River Environment

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Colorado State University

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

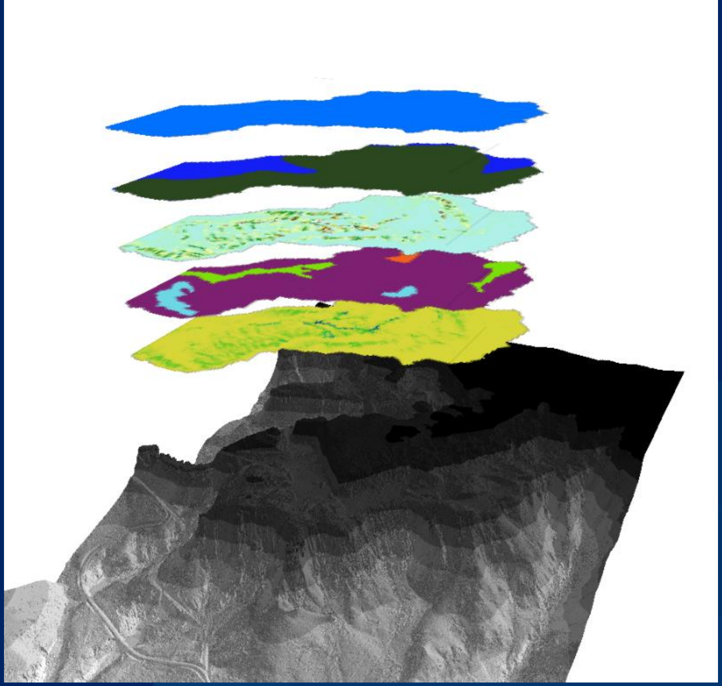
USBR Short Course

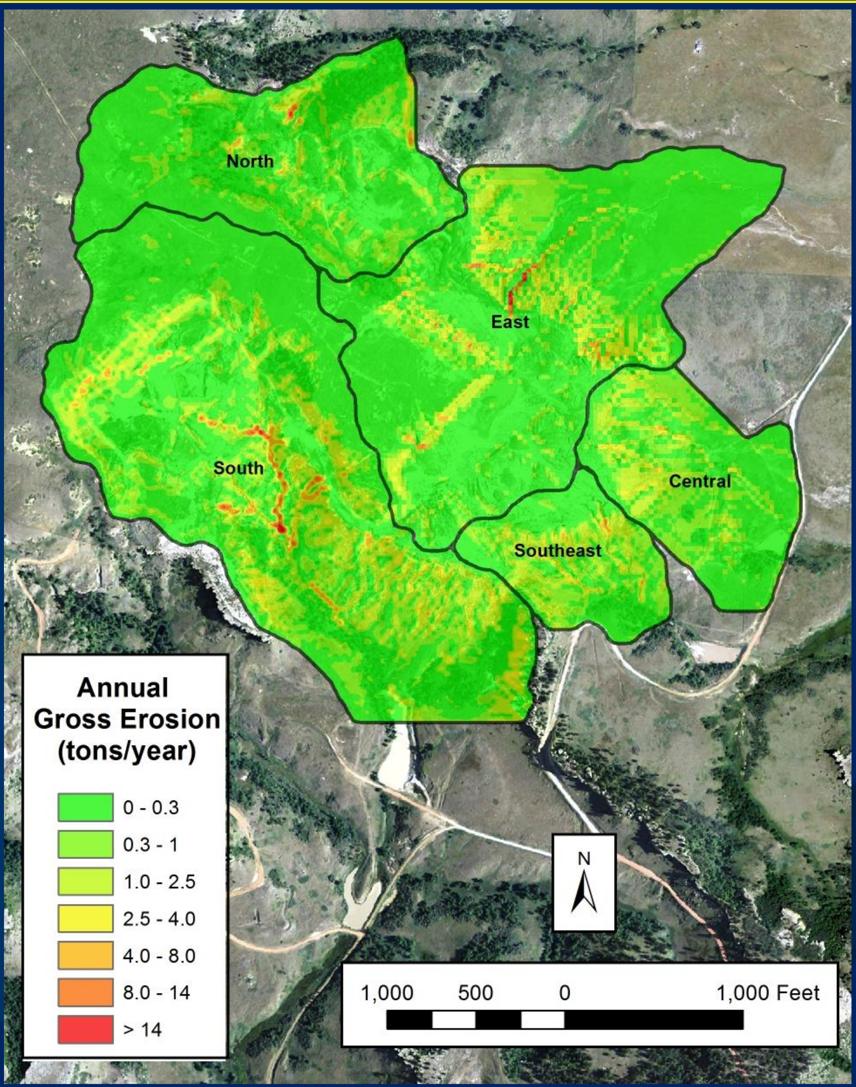
1. Watersheds and Climate
2. Sedimentation Engineering
3. Rivers and Dams
4. River Environment

River Environment

1. Upland Contamination
2. Sediment Management
3. Reservoir Turbidity
4. Aquatic Habitat

Erosion of Contaminants



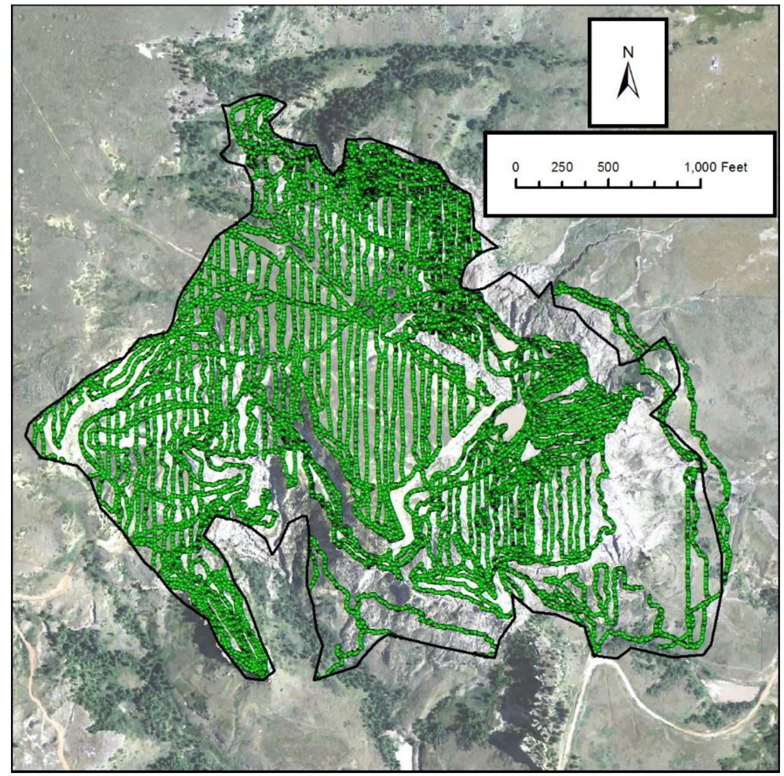


Watershed ID	Area	Gross Erosion, A_T	
	[acres]	tons/year	kg/year
North	43	713	646,462
East	72	1,836	1,665,793
Southeast	16	587	532,348
Central	25	708	642,444
South	94	3,366	3,053,933

From A. Orechwa (2015)

Contaminant Characterization Techniques

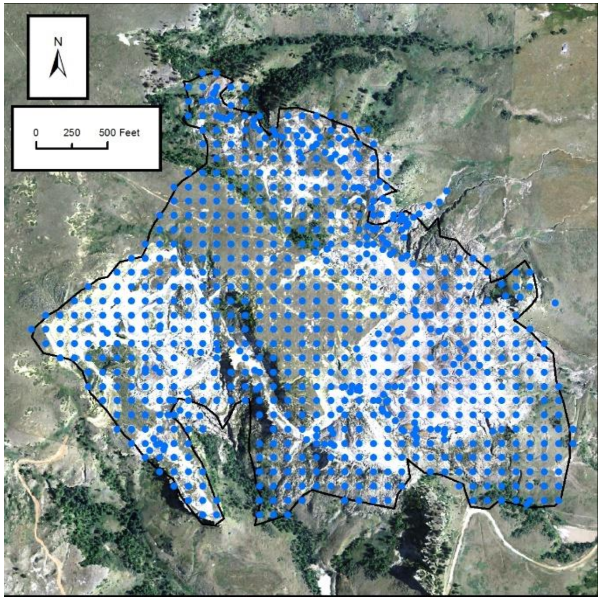
Gamma Radiation Survey for Ra-226

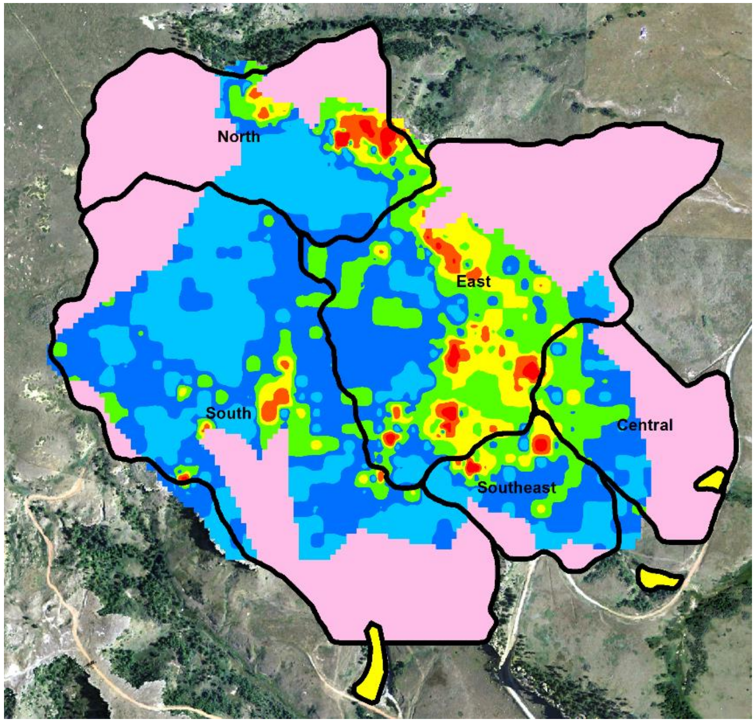


From A. Orechwa (2015)

Arsenic Mapping

X-Ray Fluorescence

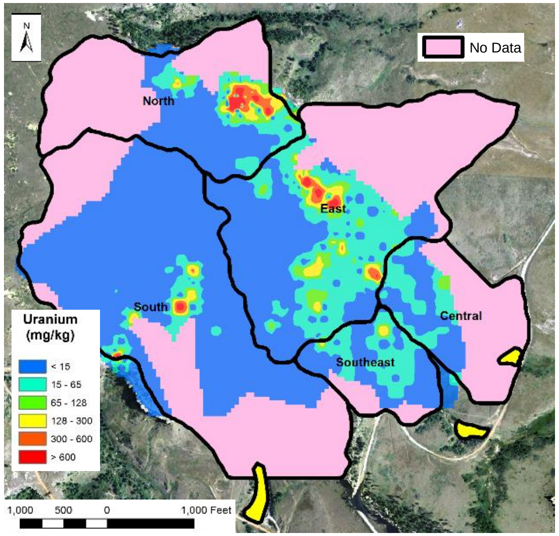




Sediment Pond ID	Observed Arsenic in Sediment			Predicted Arsenic in Sediment (mg/kg)
	Minimum (mg/kg)	Maximum (mg/kg)	Average (mg/kg)	
SP1	29	99	56	53
SP2	25	77	62	59
SP3	25	33	29	39

From A. Orechwa (2015)

Sediment and Contaminant Yield in Drainage Basins



Sediment Pond ID	Observed Uranium in Sediment			Predicted Uranium in Sediment (mg/kg)
	Minimum (mg/kg)	Maximum (mg/kg)	Average (mg/kg)	
SP1	3.2	21	10	12
SP2	11	26	16	12
SP3	3.1	36	12	11

Watershed ID	Sediment Yield (Total Sediment) [kg/year]	Sediment Yield (Uranium) [mg/year]	Predicted Sediment Concentration (Uranium) [mg/kg]
North	3.81E+05	9.2.E+06	24
East	9.19E+05	3.9.E+07	42
Southeast	3.54E+05	4.4.E+06	12
Central	4.05E+05	5.0.E+06	12
South	1.63E+06	1.7.E+07	11

From A. Orechwa (2015)

TETRA TECH

Sediment Yield

$$SDR = \frac{Y}{A_T}$$

Y = Sediment Yield (US tons/year)

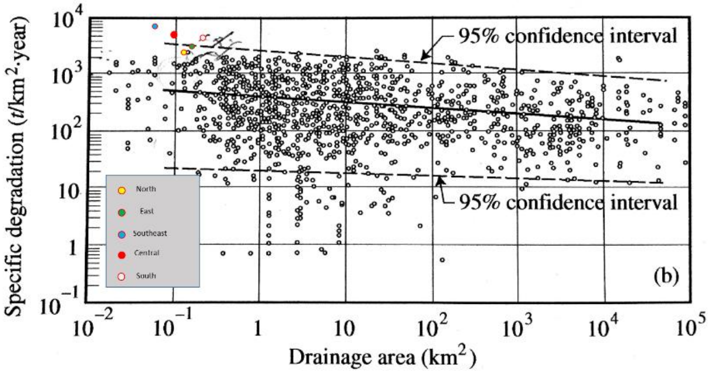
A = Gross erosion (US tons/year)

(Boyce 1975) $SDR = 0.41A^{-0.3}\ (A\ in\ km^2)$

Watershed ID	Area	Gross Erosion, A_T		Sediment Yield (U.S. tons/year)		
	[acres]	tons/year	kg/year	Boyce	SCS	Vanoni
North	43	713	646,462	495	490	420
East	72	1,836	1,665,793	1,089	1,190	1,013
Southeast	16	587	532,348	545	449	390
Central	25	708	642,444	577	516	446
South	94	3,366	3,053,933	1,844	2,120	1,797

$$Specific\ Degradation = \frac{Y\ (metric\ tons/year)}{Area\ (km2)}$$

Watershed ID	Area	Specific Degradation (metric tons/km²-year)			
	(km²)	Boyce	SCS	Vanoni	Average
North	0.17	2,604	2,576	2,209	*2,463*
East	0.29	3,380	3,695	3,144	*3,407*
Southeast	0.07	7,558	6,219	5,412	*6,396*
Central	0.10	5,176	4,626	4,000	*4,601*
South	0.38	4,398	5,055	4,285	*4,579*



From A. Orechwa (2015)

Dynamic Modeling with TREX

Environ. Sci. Technol. 2006, 40, 6996-7004

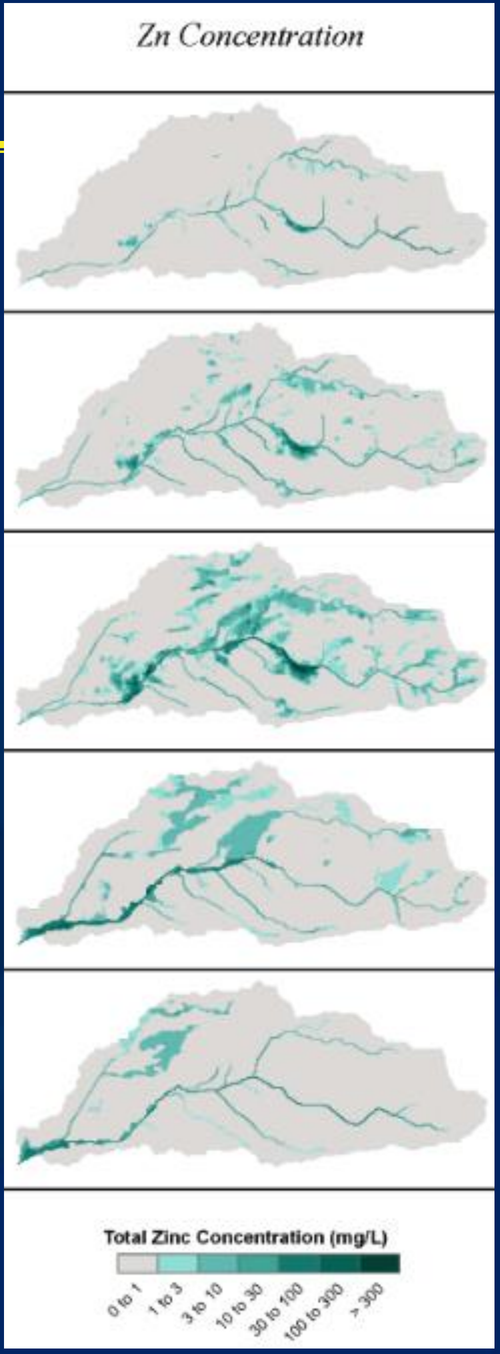
Simulation of Metals Transport and Toxicity at a Mine-Impacted Watershed: California Gulch, Colorado

MARKL.VELLEUX,*,†PIERREY.JULIEN,ROSALIAROJAS-SANCHEZ, WILLIAMH.CLEMENTS, AND JOHNF.ENGLAND,JR.

Journal of Hydro-environment Research
journal homepage: www.elsevier.com/locate/jher
Research papers

Soil erosion and transport simulation and critical erosion area identification in a headwater catchment contaminated by the Fukushima nuclear accident

Lezhang Wei[a,b,*], Tsuyoshi Kinouchi[a], Mark L. Velleux[c], Teppei Omata[a], Keiichi Takahashi[a], Megumi Araya[a]
[a] Department of Environmental

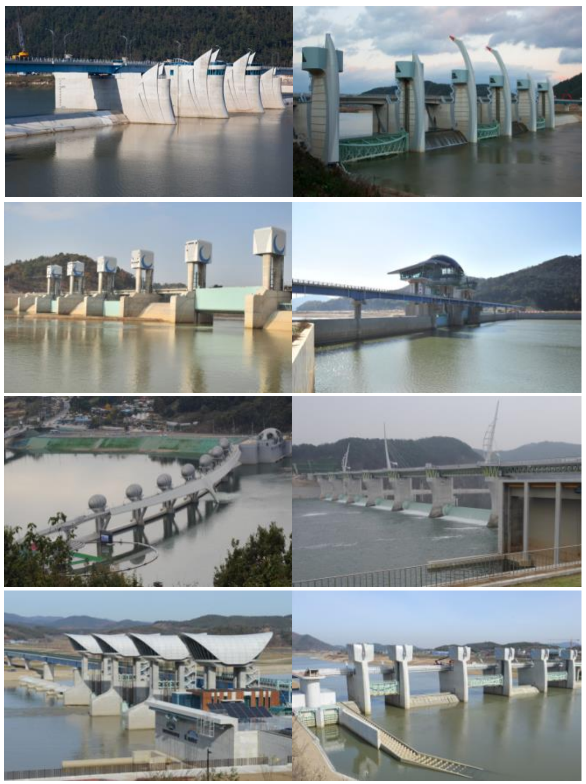


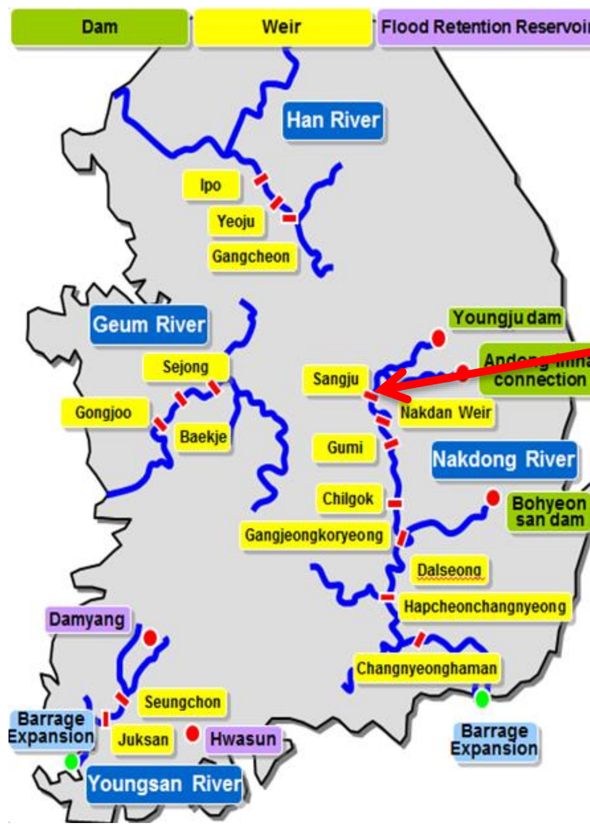
River Environment

1. Upland Contamination
2. Sediment Management
3. Reservoir Turbidity
4. Aquatic Habitat

Introduction

- Four River Restoration Project (2009-2012) (~$20 Billion USD)
- Construction 16 Weirs and ~ 0.5 cubic km riverbed excavation





Mitigation of Sedimentation Problems at Sangju Weir

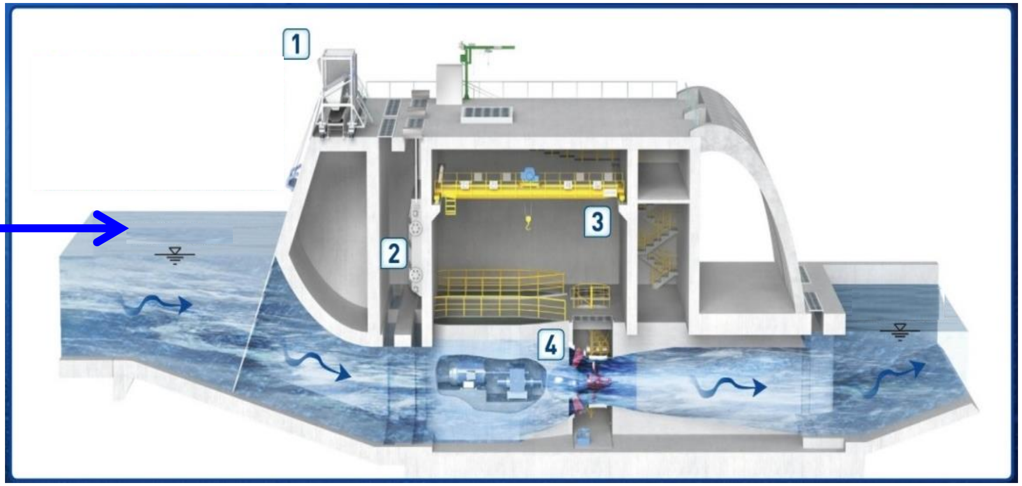
Sangju Weir, South Korea
from Hwayoung Kim, K-water

Benefit and Cost Analysis
Hydropower Revenues

- Capacity: 1,500 kW * 2 units
- $P = 9.81 \times \eta \times Q_a \times H_a$
- Unit cost of sales = 0.13 USD/kWh

Weir	Production and benefit			Unit cost of sales	
	MWh	Benefit(10^6 KRW)	benefit(10^3USD)	KRW/kWh	USD/kWh
Sangju	8,004	1,179	1,072	147.32	0.13

(Data: K-water, 2014, 1 USD = 1,100 KRW)



from Hwayoung Kim, K-water

Excavation Costs

- Nakdong River Estuary Barrage (1990 – 2010)
- $V = 13,678,000\ m^3$ (43.2 million dollars)
- Unit cost = 6.31 USD/m^3

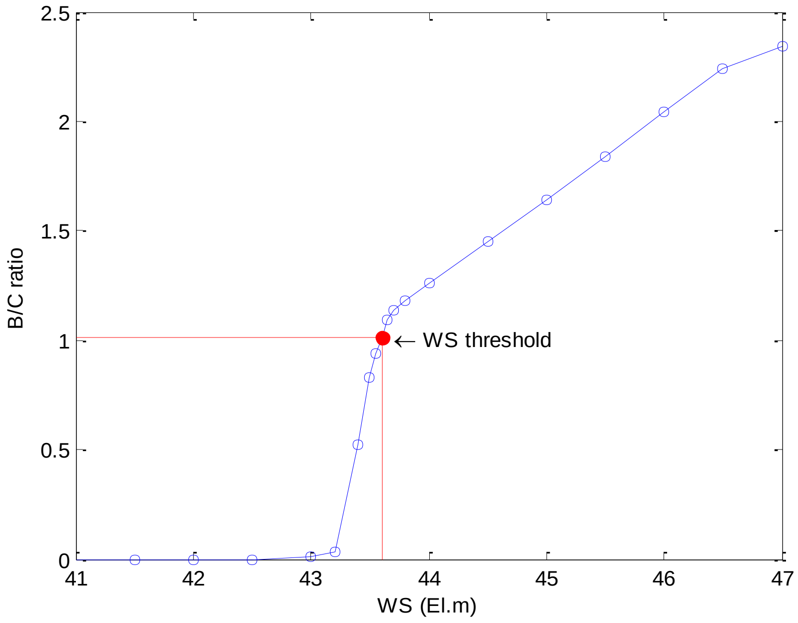
Nakdong River Estuary Barrage

Photos of excavation

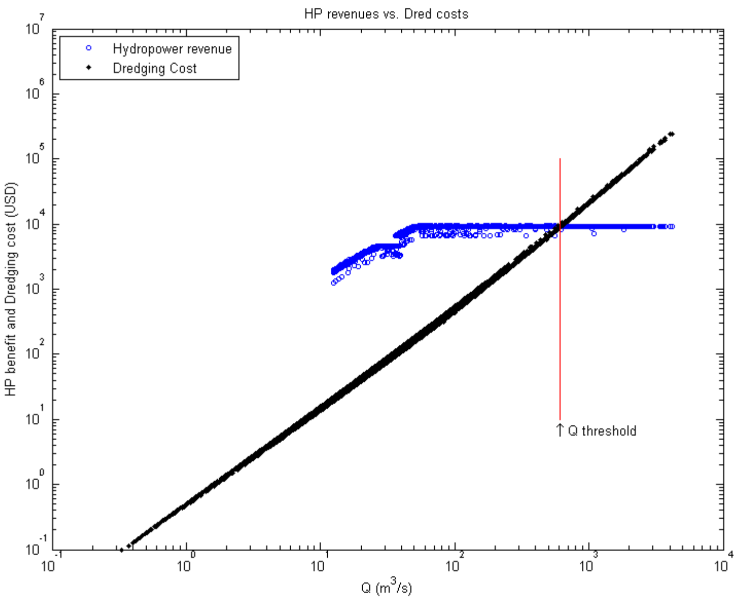
from Hwayoung Kim, K-water

Hydraulic Thresholds

Operate the dam above
H threshold = EL. 43.6 m



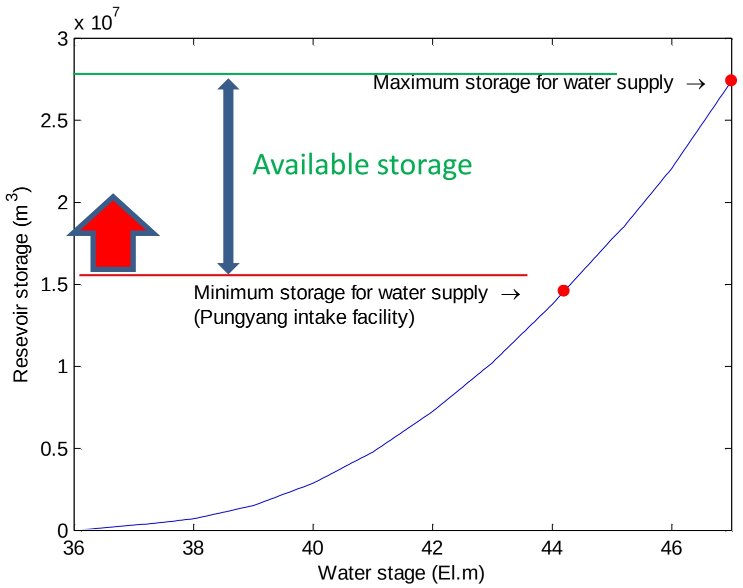
Open the gates above
Q threshold = 620 m³/s



from H. Kim and Julien ASCE-JHE, 2018

Water Supply

Max. Reservoir Storage (V)

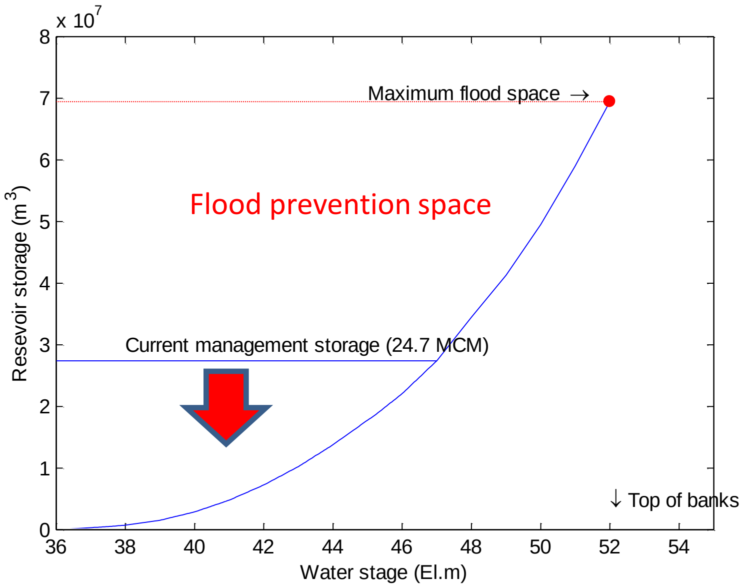


from Hwayoung Kim, K-water

Step 1 Criteria Identification | Step 2 RIF Definition | Step 3 Constraints Analysis | Step 4 Alternatives development | Step 5 MCDA Modeling

Flood Control

Min. Reservoir storage (V)



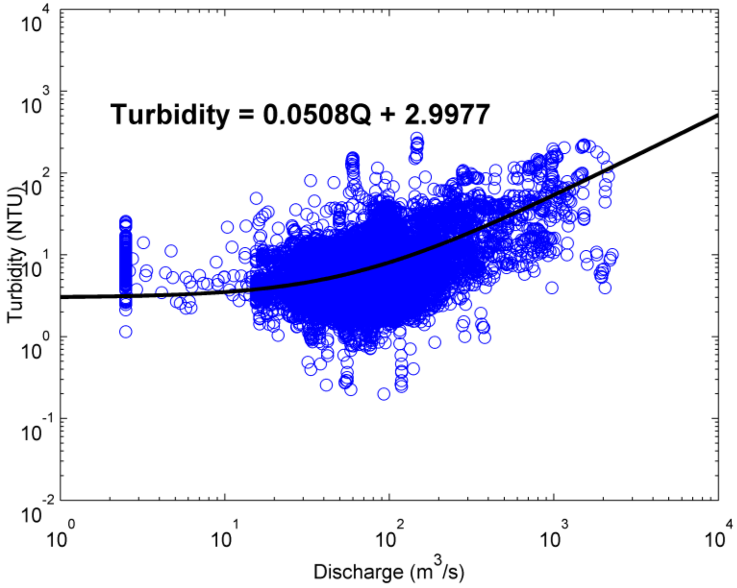
from Hwayoung Kim, K-water

Step 1 Criteria Identification → Step 2 RIF Definition → Step 3 Constraints Analysis → Step 4 Alternatives development → Step 5 MCDA Modeling

Minimize (Turbidity)

Minimize Discharge (Q)

(High uncertainty)



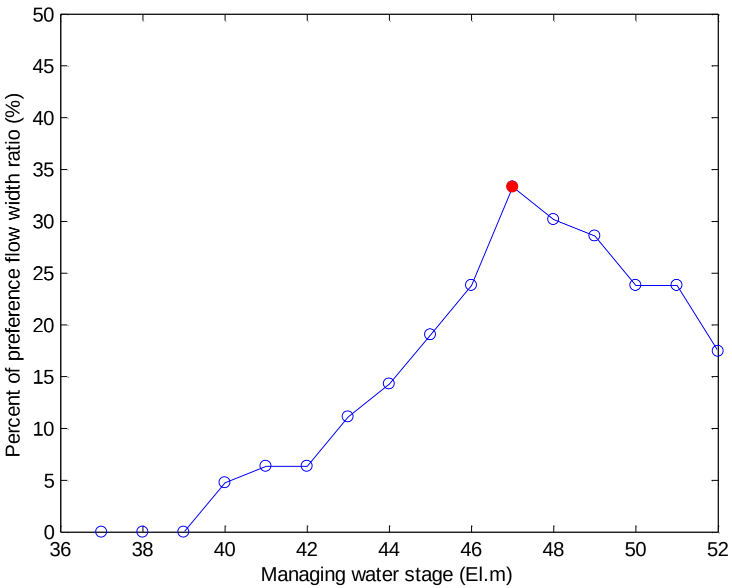
Haepyeong intake station

(Jan. 1st, 2013-Feb. 28th, 2015)

Stream Ecology & Riverside Environment

Max. GVSR

(Good View Station Ratio)

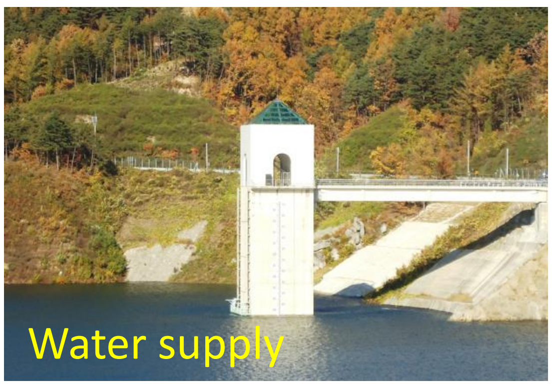


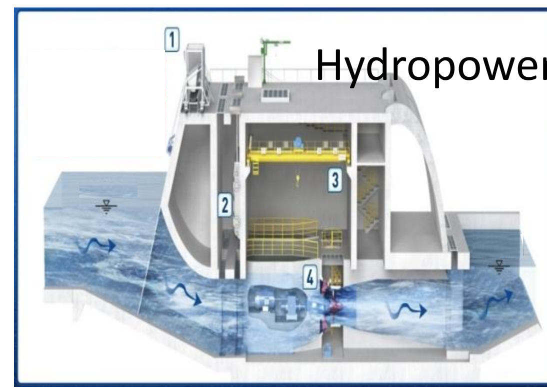
from Hwayoung Kim, K-water

Step 1 Criteria Identification → Step 2 RIF Definition → Step 3 Constraints Analysis → Step 4 Alternatives development → Step 5 MCDA Modeling

Other Issues besides sedimentation

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

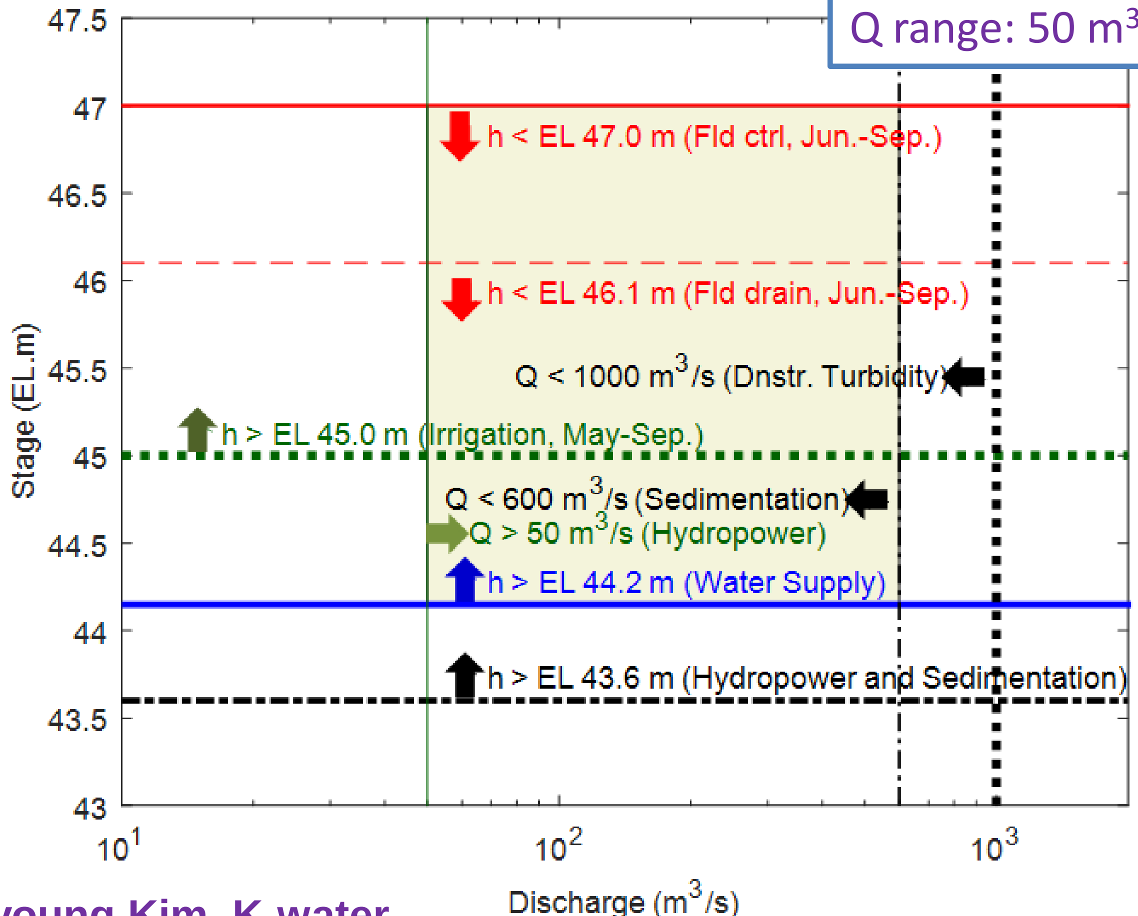




From Hwayoung Kim et al., ASCE, 2017

Stage and Discharge Constraints

H range: EL. 44.2 - 47.0m
Q range: 50 m^3/s – 620 m^3/s



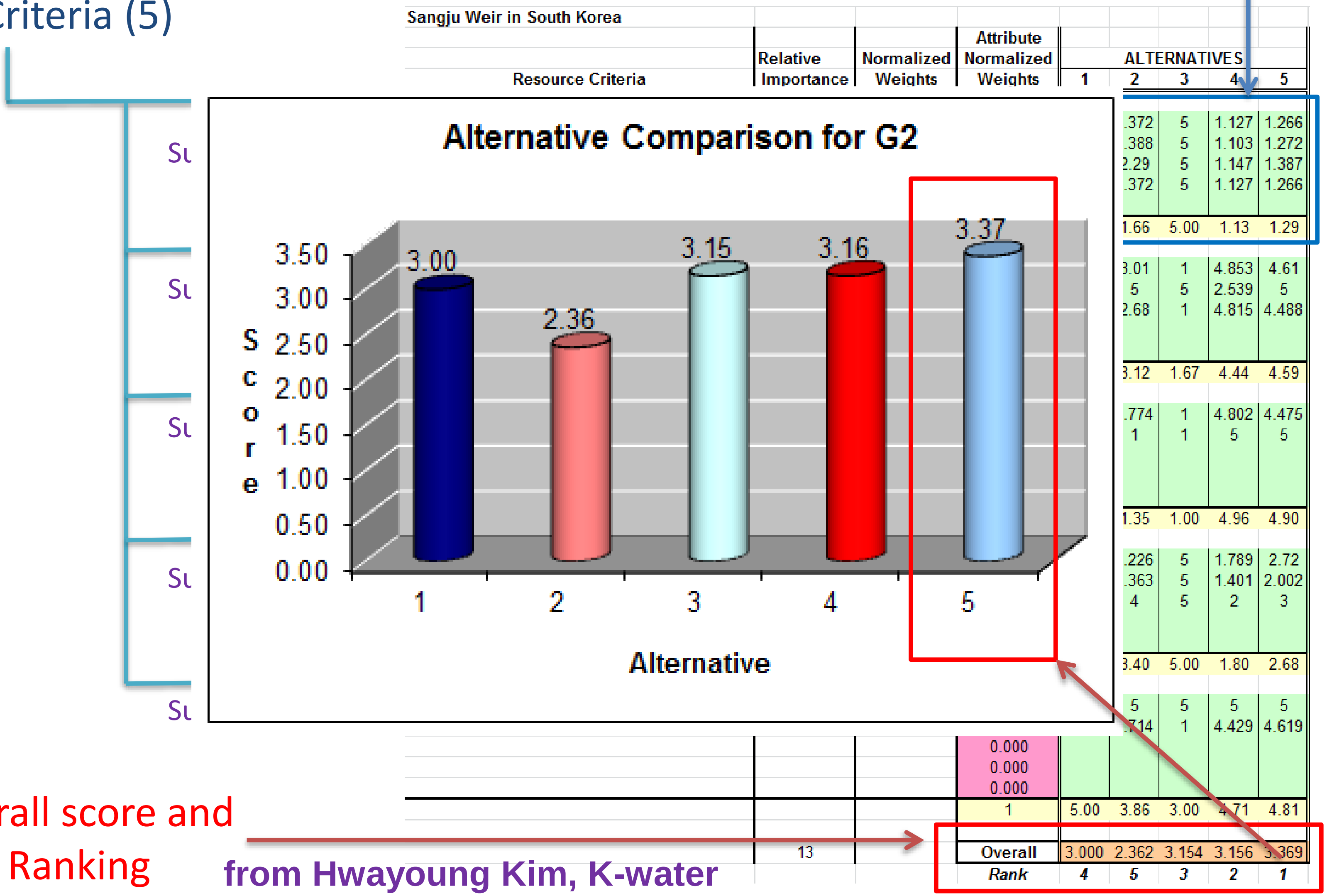
from Hwayoung Kim, K-water

Step 1 Criteria Identification → Step 2 RIF Definition → Step 3 Constraints Analysis → **Step 4 Alternatives development** → Step 5 MCDA Modeling

MCDA Rating (WAM)

Main Criteria (5)

Rating



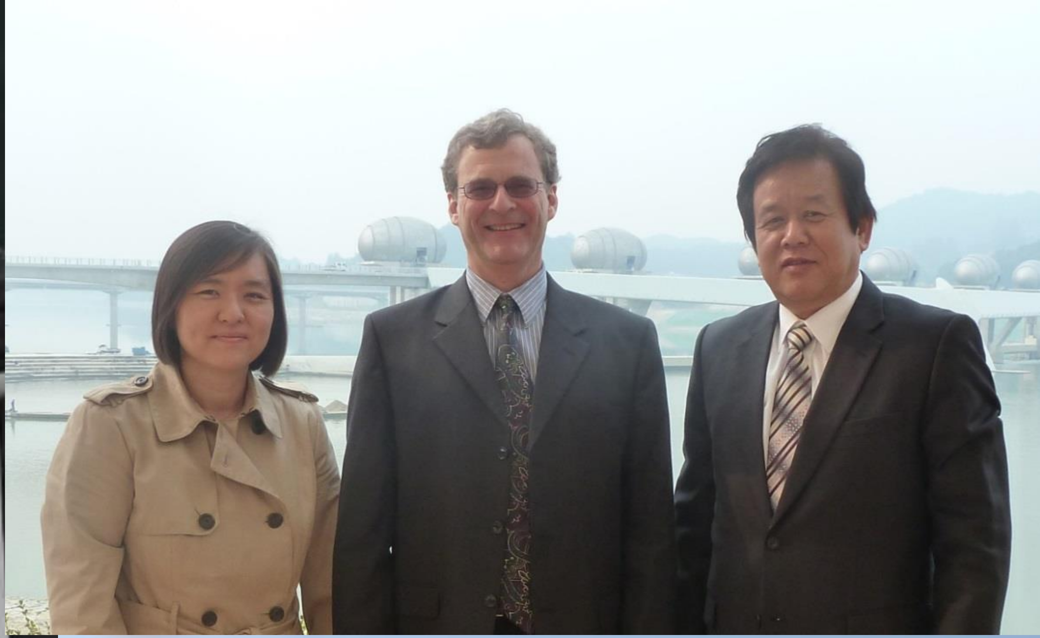
Overall score and Ranking

from Hwayoung Kim, K-water

Step 1 Criteria Identification → Step 2 RIF Definition → Step 3 Constraints Analysis → Step 4 Alternatives development → **Step 5 MCDA Modeling**

IPO (Han River)

Professor Julien talking to the Minister Myung Pil Shim about the Ipo Weir



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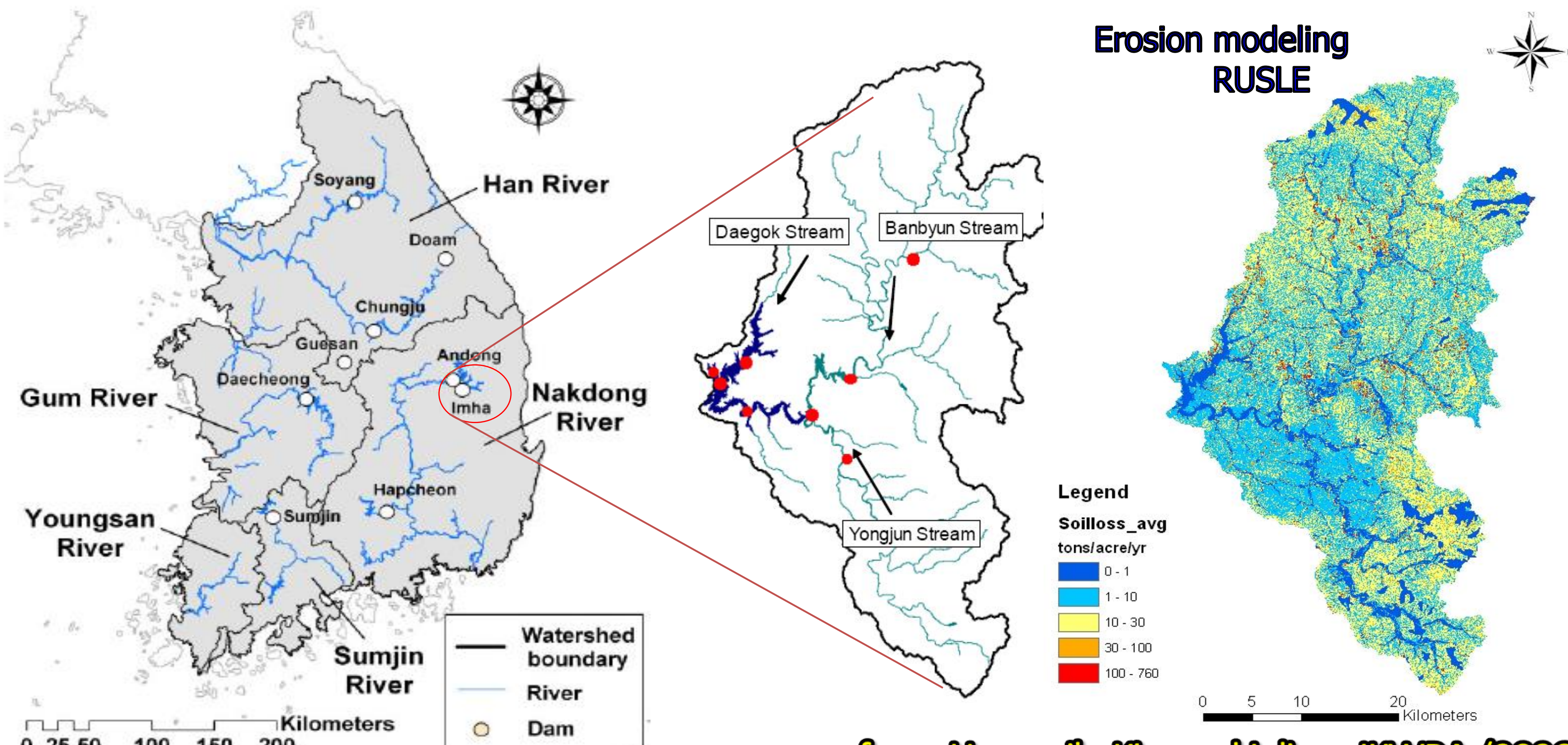
Density Currents and Turbidity
Imha Dam, South Korea

Example

Imha Reservoir has suffered from turbidity problems since 2002.

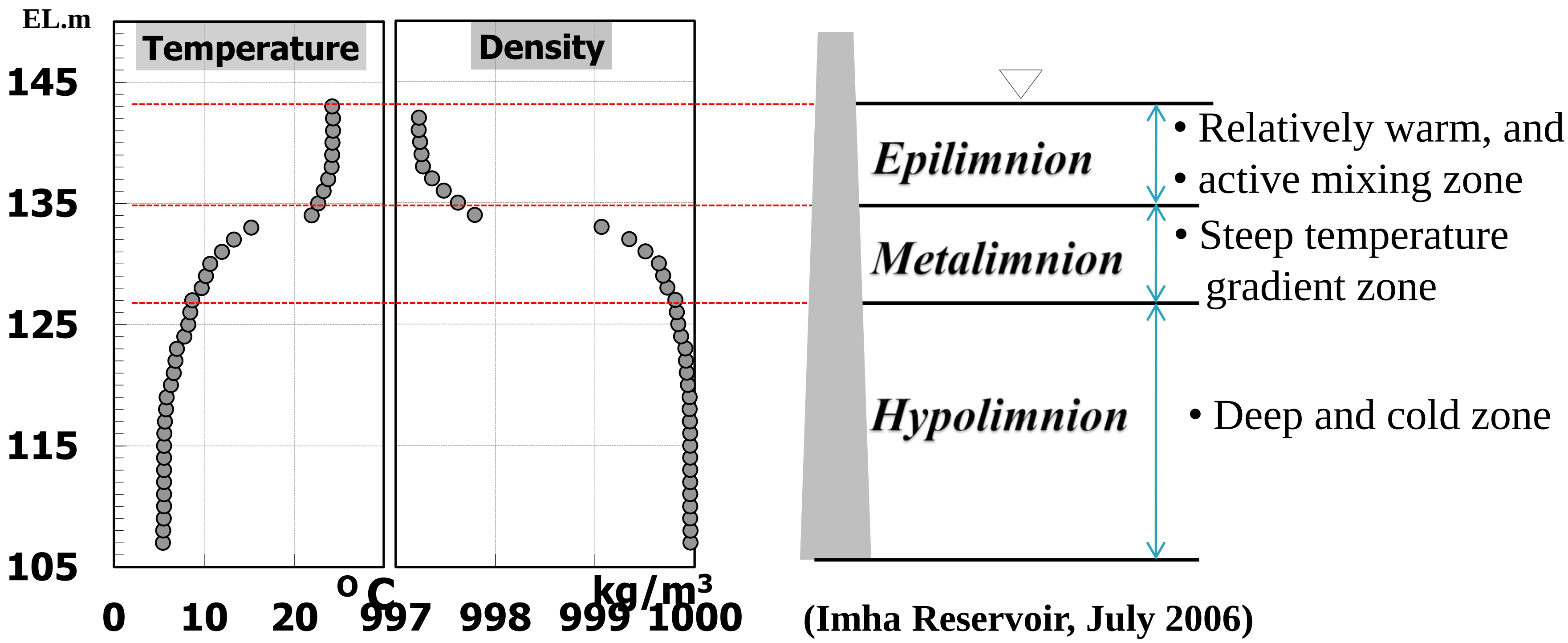
- Watershed area covers 1,361 km^2
- Three major tributaries



from Hyeonsik Kim and Julien, JKWRA (2006)

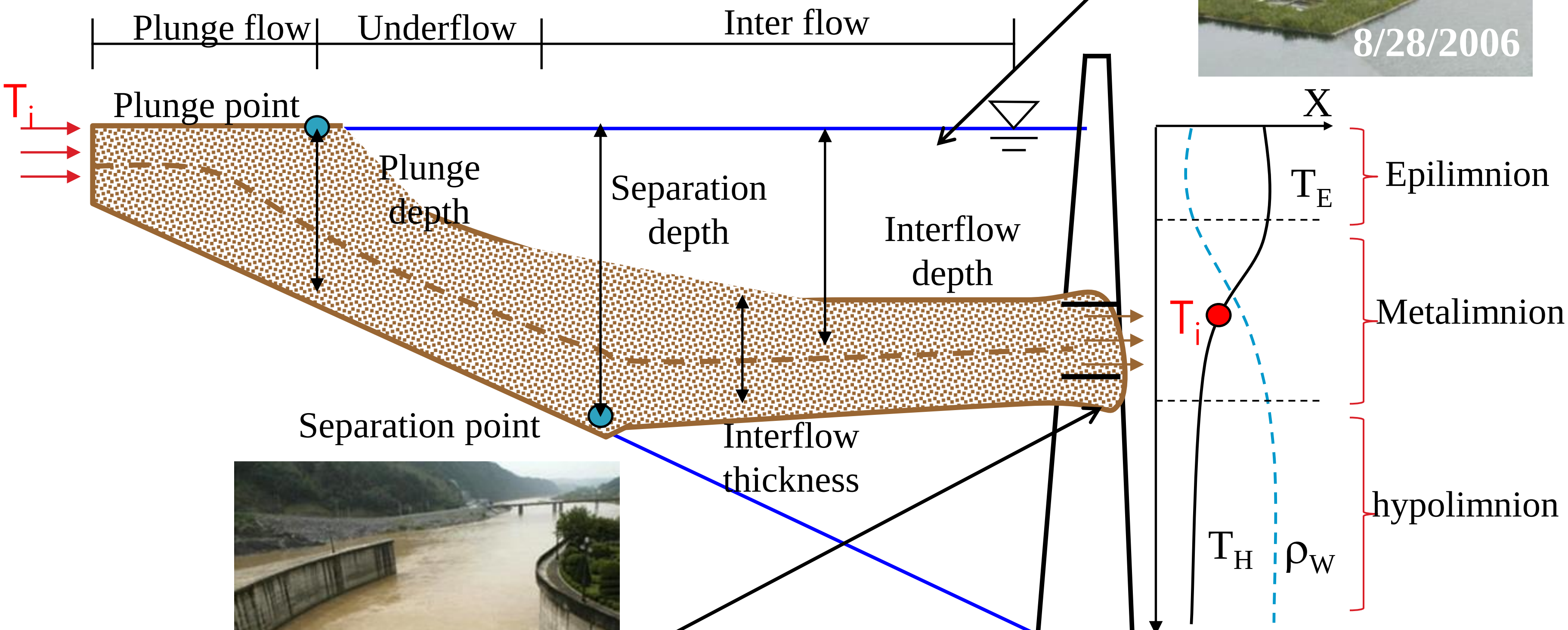
Turbid density currents are developed by thermal stratification

In a deep reservoir, the density is determined by the result of **solar heating** of surface water which produces thermal stratification



(Imha Reservoir, July 2006)

A general type of turbid density currents during summer



from Sangdo An (2011)

Discharge water through intake tower, 8/28/2006

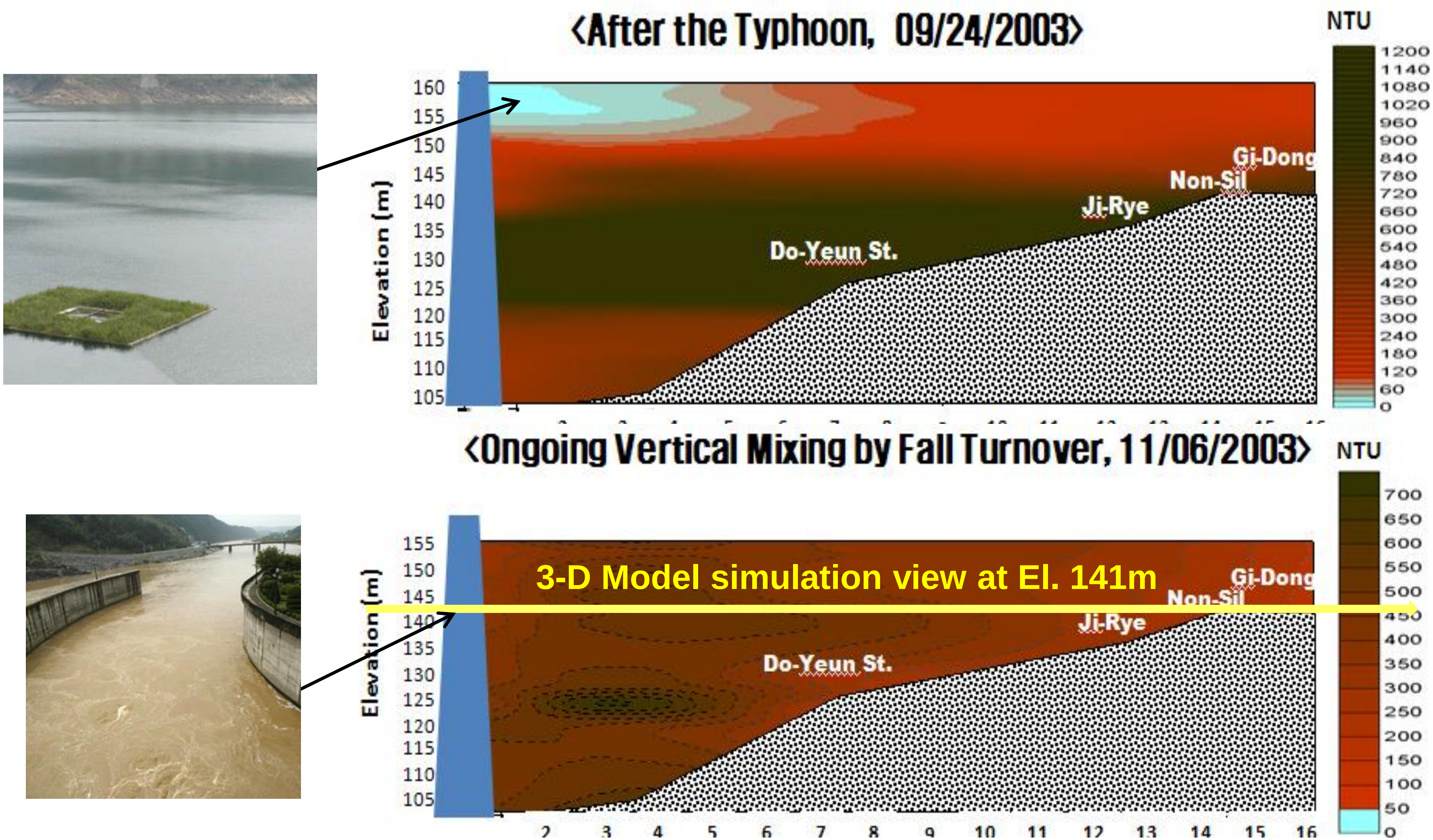
Measuring System

Real-time gaging stations were installed at five stations to monitor turbid density currents propagating from each of tributaries to the reservoir

Real-time monitoring system for Imha Reservoir; installed and has been operating by K-water since 2006

from K-water and Sangdo An (2011)

Turbidity Measurements



from K-water and Sangdo An (2011)

Governing Equations *based on the Reynolds-averaged Navier–Stokes (RANS) equations combined with a turbulence closure model* (RNG k- ε)

- **Continuity :**

$$\frac{\partial U_1}{\partial x_1} + \frac{\partial U_2}{\partial x_2} + \frac{\partial U_3}{\partial x_3} = 0$$

- **Momentum (with Boussinesq approximation, non-hydrostatic) :**

$$\underbrace{\frac{\partial U_i}{\partial t}}_{\text{Local acceleration}} + \underbrace{\sum_{j=1}^{3} U_j \frac{\partial U_i}{\partial x_j}}_{\text{Convective acceleration}} = \underbrace{-g_i}_{\text{Gravity force}} - \underbrace{\frac{1}{\rho_0}\frac{\partial P_{nh}}{\partial x_i}}_{\text{Non-hydrostatic pressure gradient}} - \underbrace{g\frac{\partial \eta}{\partial x_i}}_{\text{Free-surface or 'barotropic' pressure gradient}} - \underbrace{\frac{g}{\rho_0}\frac{\partial}{\partial x_i}\int_z^{\eta} \Delta\rho \, dx_3}_{\text{Stratification or 'baroclinic' pressure gradient}} + \underbrace{\sum_{j=1}^{3}\frac{\partial}{\partial x_j}\left(\nu \frac{\partial U_i}{\partial x_j} - \overline{u_i u_j}\right)}_{\text{Viscous force and turbulent fluctuations}}$$

$: \; i = 1, 2, 3$

$$\nu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)$$

- **Scalar transport equation :**

$$\frac{\partial \Phi}{\partial t} + \sum_{j=1}^{3}\frac{\partial}{\partial x_j}(U_j \Phi) = \sum_{j=1}^{3}\frac{\partial}{\partial x_j}\left(\Gamma \frac{\partial \Phi}{\partial x_j} - \overline{u_i \phi}\right)$$

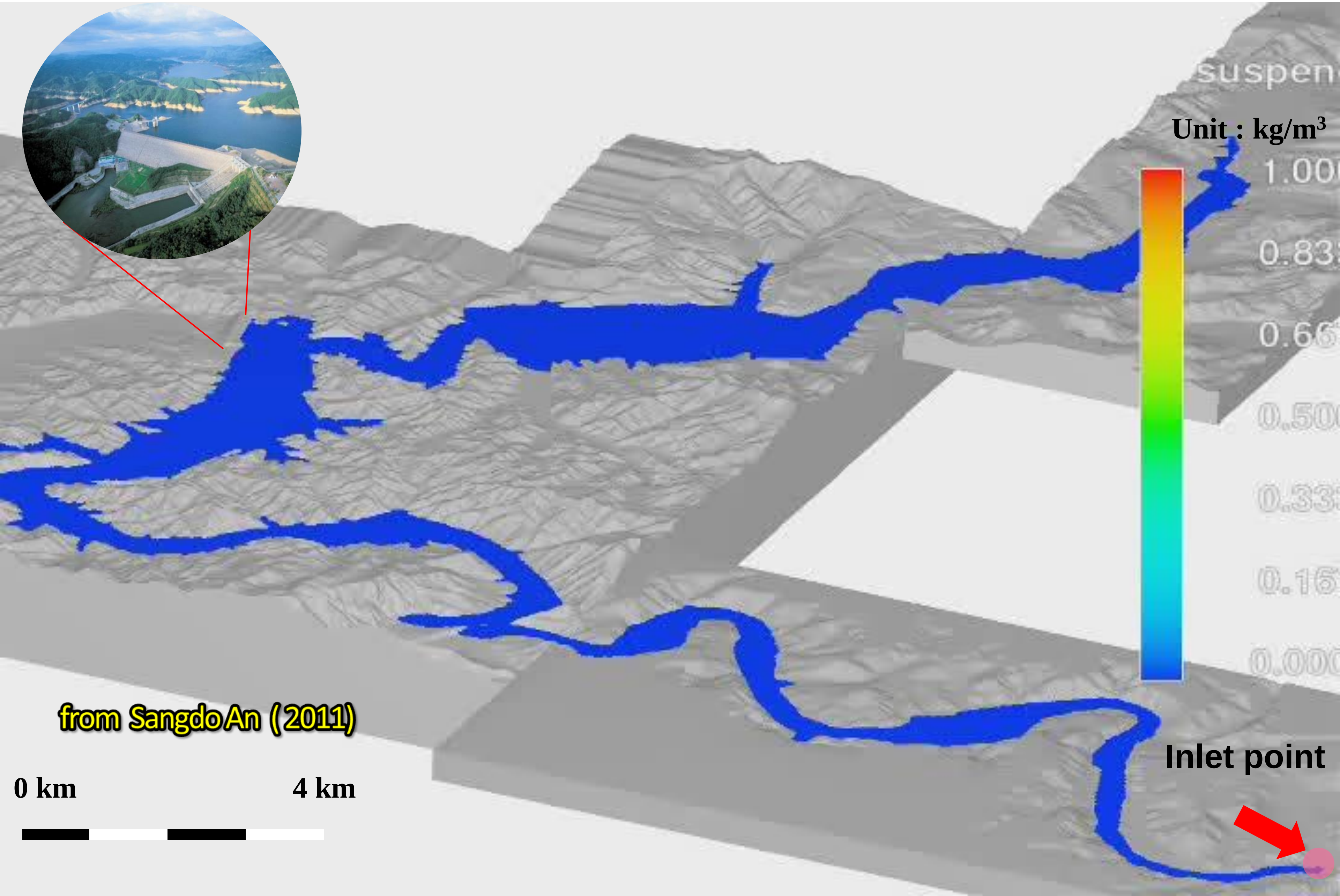
$$\Gamma_t \frac{\partial \Phi}{\partial x_i}$$

$$\Gamma_t = \frac{\nu_t}{Pr_t}$$

- x_i : Cartesian space (i=1,2 are horizontal; i=3 is vertical),
- U_i : Mean velocity components,
- u_i : Fluctuating velocity components,
- η : Free surface elevation,
- B : Bottom elevation,
- g : Gravitational acceleration,
- ν : Kinematic viscosity,
- p_{nh} : Non-hydrostatic pressure,
- ρ_0 : Reference density,
- $\Delta\rho$: Difference between local density and reference density,
- Γ : Diffusivity for property Φ ,
- Φ : Mean scalar,
- ϕ : The corresponding fluctuating scalar,
- $\bar{\ }$: (Overbar) averaging of fluctuating quantities.

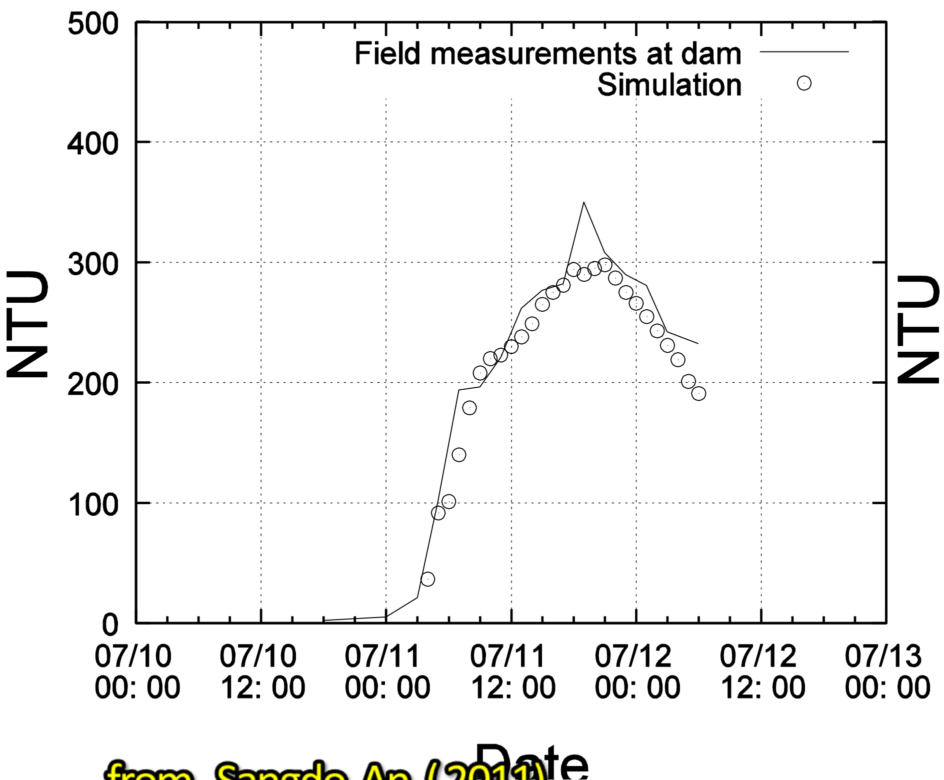
from Sangdo An (2011)

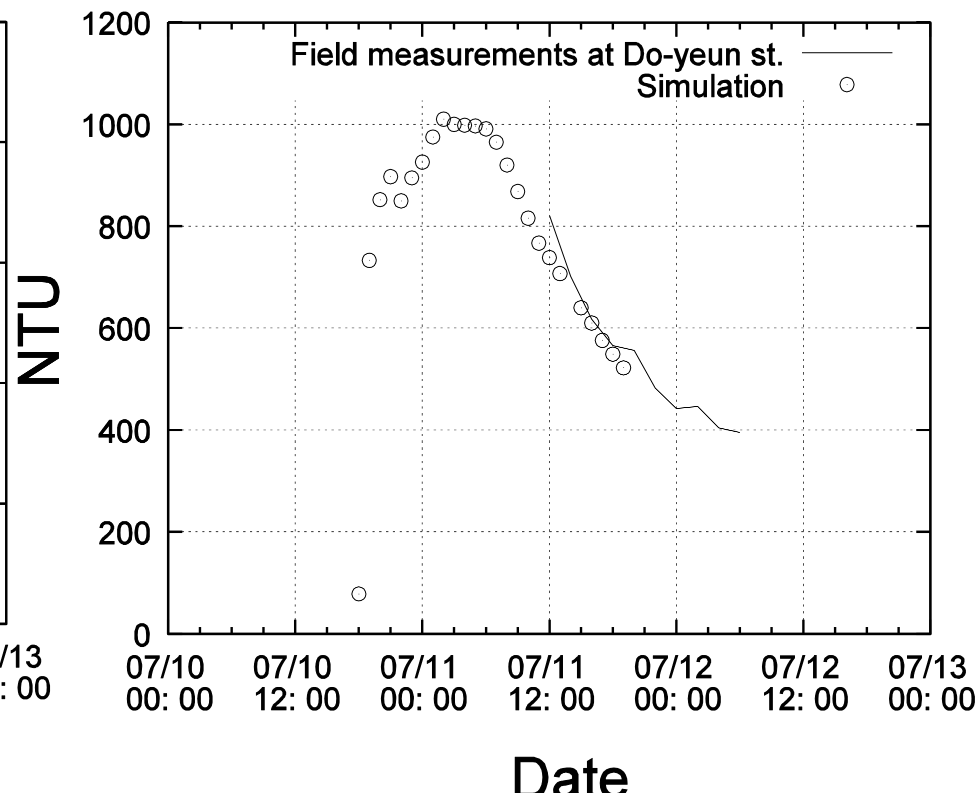
Numerical animation with bird's-eye viewpoint at EL. 141m



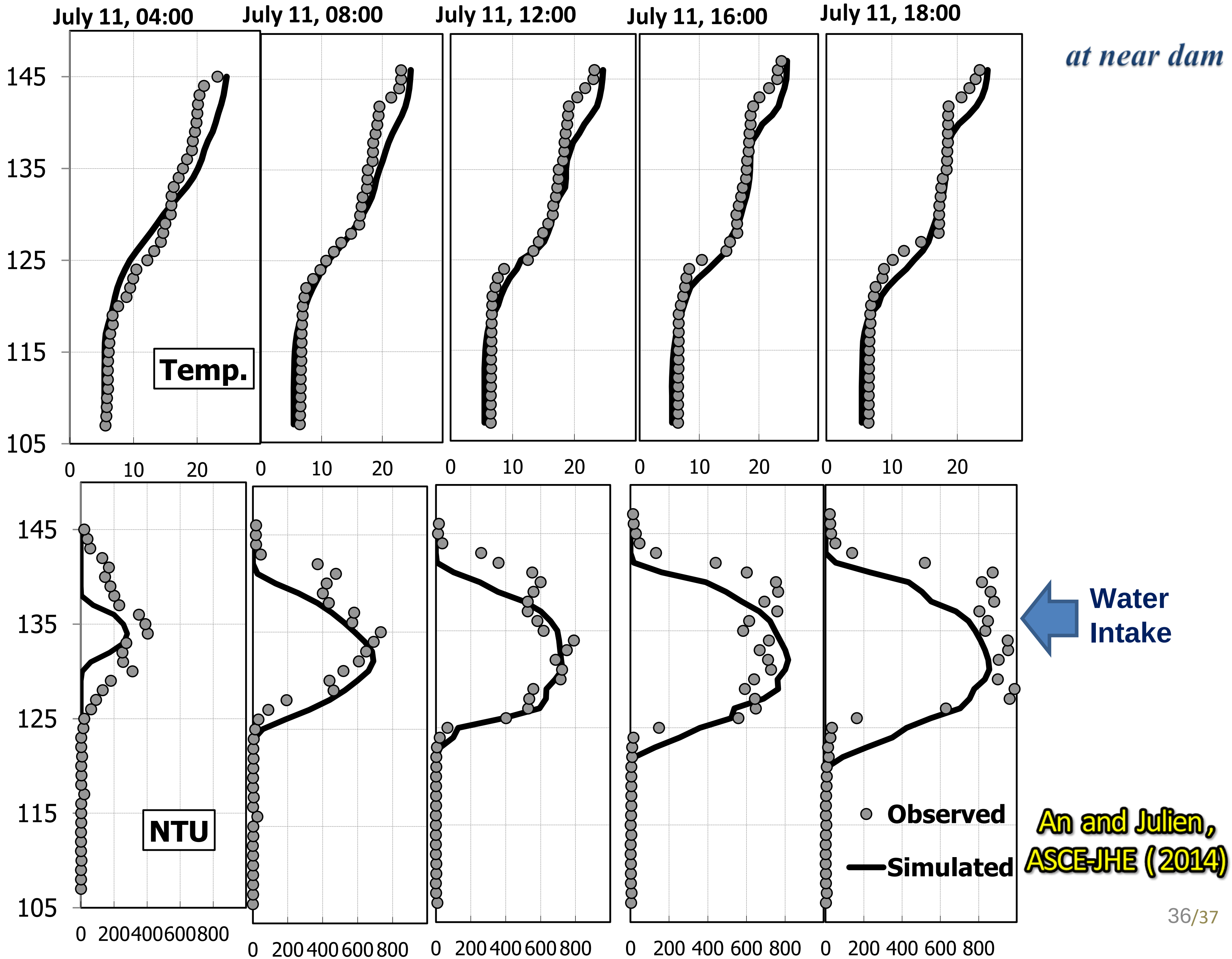
Ⅲ. Field Application

Comparison with time series measurements



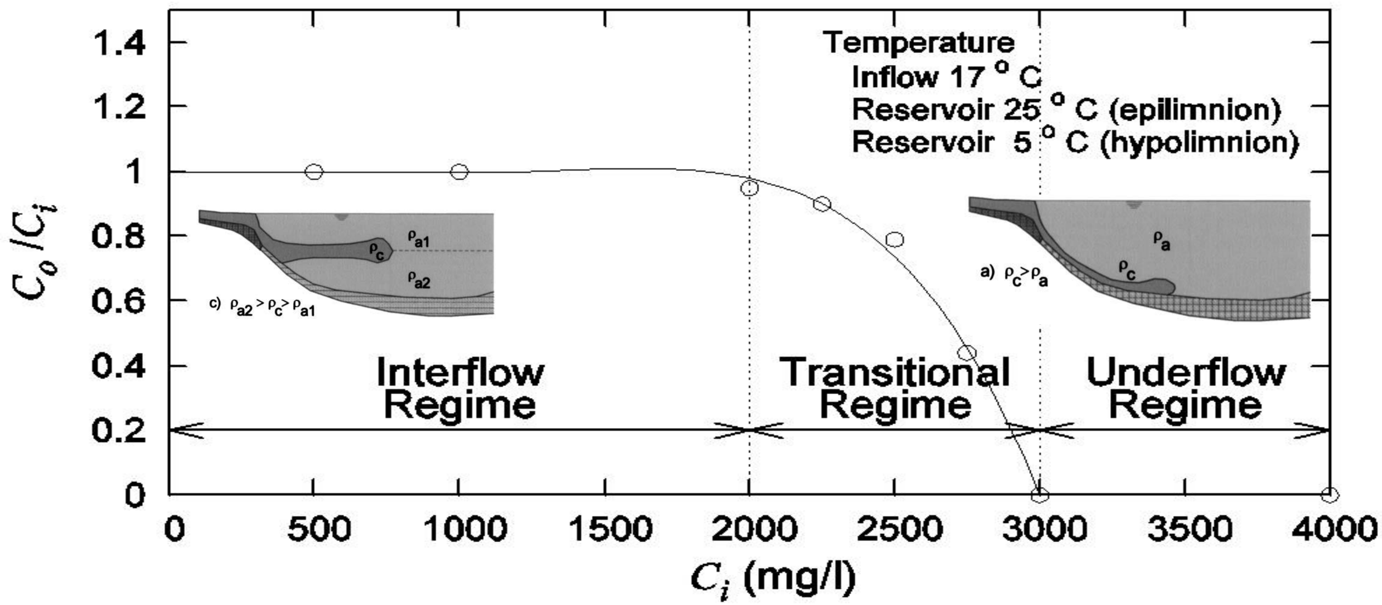


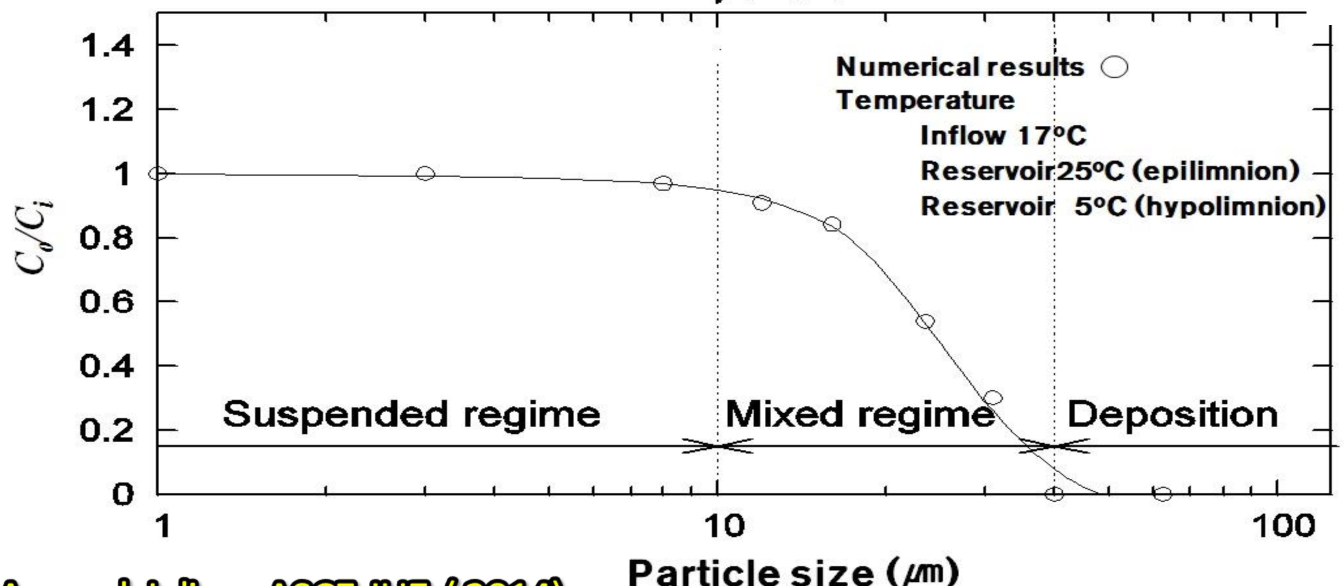
from Sangdo An (2011)



July 11, 04:00
July 11, 08:00
July 11, 12:00
July 11, 16:00
July 11, 18:00
at near dam
Temp.
NTU
Water Intake
Observed
Simulated
An and Julien, ASCE-JHE (2014)
145
135
125
115
105
0
10
20
0
200
400
600
800

NEW Results on Density Currents!





from An and Julien, ASCE-JHE (2014)

River Environment

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Cochiti Dam

How has it impacted the Aquatic Habitat for the Rio Grande Silvery Minnow RGSM?

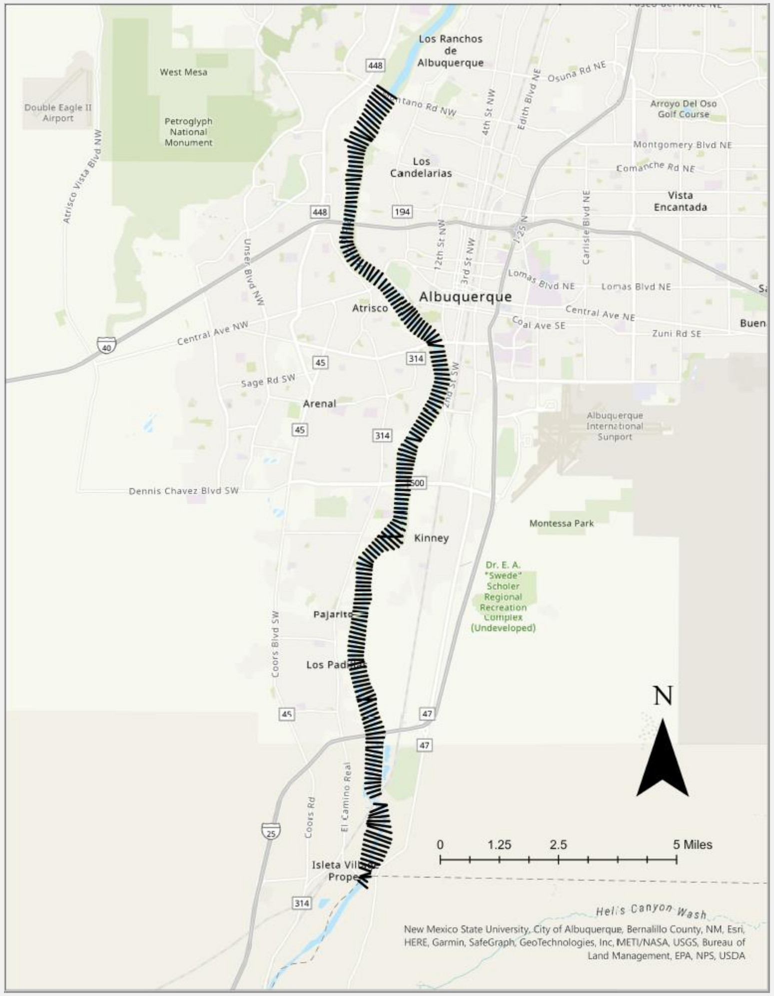
Methodology

- Available Data:
  - Aerial Imagery (dating back to 1935)
  - Survey Data (50-year period)

- Developed:

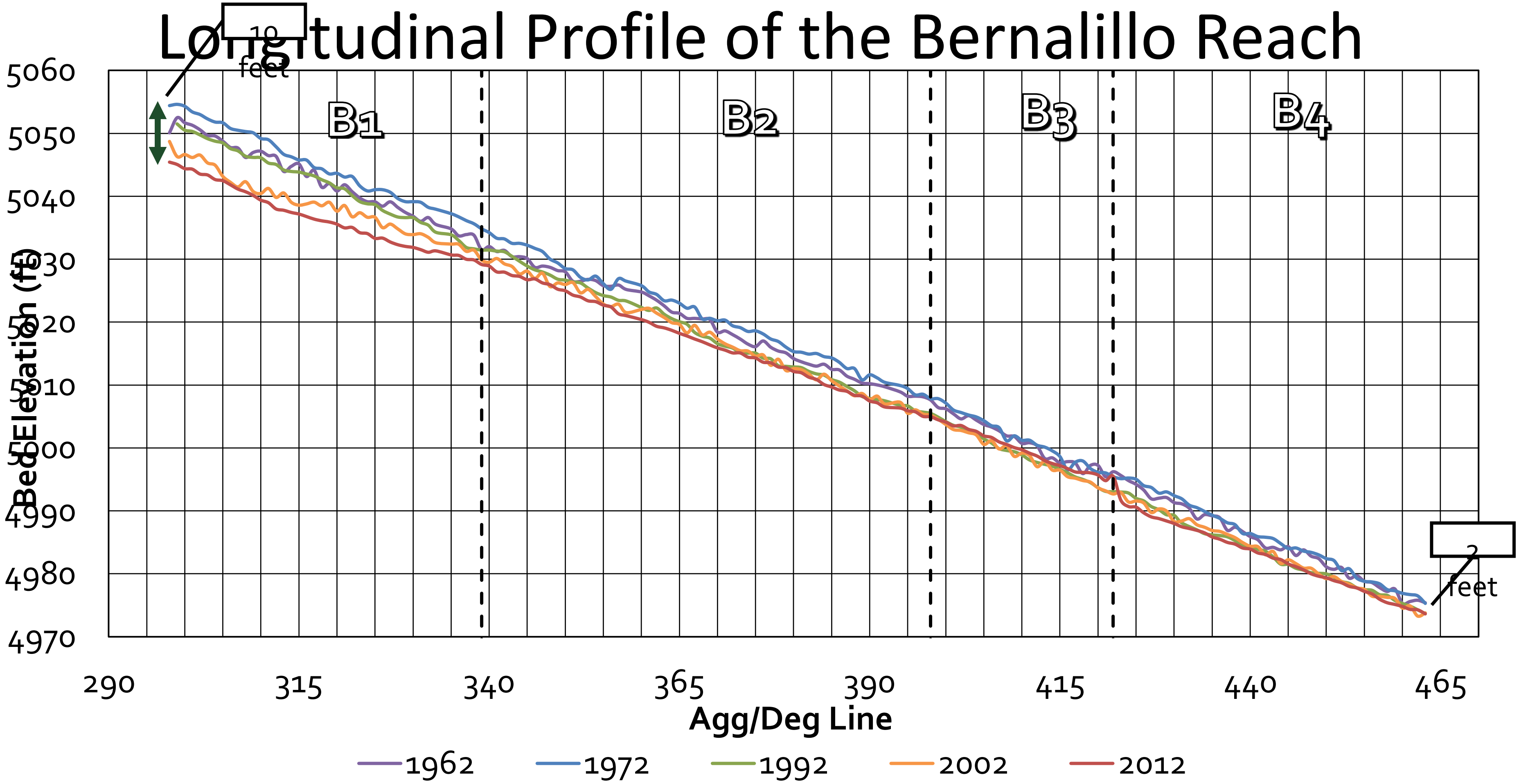
  1D Hydraulic Model (HEC-RAS)

- Post-Processing:
  - Mapping software (ArcGIS Pro)

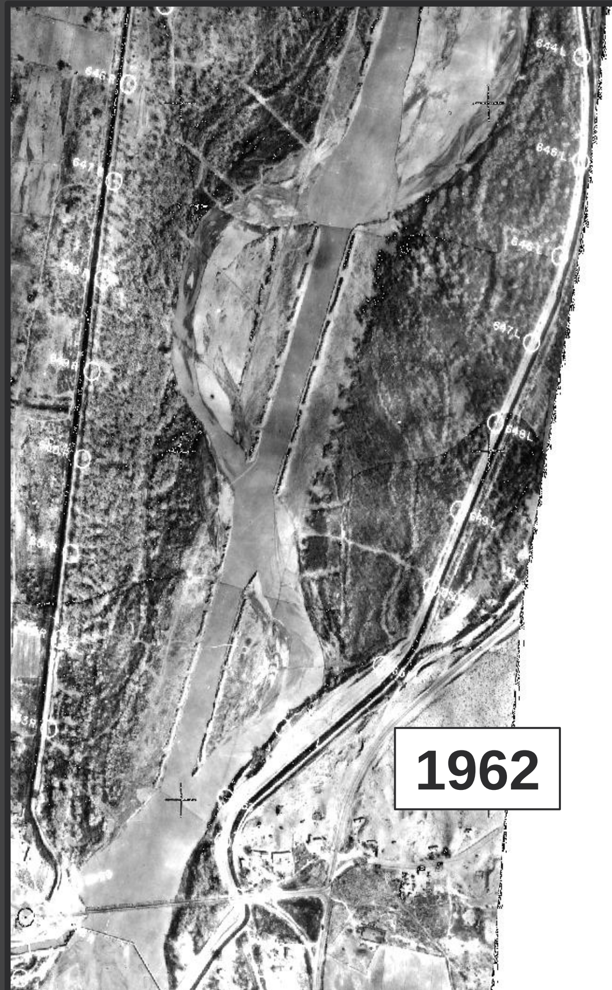


from T. Anderson, B. Corsi, C. Radobenko

Longitudinal Profile of the Bernalillo Reach

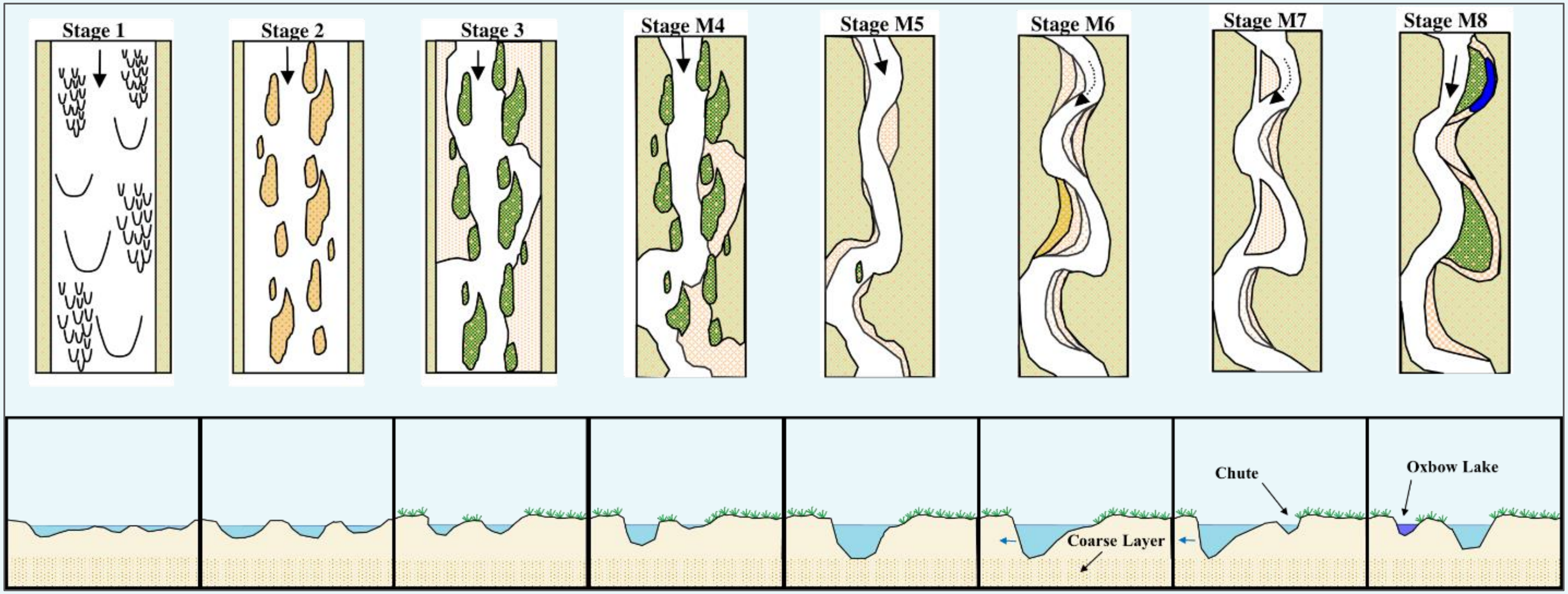


from T. Anderson, B. Corsi, C. Radobenko



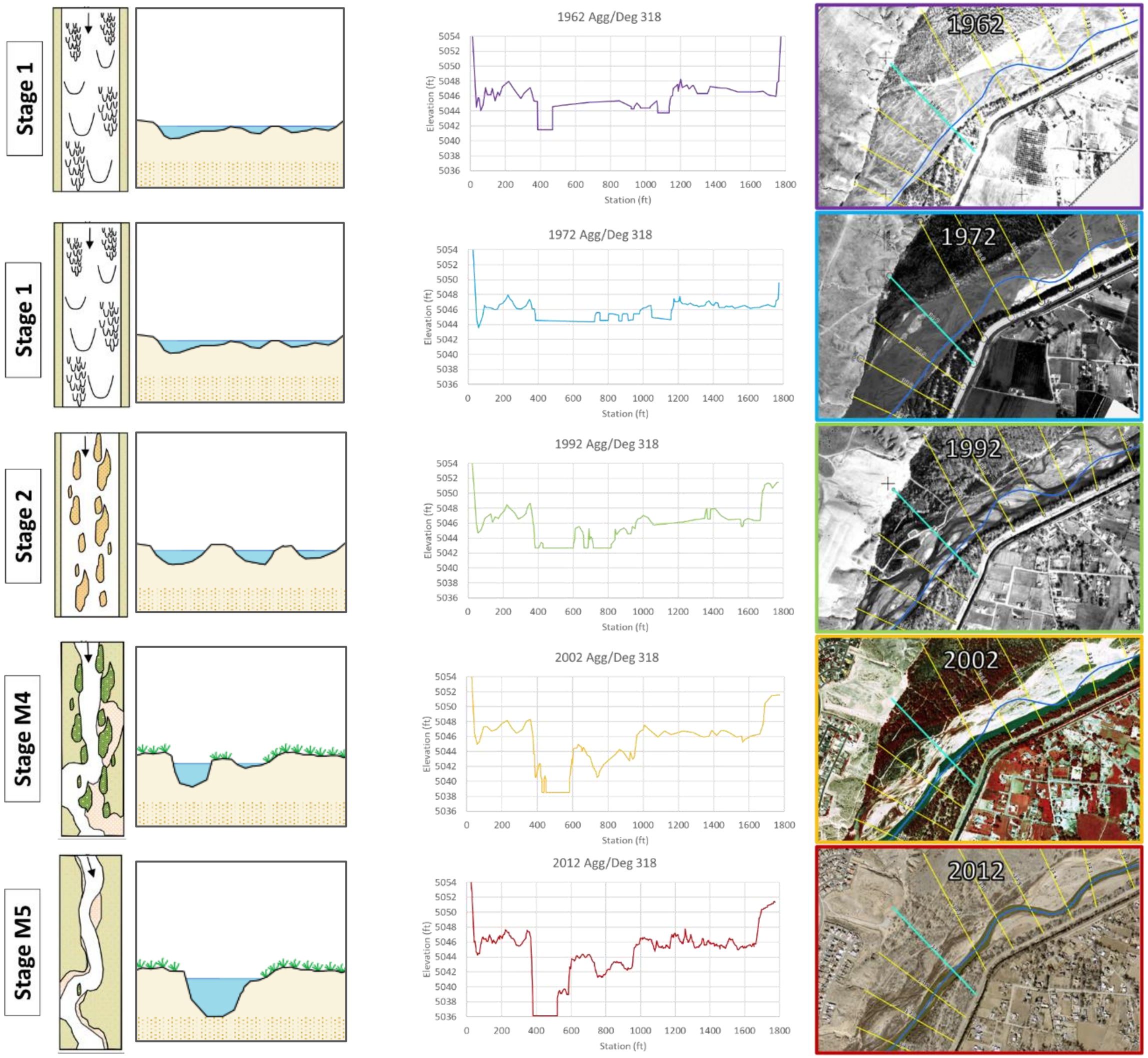
from T. Anderson, B. Corsi, C. Radobenko

Massong Conceptual Planform Model



Subreach B1

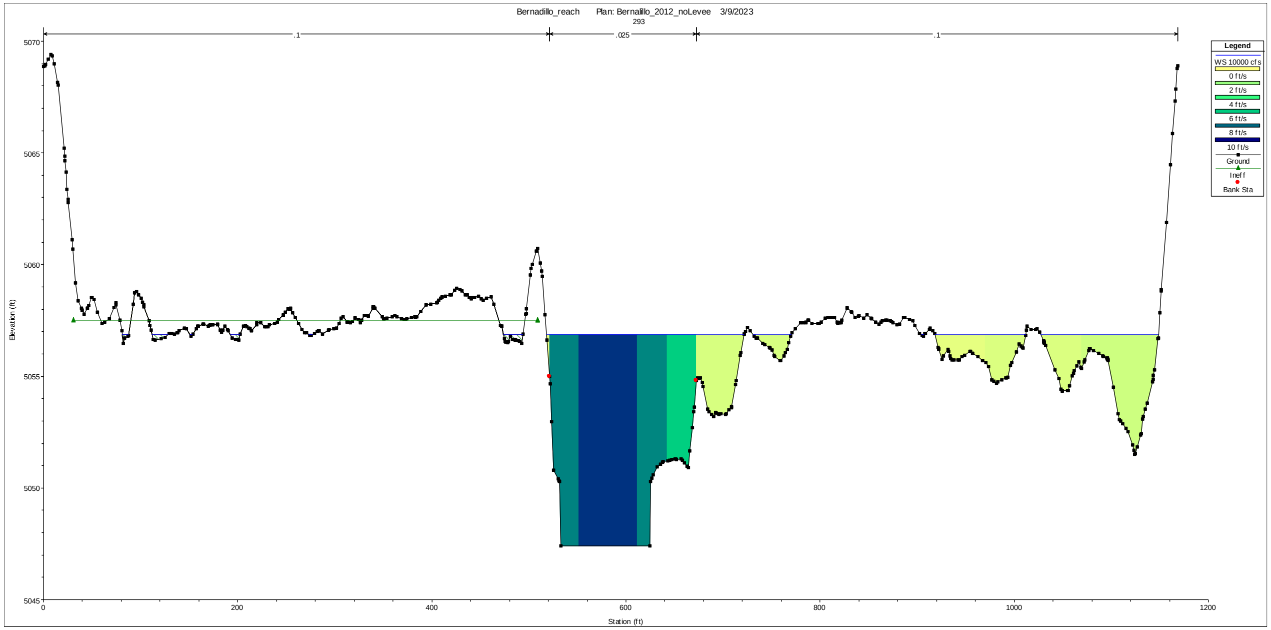
Planform Classification



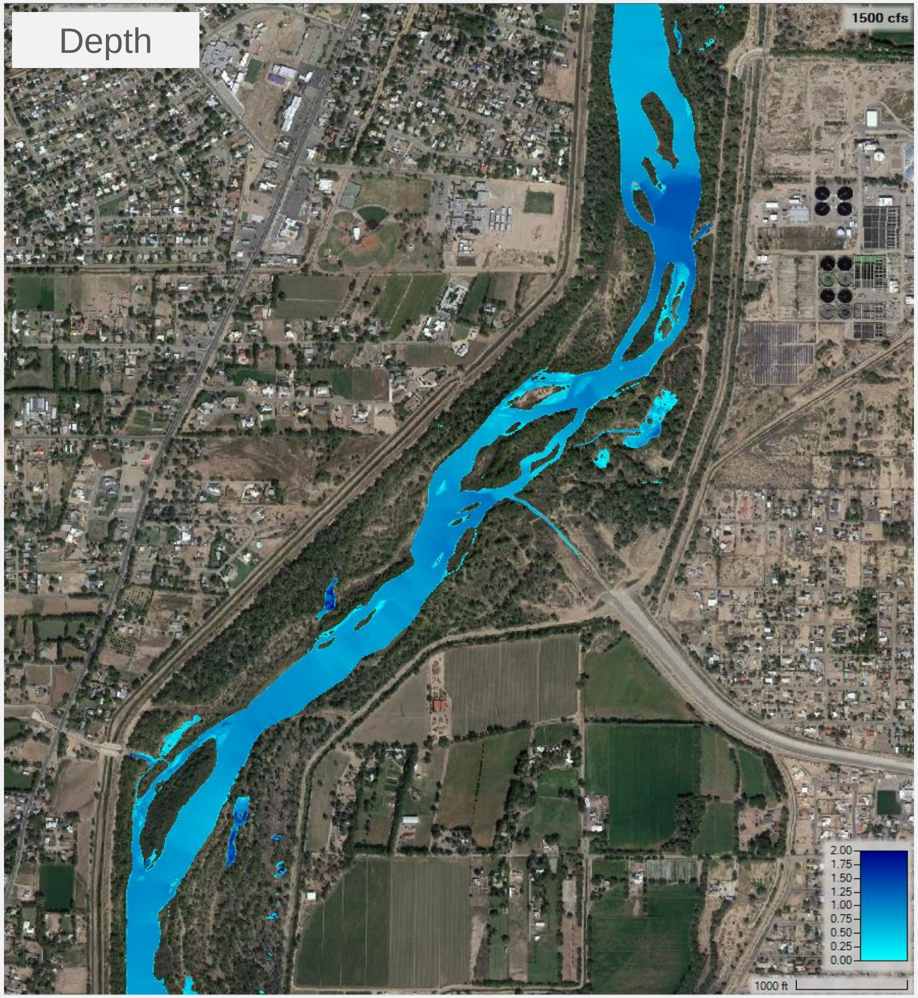
from T. Anderson, B. Corsi, C. Radobenko

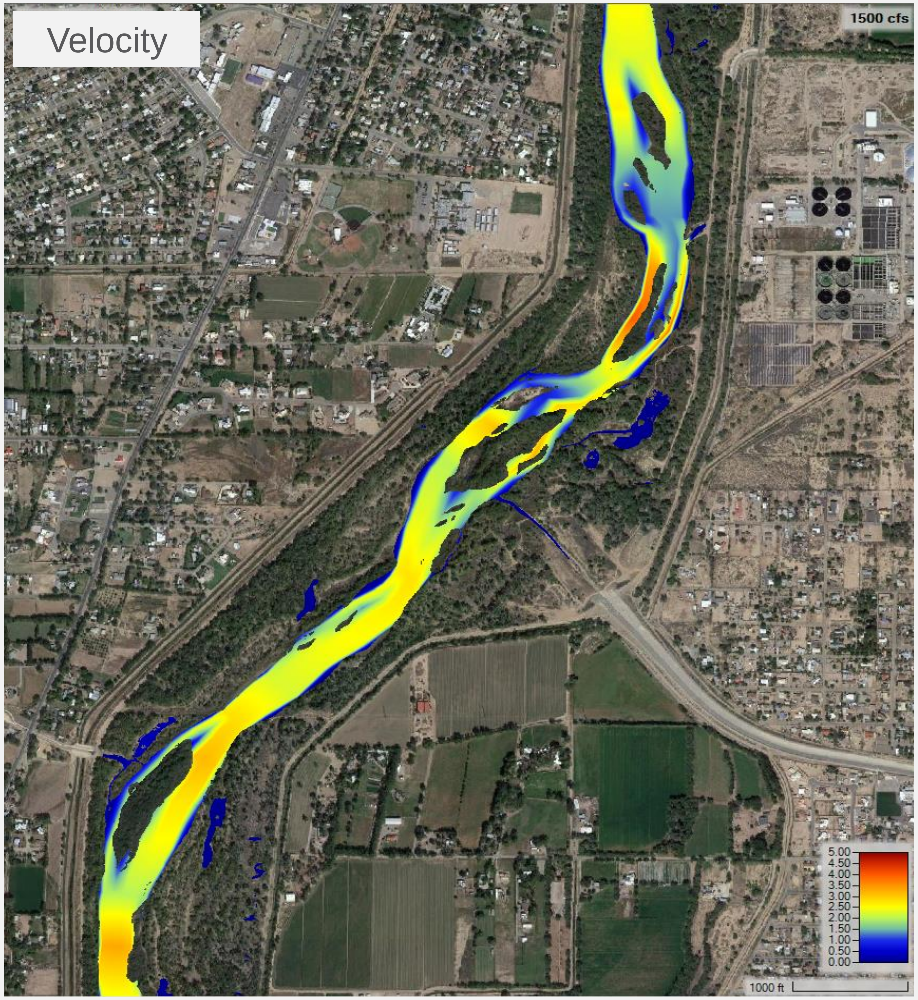
1D Model Methods

- 1D HEC-RAS Model provided by USBR
- Ineffective flow using aerial imagery
- Width-Slice Method
- RAS-Mapper to create "pseudo" 2D Mapping
- Flows: 500 to 10,000 cfs



from T. Anderson, B. Corsi, C. Radobenko



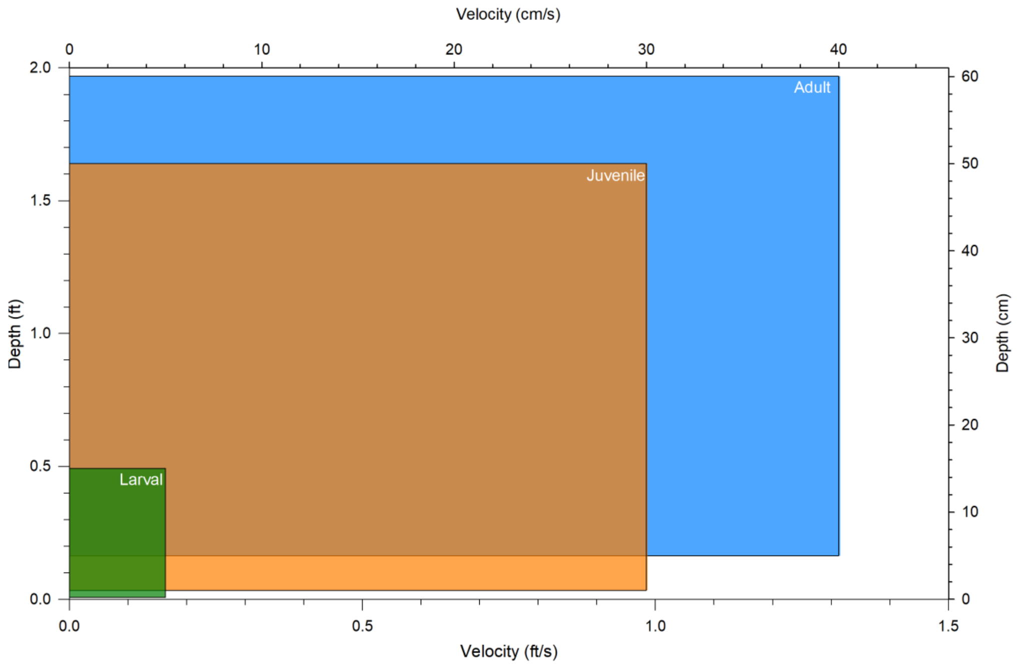


from T. Anderson, B. Corsi, C. Radobenko

Rio Grande Silvery Minnow (listed as endangered since 1994)

- Suitable range of velocity and depths for three phases of the RGSM: larvae (green), juveniles (orange) and adults(blue)
- Shallow conditions on floodplains are ideal habitat

(Rio Grande silvery minnow. (2023, February 20). In *Wikipedia)*

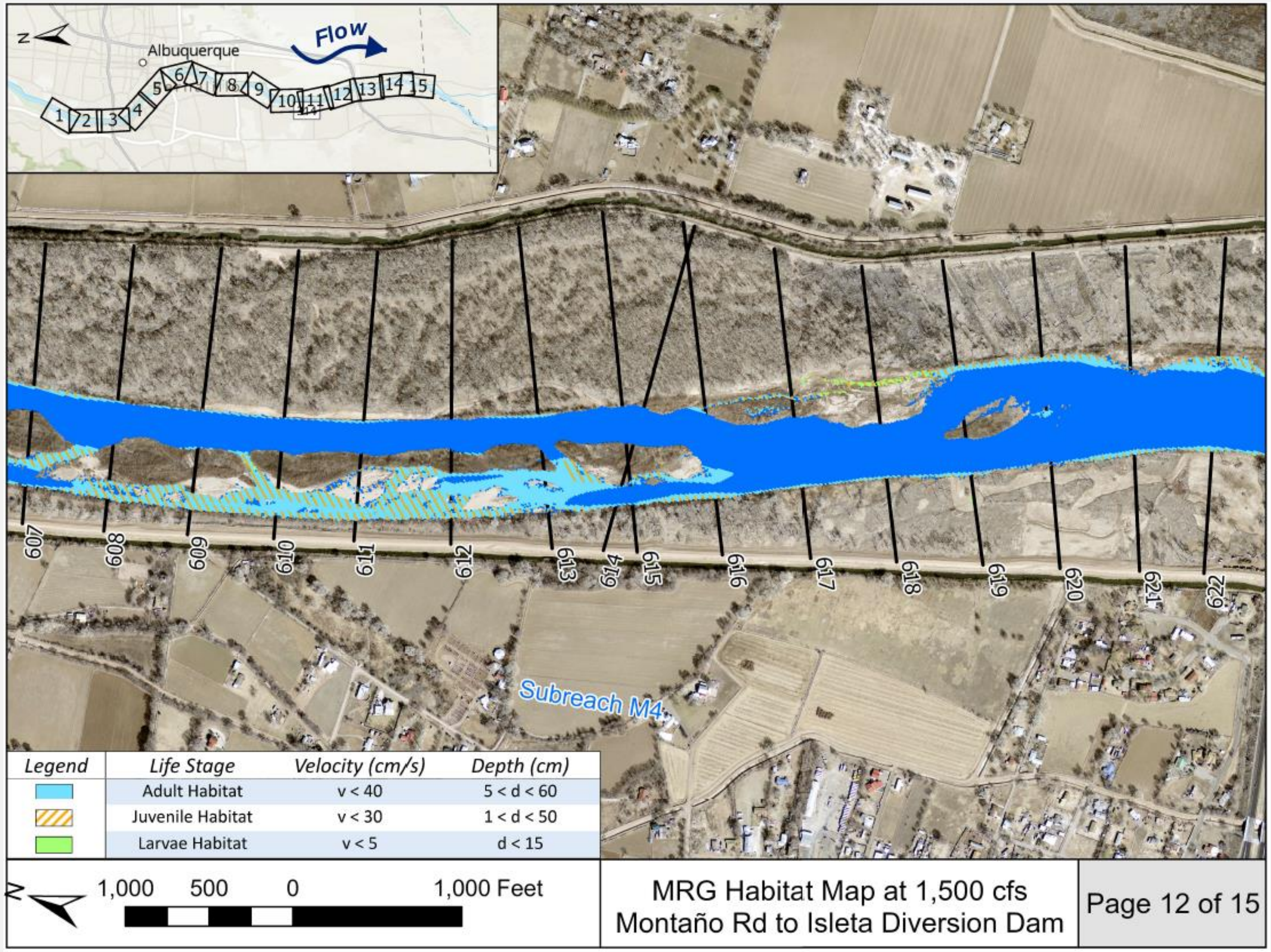


from J. Mortensen et al. (2022)

Habitat Map

- Spatially illustrates RGSM habitat for each life stage.
  - Larvae
  - Juvenile
  - Adult

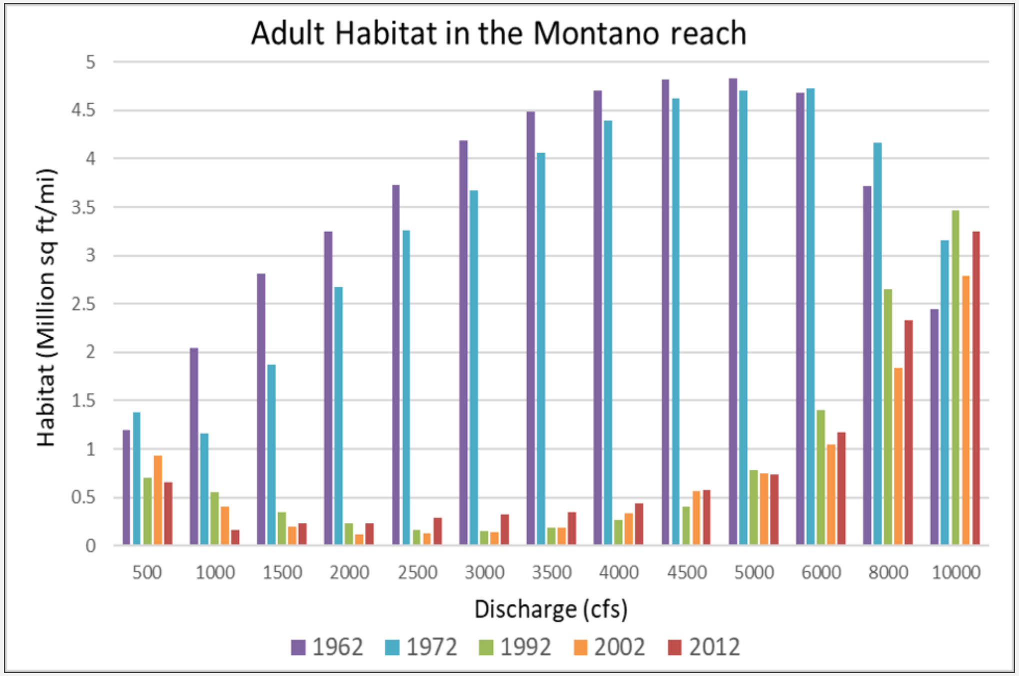
- Habitat Locations:
  - Activated side channels
  - Islands
  - Riverbanks
  - Inlets



from T. Anderson, B. Corsi, C. Radobenko

Major Findings

- Braided River ➡ Single Thread river
- Significant decrease in habitat from 1962 to 2012
- Hydraulically suitable habitat locations:
  - Riverbanks (shoreline)
  - Submerged/Partially submerged islands
  - Activated side-channels



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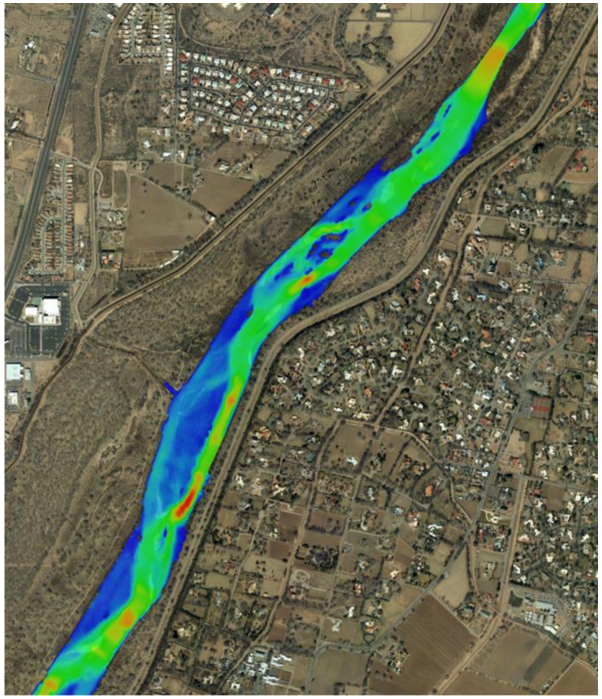
2D Model Comparison Study

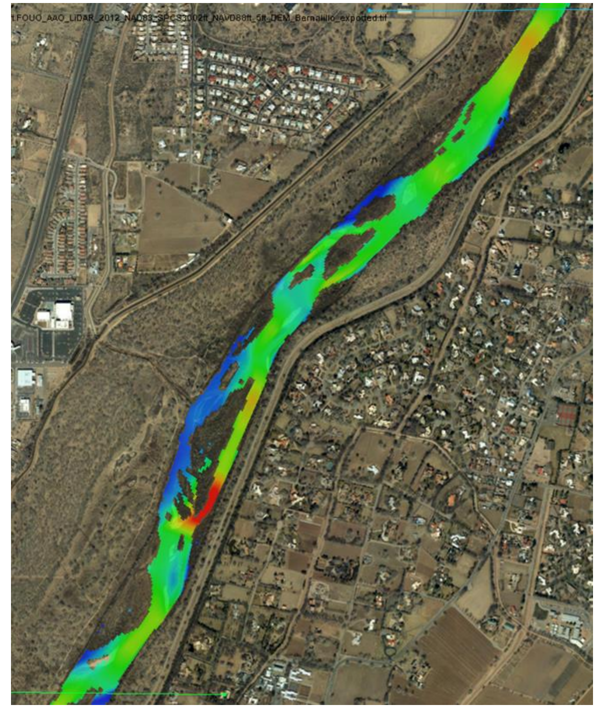
2D hydraulics vs "pseudo" 2D hydraulics created from 1D HEC-RAS and RasMapper

Determine if 1D model is sufficient for habitat availability predictions.

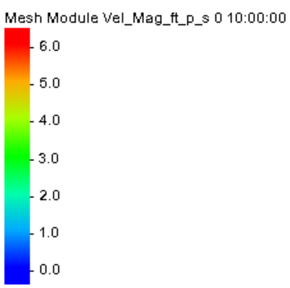
from T. Anderson, B. Corsi, C. Radobenko



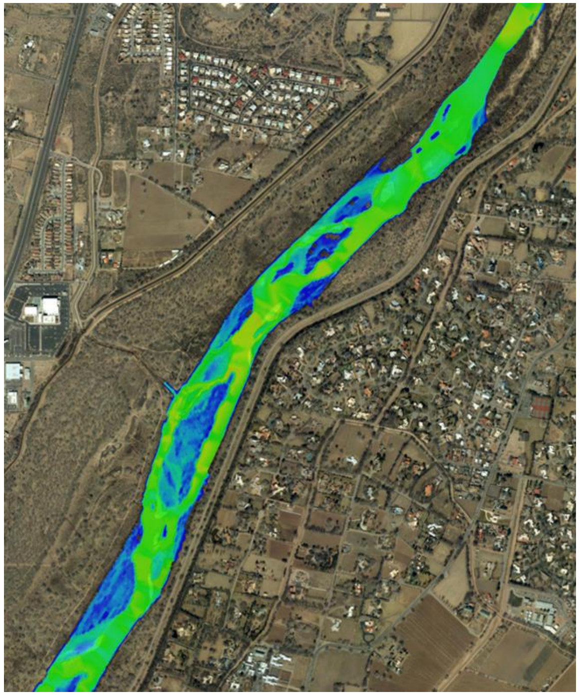
SRH-2D



1D HEC-RAS “pseudo” 2D



3,000 cfs Velocity Results



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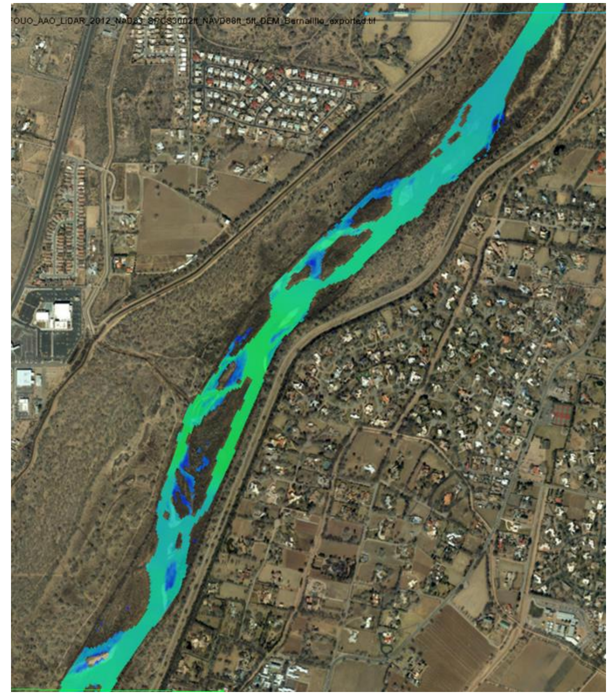
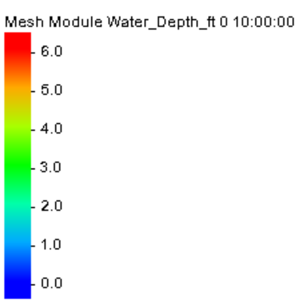


1D HEC-RAS “pseudo” 2D



3,000 cfs Depth Results

from T. Anderson, B. Corsi, C. Radobenko

Habitat Locations

SRH-2D

1D HEC-RAS

from T. Anderson, B. Corsi, C. Radobenko

Summary and Conclusions

1. Upland Contamination

Contaminant mapping locates problem source areas

2. Sediment Management

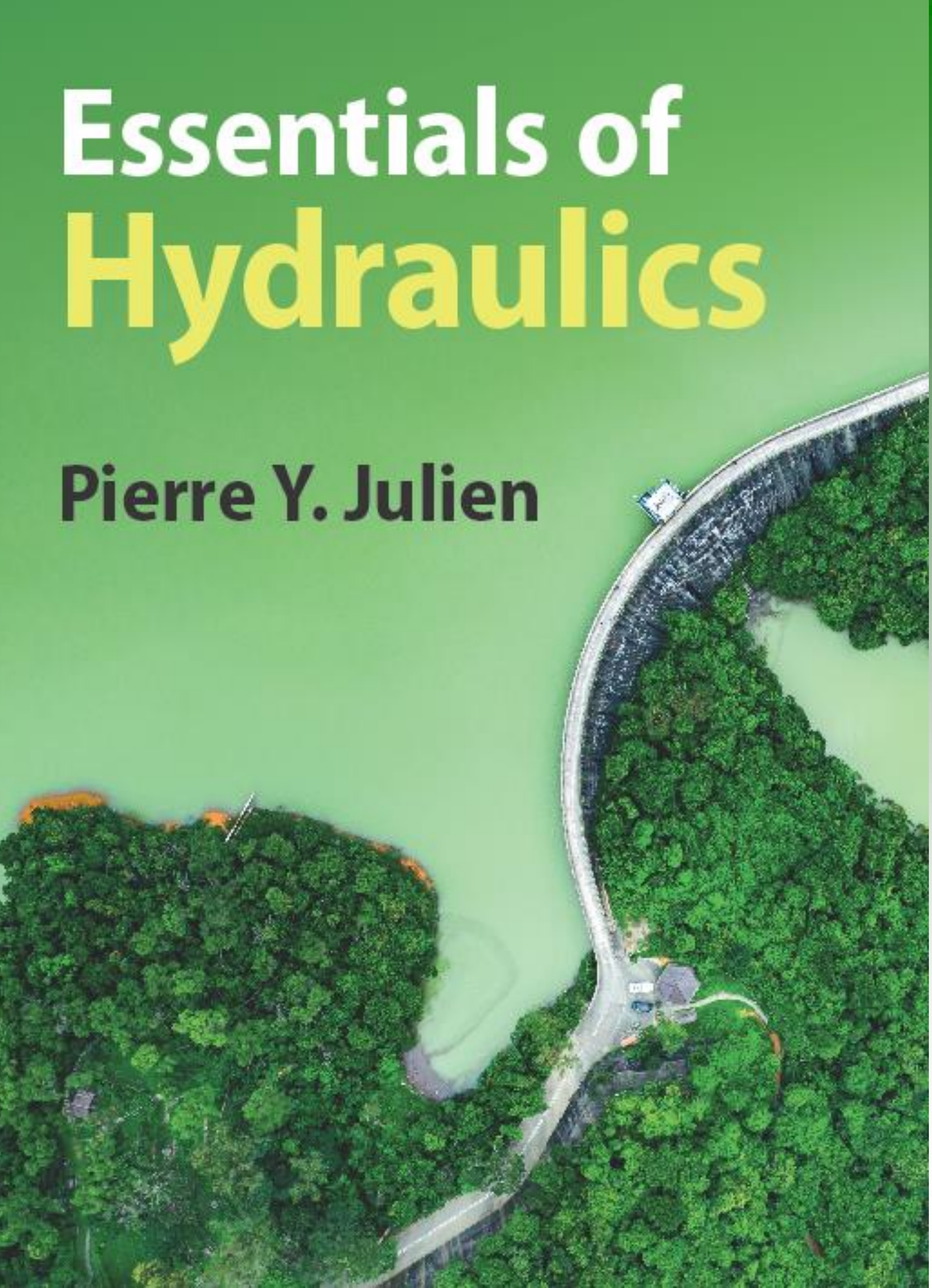
Hydraulic thresholds and MCDA are helpful.

3. Density Currents

Turbidity problems from density currents can be modeled

4. Aquatic Habitat

New models define mapping of suitable aquatic habitat



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Dr. Nate Bradley, USBR
Apologies if I forgot anyone …

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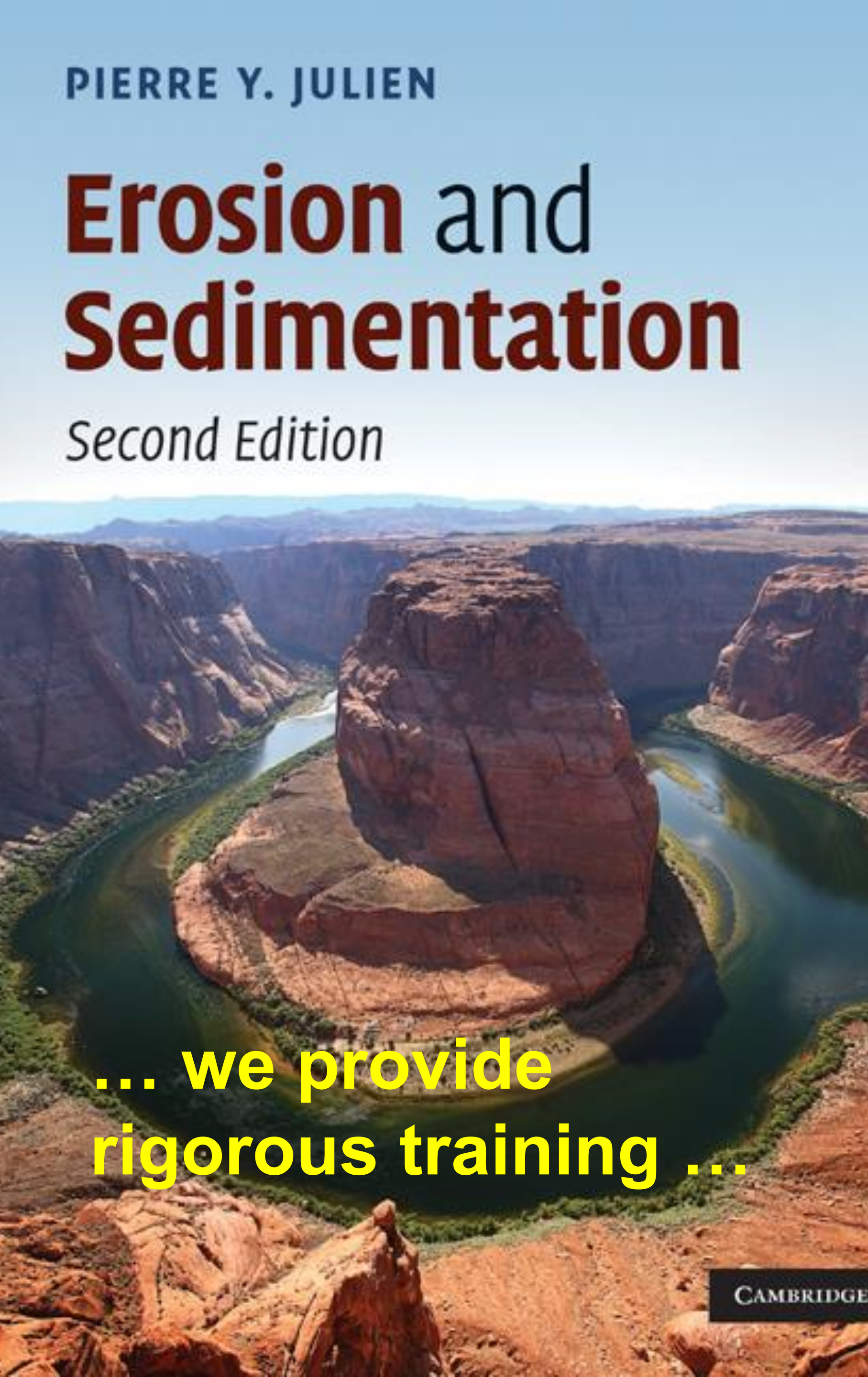

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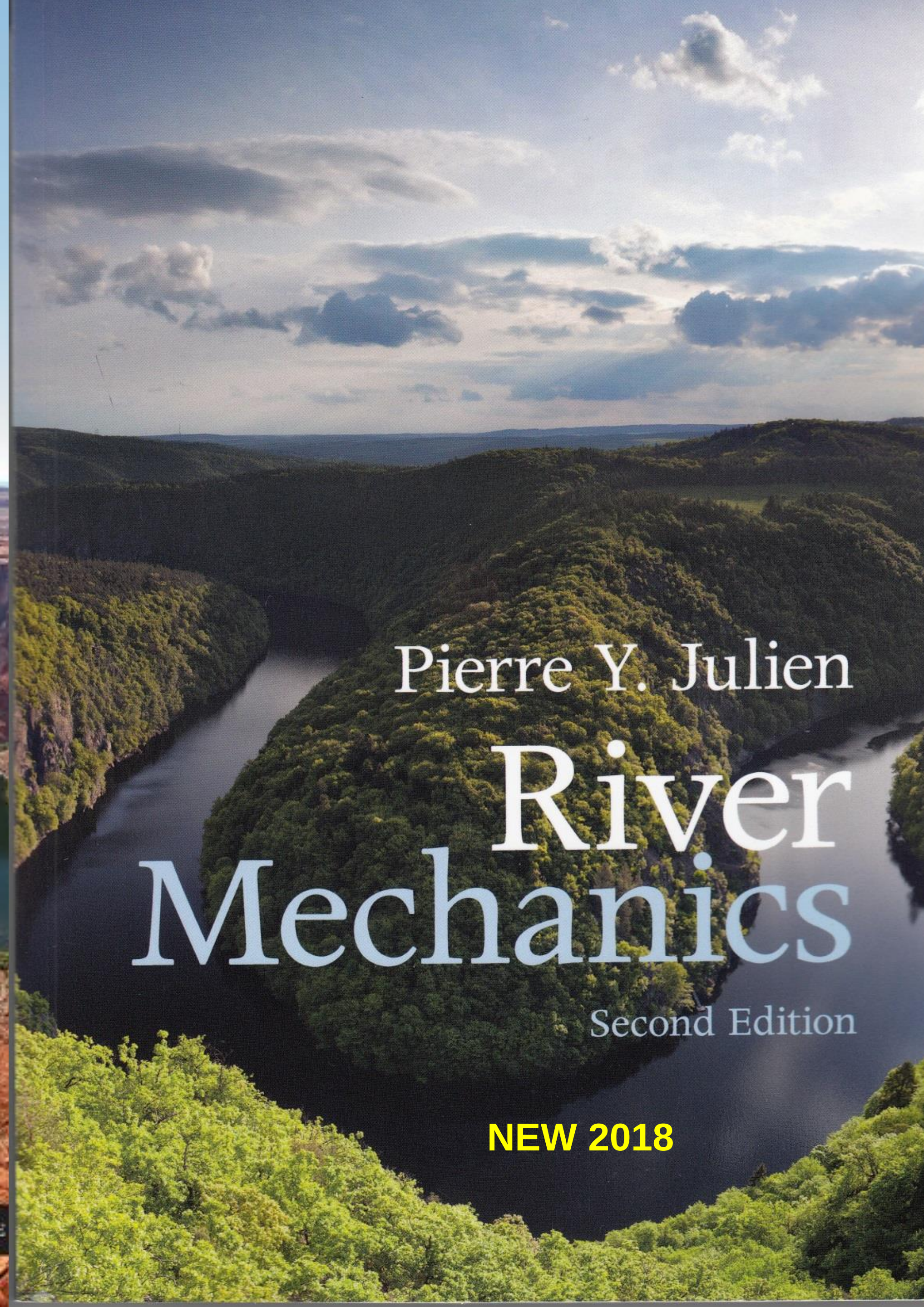

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Thank You!!