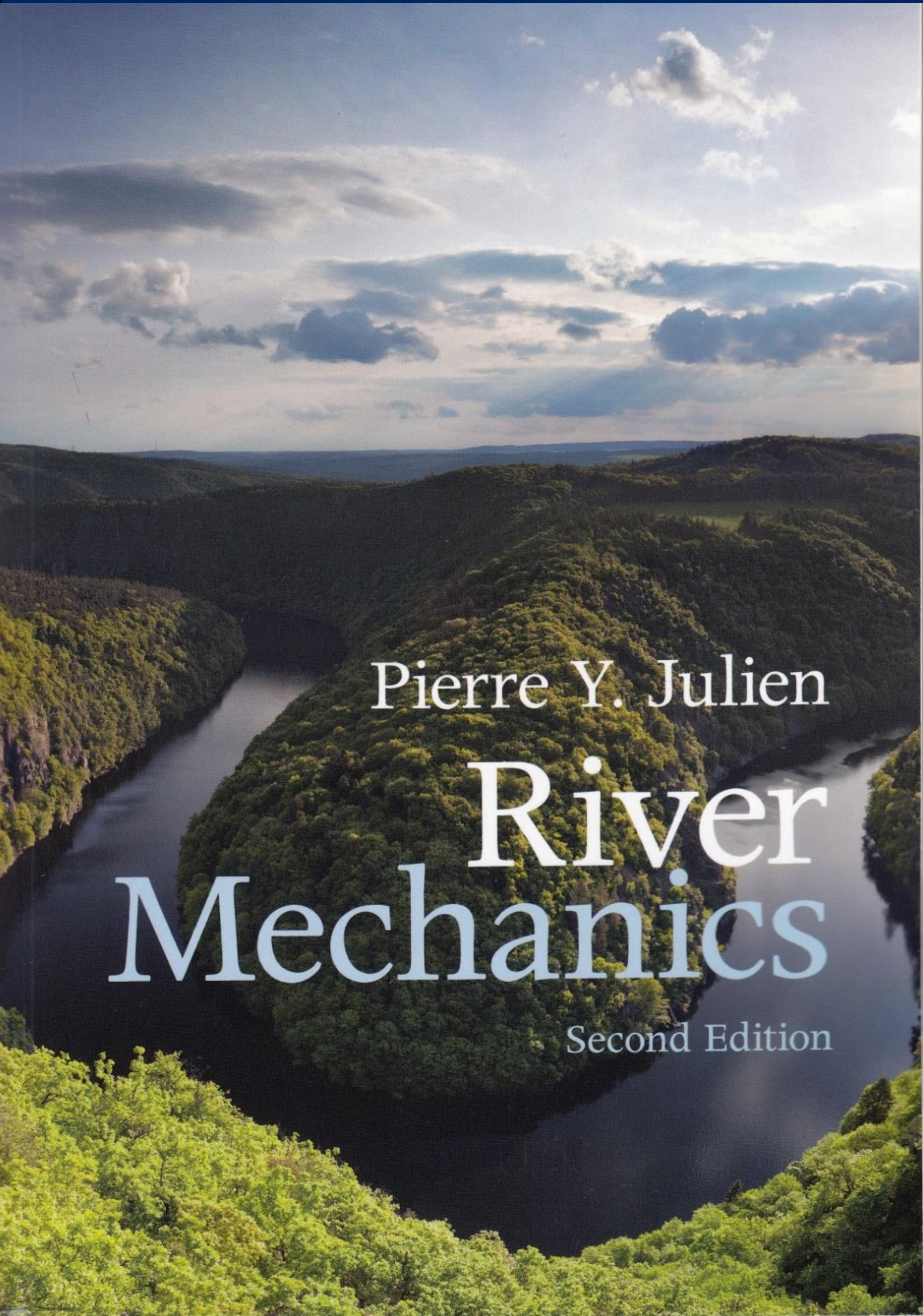
Degradation causes incision and narrowing with possible impact on structures.

4. Case-study Gupo Bridge

Retrofitting based on stability, not equilibrium.

5. Case-study Dam Break

Numerical modeling of flood and sediment waves.



Thank You!

ACKNOWLEDGMENTS

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Dr. Shigeru Kawai, Japan
Dr. Deborah Anthony USA
Dr. Jenifer Duan, UArizona
Dr. Phil Combs, USACE
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Dr. Ev. Richardson, CSU
Dr. Gigi Richard, FLC, Colorado
Dr. Un Ji, KICT, S. Korea
Dr. Sang-kil Park, PNU, S. Korea
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