

An aerial photograph showing a large, dark blue reservoir or river bend. To the left of the reservoir, there are several large, rectangular, light-colored areas that appear to be agricultural fields or industrial sites. The surrounding landscape is a mix of green fields and dense forest. The title 'River Environment' is overlaid in large, bold, yellow text with a black outline.

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**

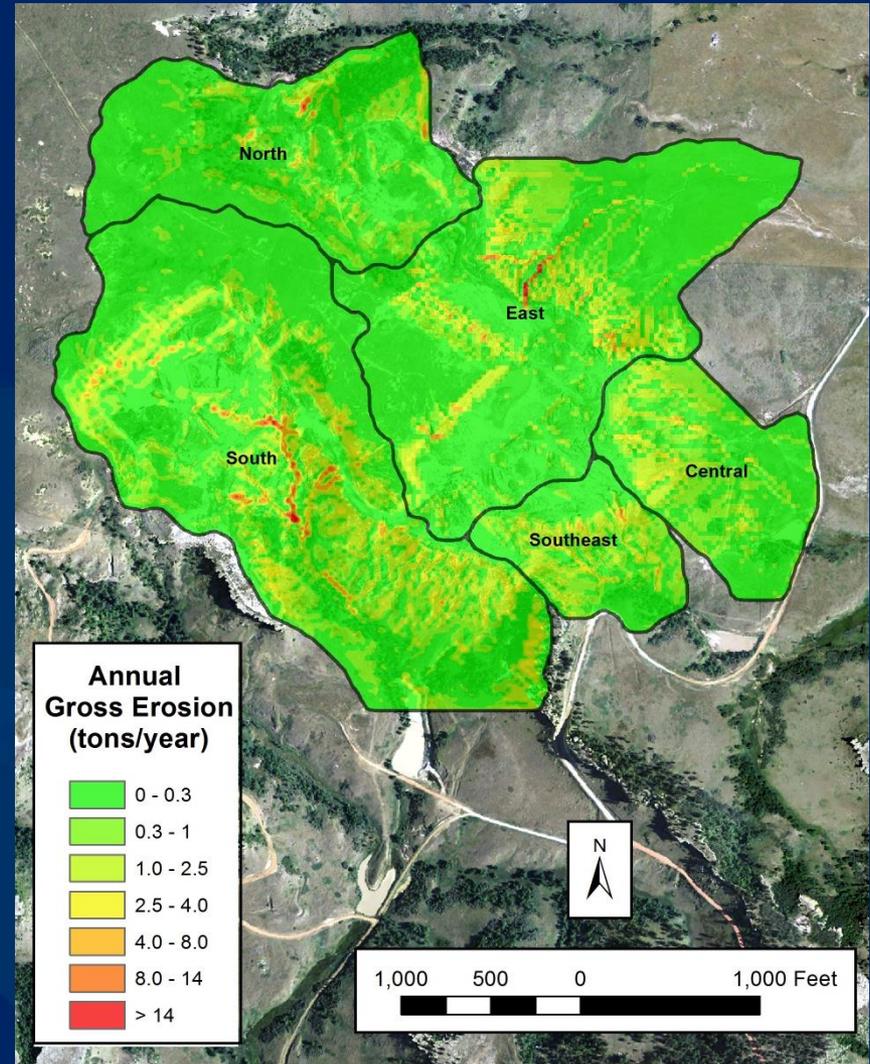
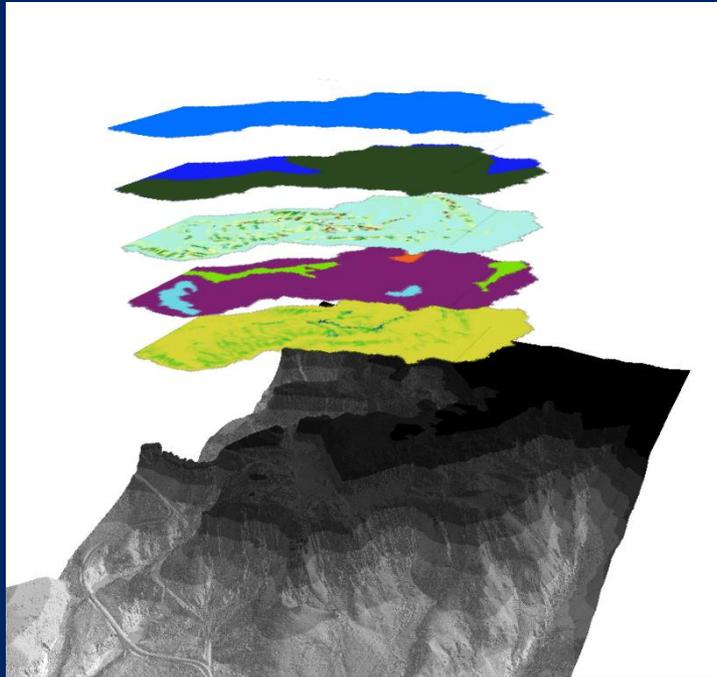


River Environment

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



Erosion of Contaminants

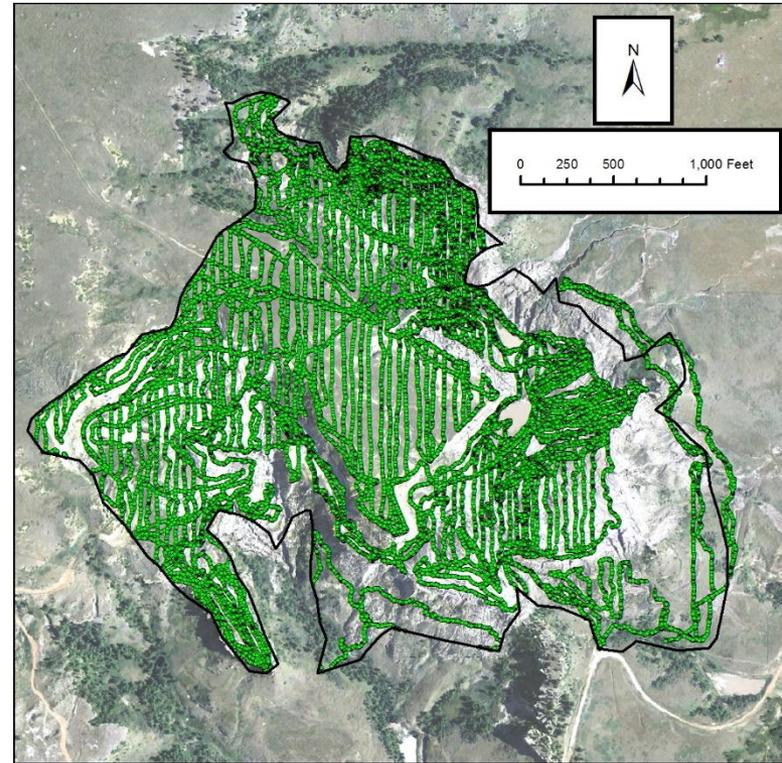


Watershed ID	Area	Gross Erosion, A_T	
	[acres]	tons/year	kg/year
North	43	713	646,462
East	72	1,836	1,665,793
Southeast	16	587	532,348
Central	25	708	642,444
South	94	3,366	3,053,933



Contaminant Characterization Techniques

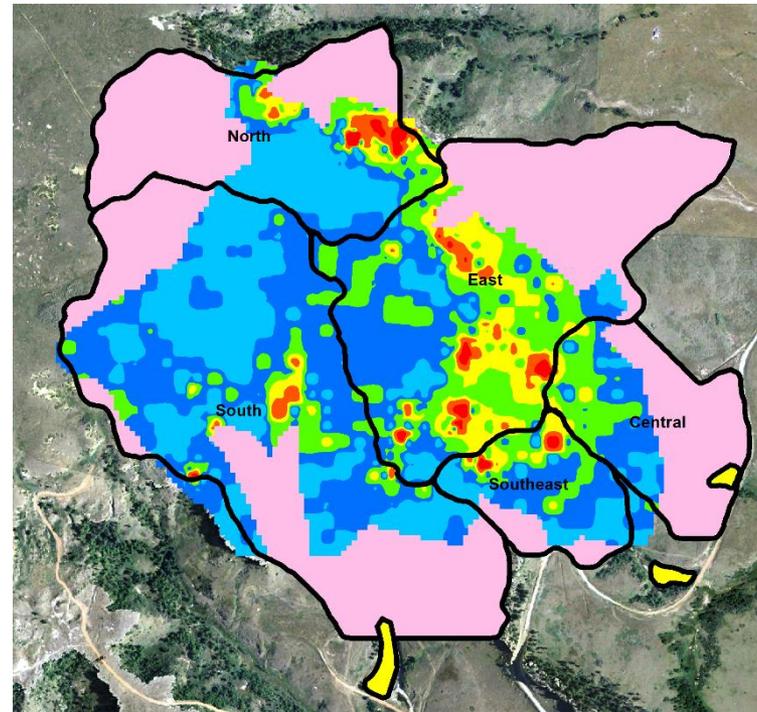
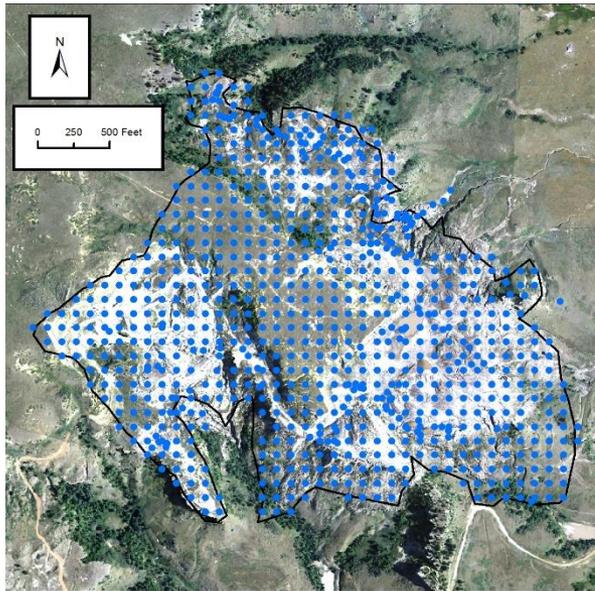
Gamma Radiation Survey for Ra-226



From A. Orechwa (2015)

Arsenic Mapping

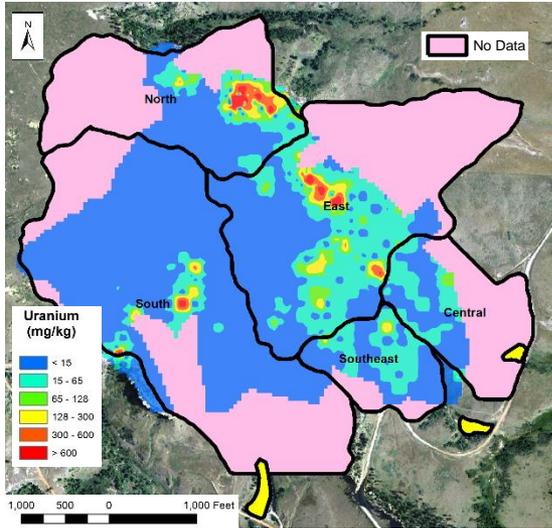
X-Ray Fluorescence



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

Sediment Yield

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

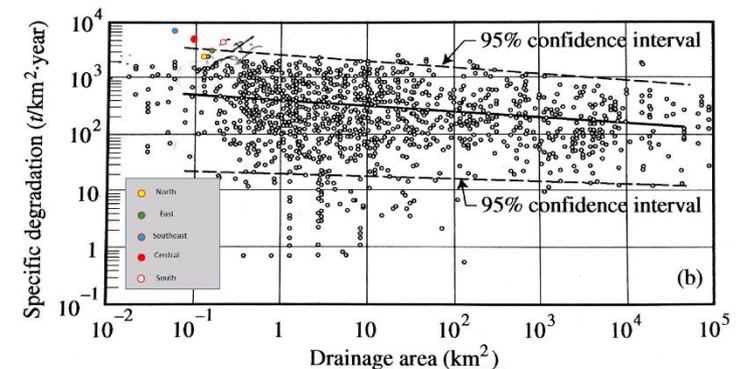
Y = Sediment Yield (US tons/year)
 A = Gross erosion (US tons/year)

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

Watershed ID	Area [acres]	Gross Erosion, A_T		Sediment Yield (U.S. tons/year)		
		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

$$\text{Specific Degradation} = \frac{Y \text{ (metric tons/year)}}{\text{Area (km}^2\text{)}}$$

Watershed ID	Area (km^2)	Specific Degradation (metric tons/ km^2 -year)			
		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



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

MARK L. VELLEUX,*, †, PIERREY. JULIEN, ROSALI AROJAS-SANCHEZ, WILLIAM H. CLEMENTS, AND JOHN F. ENGLAND, JR.

Journal of Hydro-environment Research

journal homepage: www.elsevier.com/locate/jher

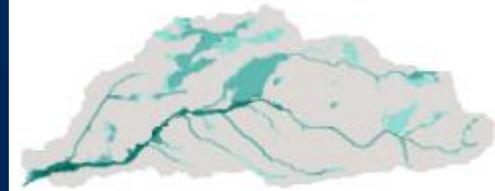
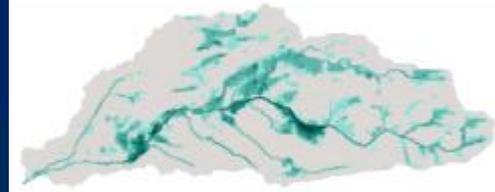
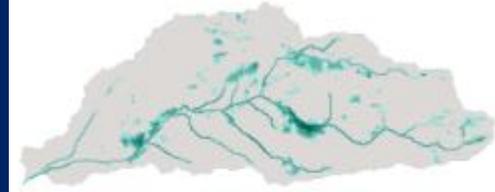
Research papers

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

Lezhang Weia,b,*, Tsuyoshi Kinouchia, Mark L. Velleuxc, Teppei Omataa, Keiichi Takahashia, Megumi Arayaa

^aDepartment of Environmental

Zn Concentration



Total Zinc Concentration (mg/L)



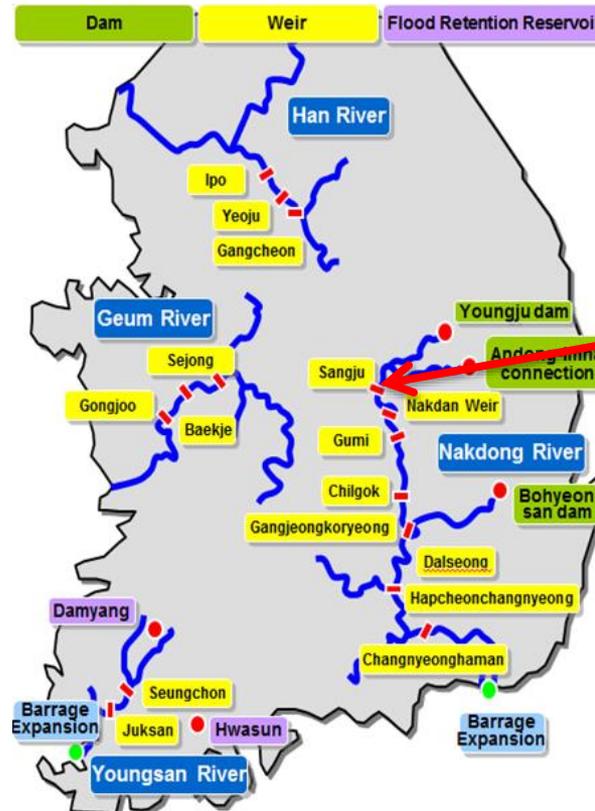
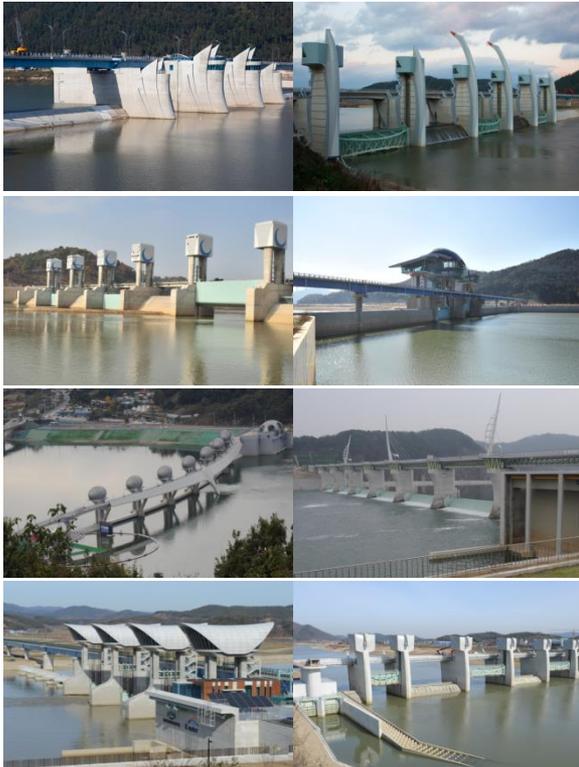
River Environment

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 Site





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

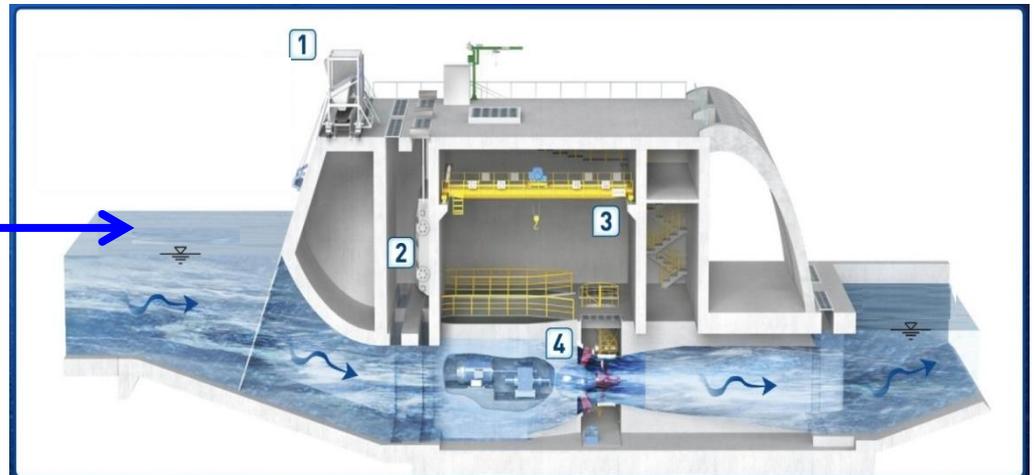
Benefit and Cost Analysis

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 ³ USD)	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)
- $V = 13,678,000 \text{ m}^3$ (43.2 million dollars)
- Unit cost = 6.31 USD/m³



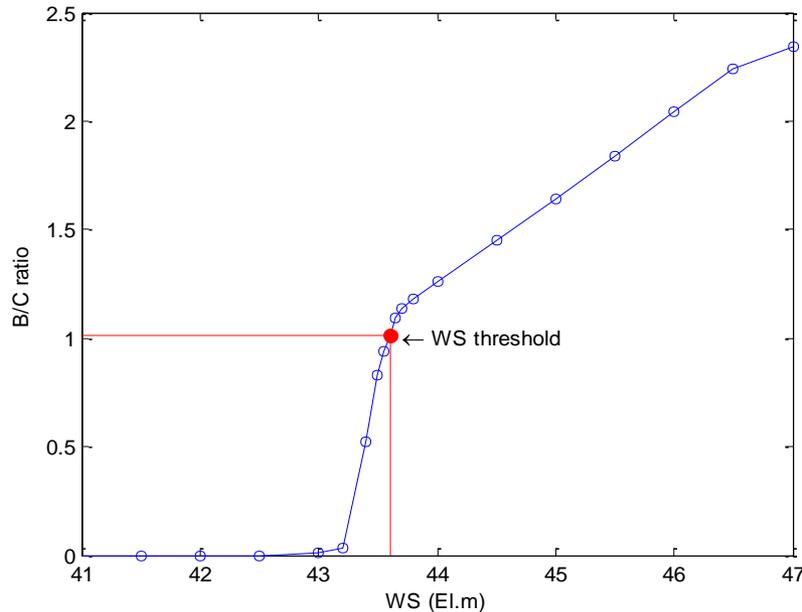
Nakdong River Estuary Barrage
from Hwayoung Kim, K-water



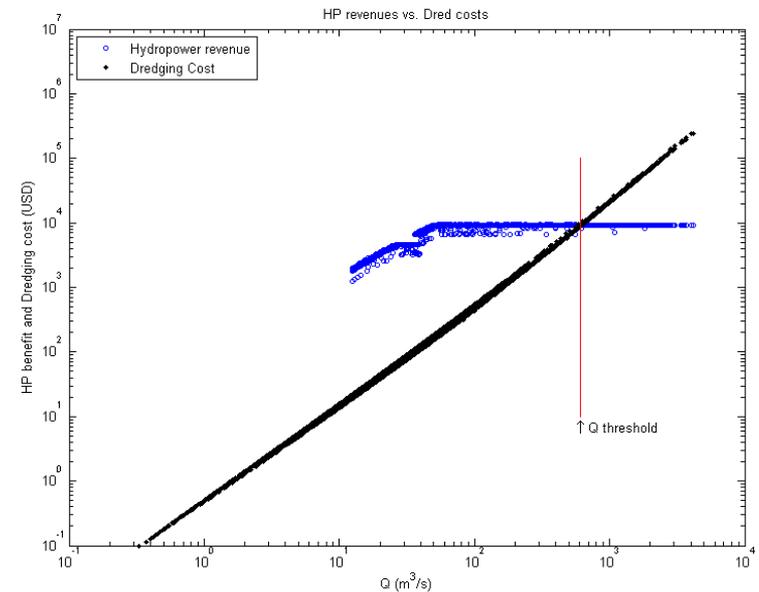
Photos of excavation

Hydraulic Thresholds

Operate the dam above
H threshold = **EL. 43.6 m**

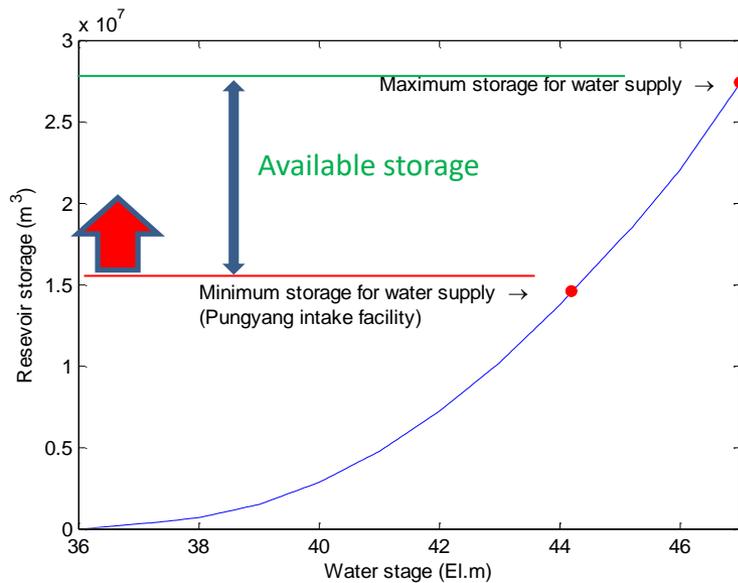


Open the gates above
Q threshold = **620 m³/s**



Water Supply

Max. Reservoir Storage (V)

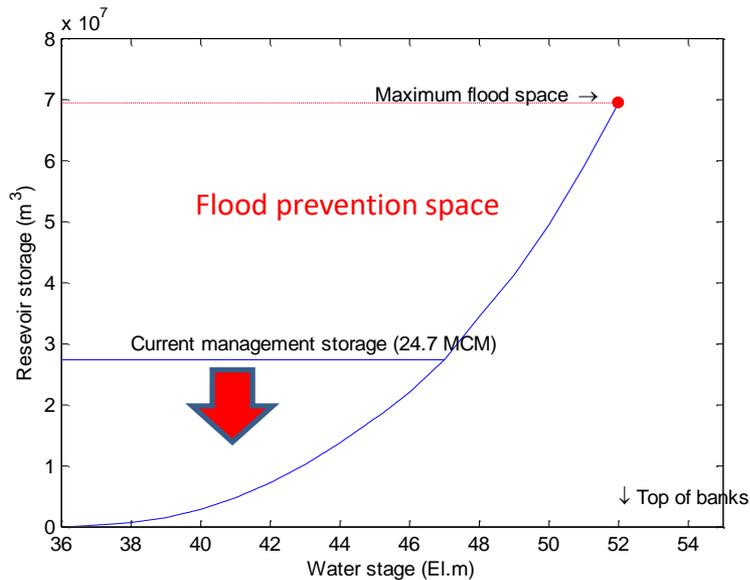


from Hwayoung Kim, K-water



Flood Control

Min. Reservoir storage (V)

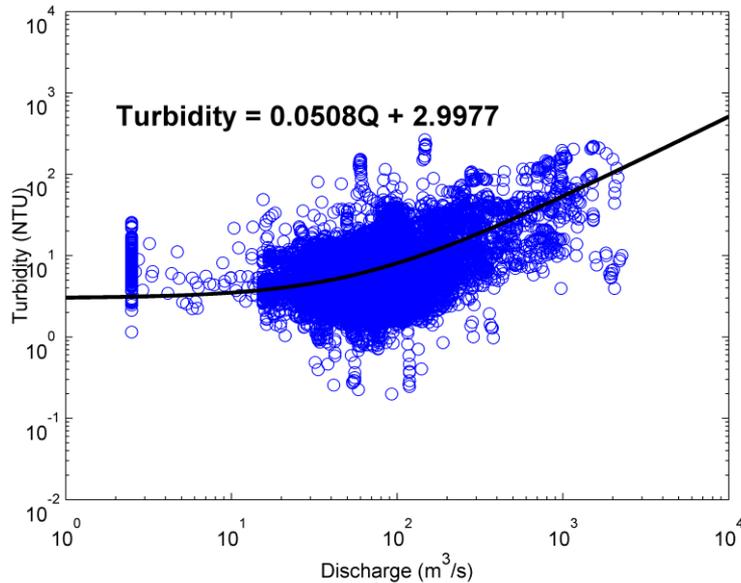


from Hwayoung Kim, K-water



Minimize (Turbidity)

Minimize Discharge (Q)
(High uncertainty)



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



Step 1
Criteria Identification

Step 2
RIF Definition

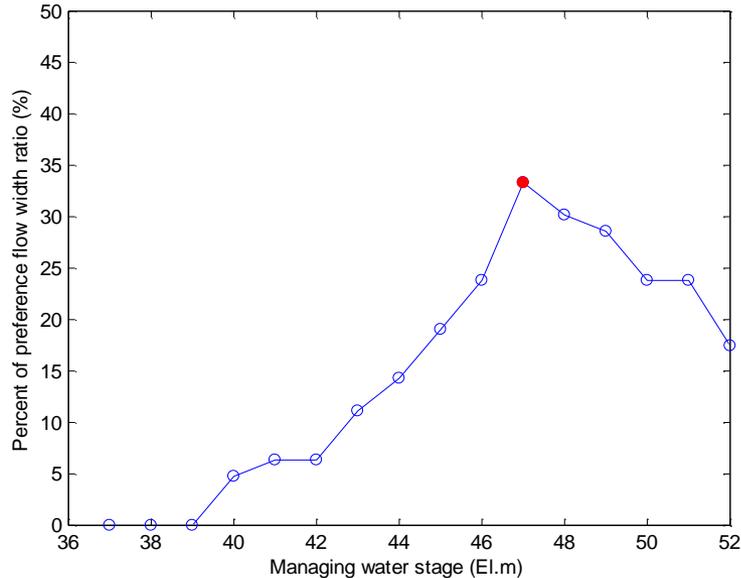
Step 3
Constraints Analysis

Step 4
Alternatives development

Step 5
MCDA Modeling

Stream Ecology & Riverside Environment

Max. GVSR (Good View Station Ratio)

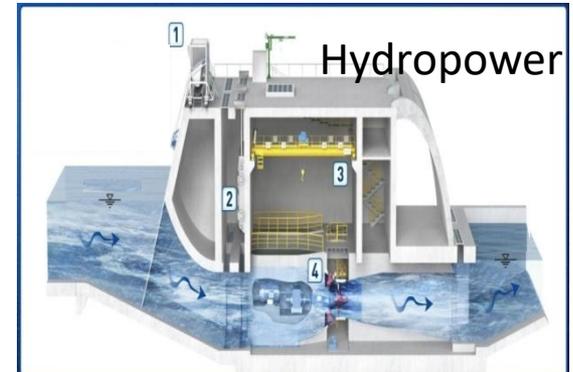
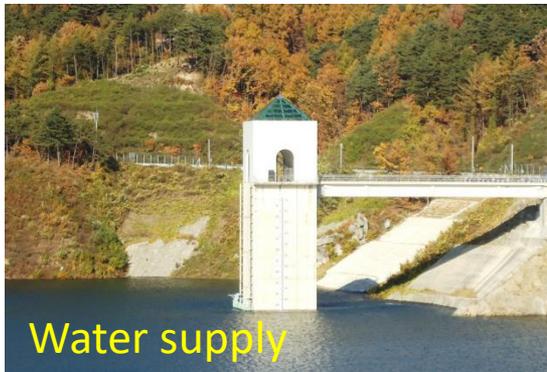


from Hwayoung Kim, K-water

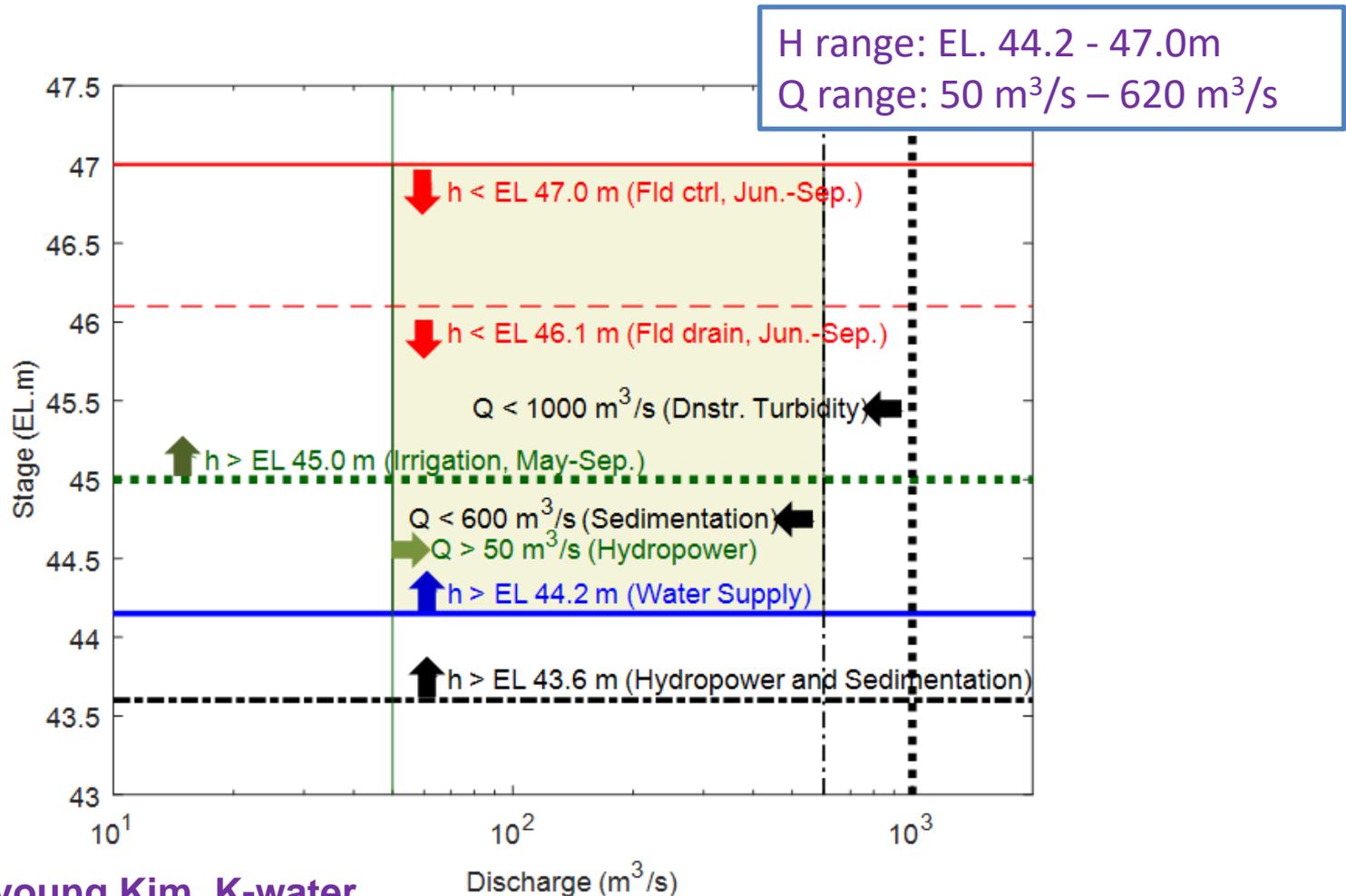


Other Issues besides sedimentation

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



Stage and Discharge Constraints



from Hwayoung Kim, K-water



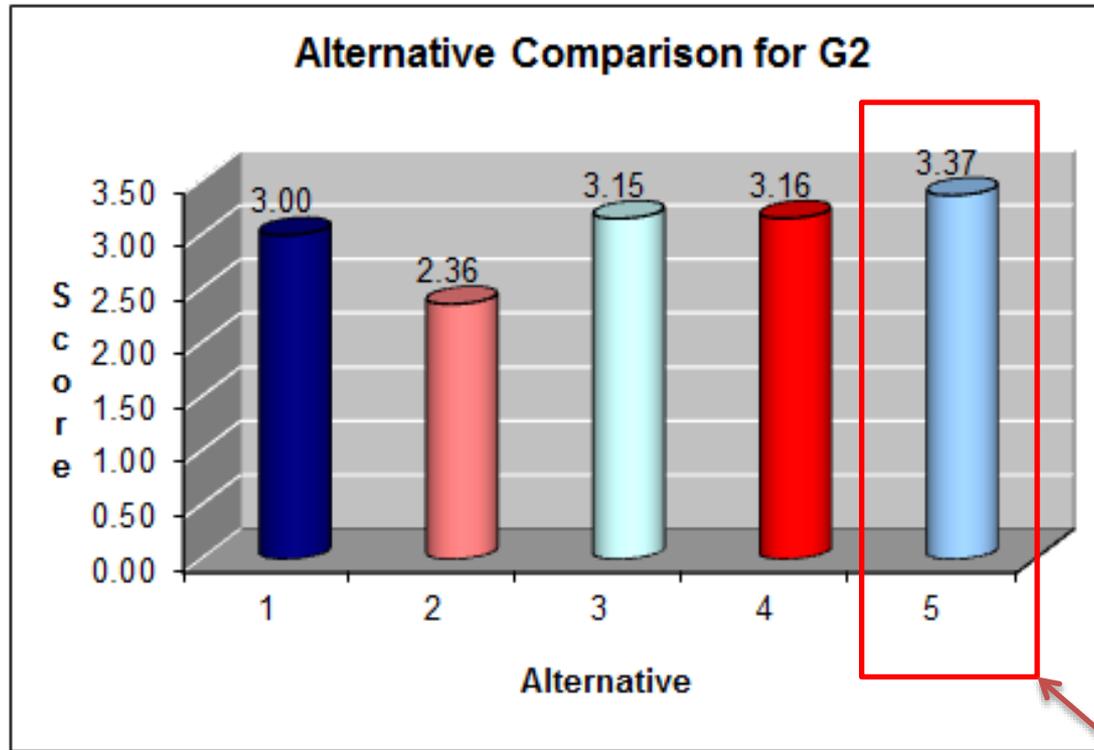
MCDA Rating (WAM)

Main Criteria (5)

Rating

Sangju Weir in South Korea

Resource Criteria	Relative Importance	Normalized Weights	Attribute Normalized Weights	ALTERNATIVES				
				1	2	3	4	5



372	5	1.127	1.266
388	5	1.103	1.272
2.29	5	1.147	1.387
372	5	1.127	1.266
1.66	5.00	1.13	1.29
3.01	1	4.853	4.61
5	5	2.539	5
2.68	1	4.815	4.488
3.12	1.67	4.44	4.59
0.774	1	4.802	4.475
1	1	5	5
1.35	1.00	4.96	4.90
226	5	1.789	2.72
363	5	1.401	2.002
4	5	2	3
3.40	5.00	1.80	2.68
5	5	5	5
714	1	4.429	4.619

Overall score and Ranking

from Hwayoung Kim, K-water

0.000					
0.000					
0.000					
1	5.00	3.86	3.00	4.71	4.81
Overall	3.000	2.362	3.154	3.156	3.369
Rank	4	5	3	2	1

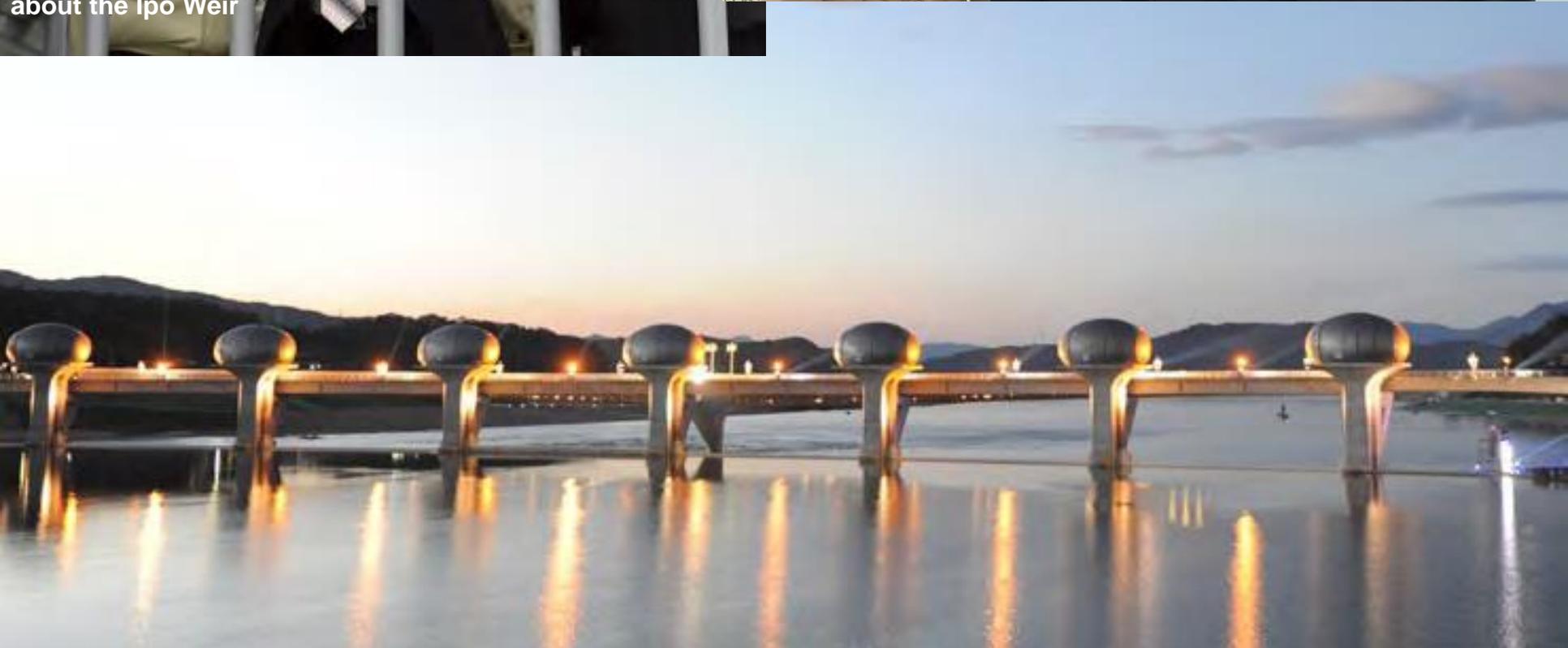
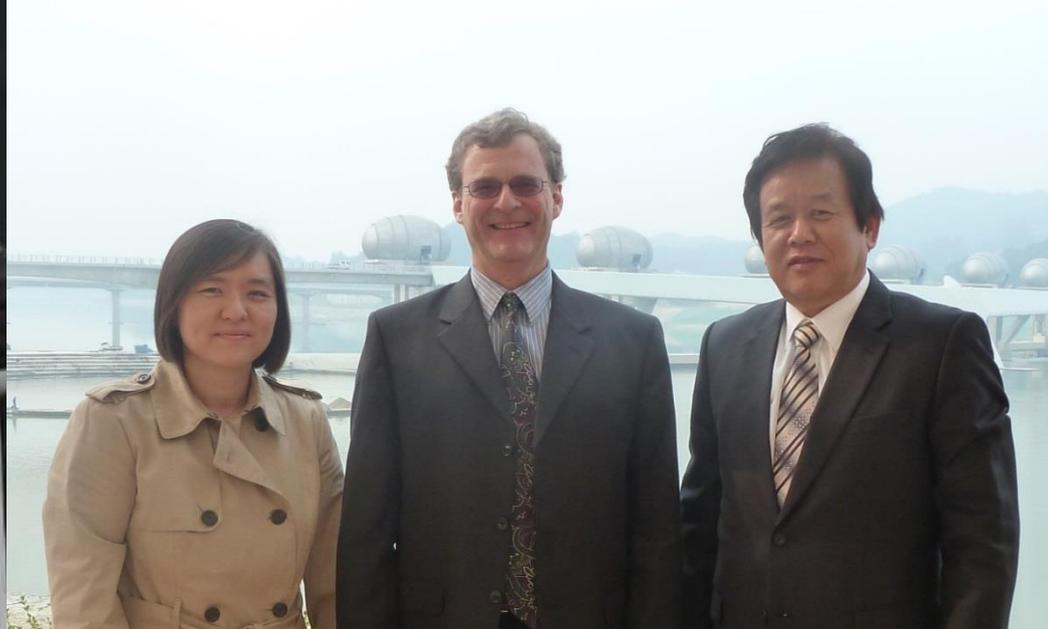


IPO (Han River)





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



River Environment

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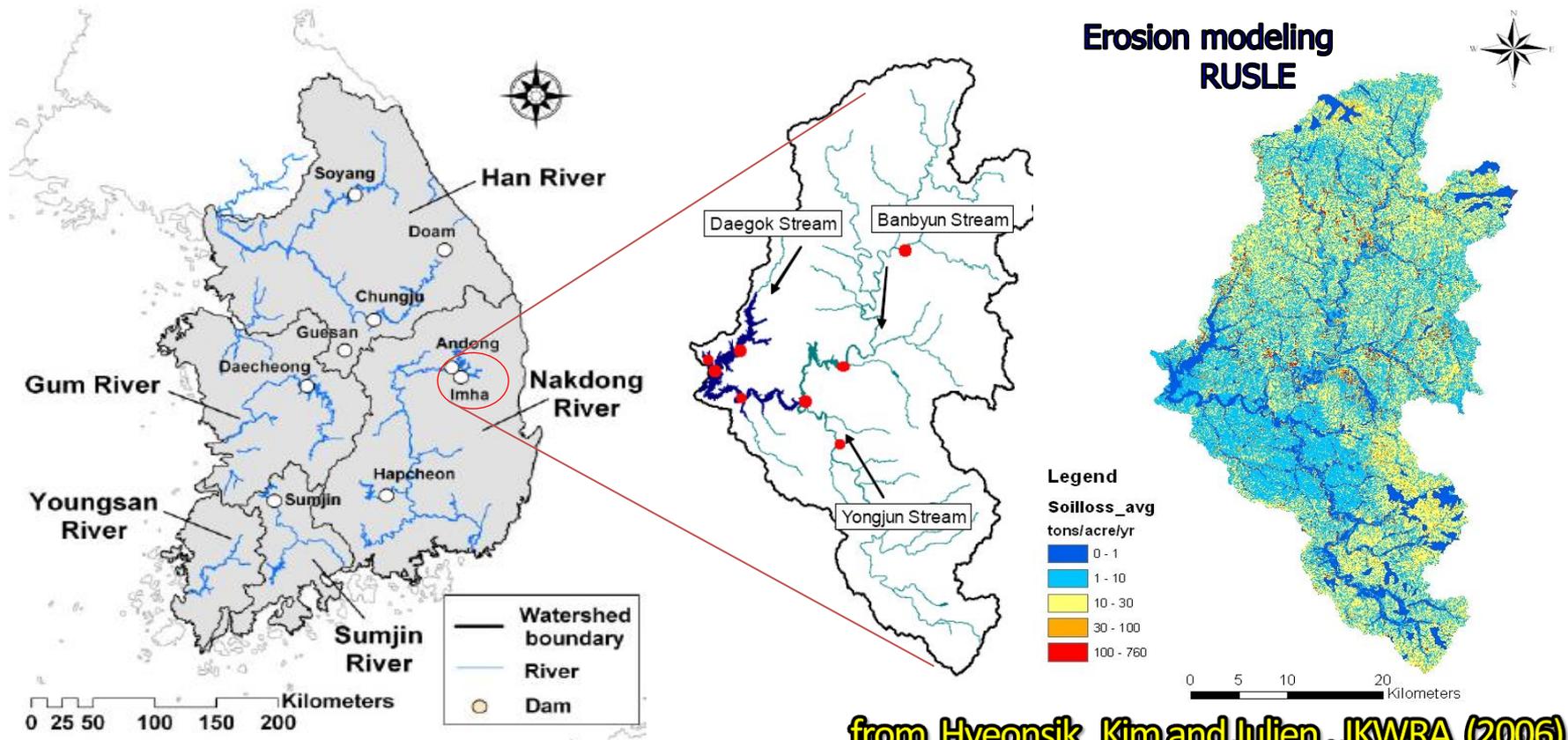
Density Currents and Turbidity Imha Dam, South Korea



Example

Imha Reservoir has suffered from turbidity problems since 2002.

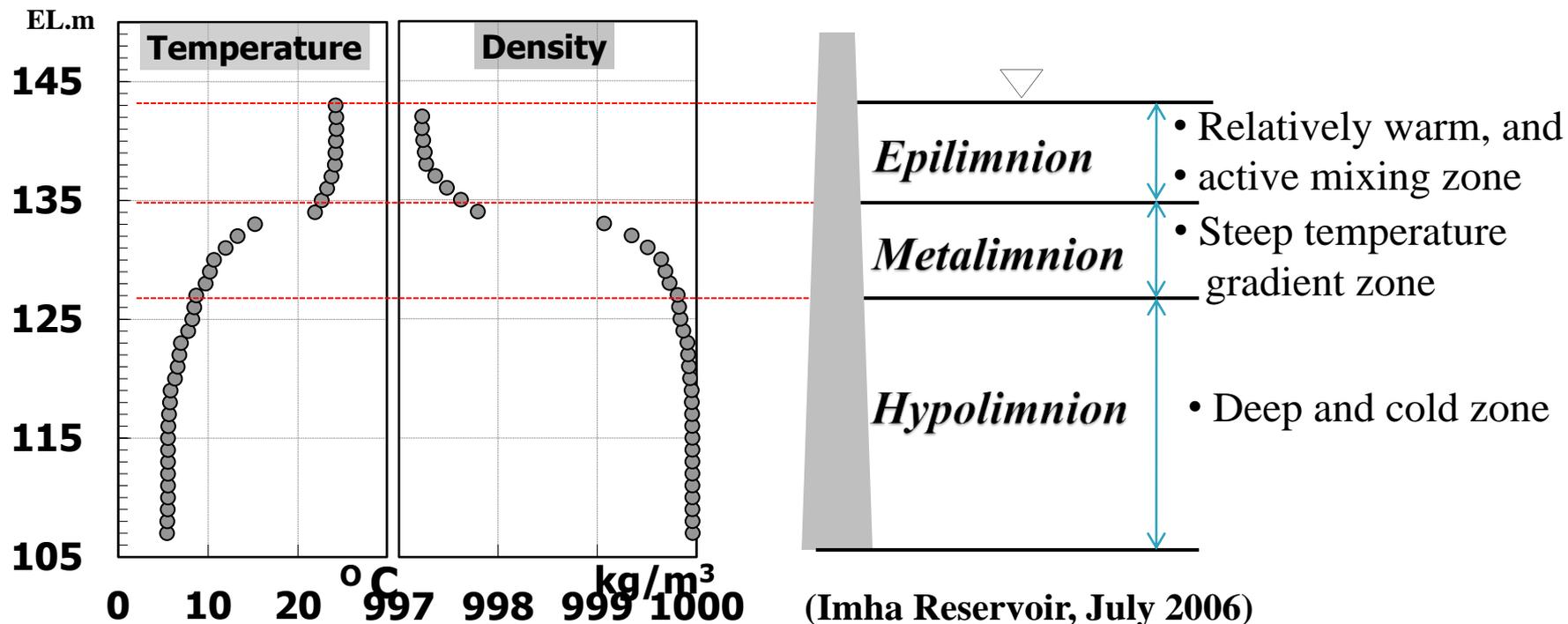
- Watershed area covers 1,361 km²
- Three major tributaries



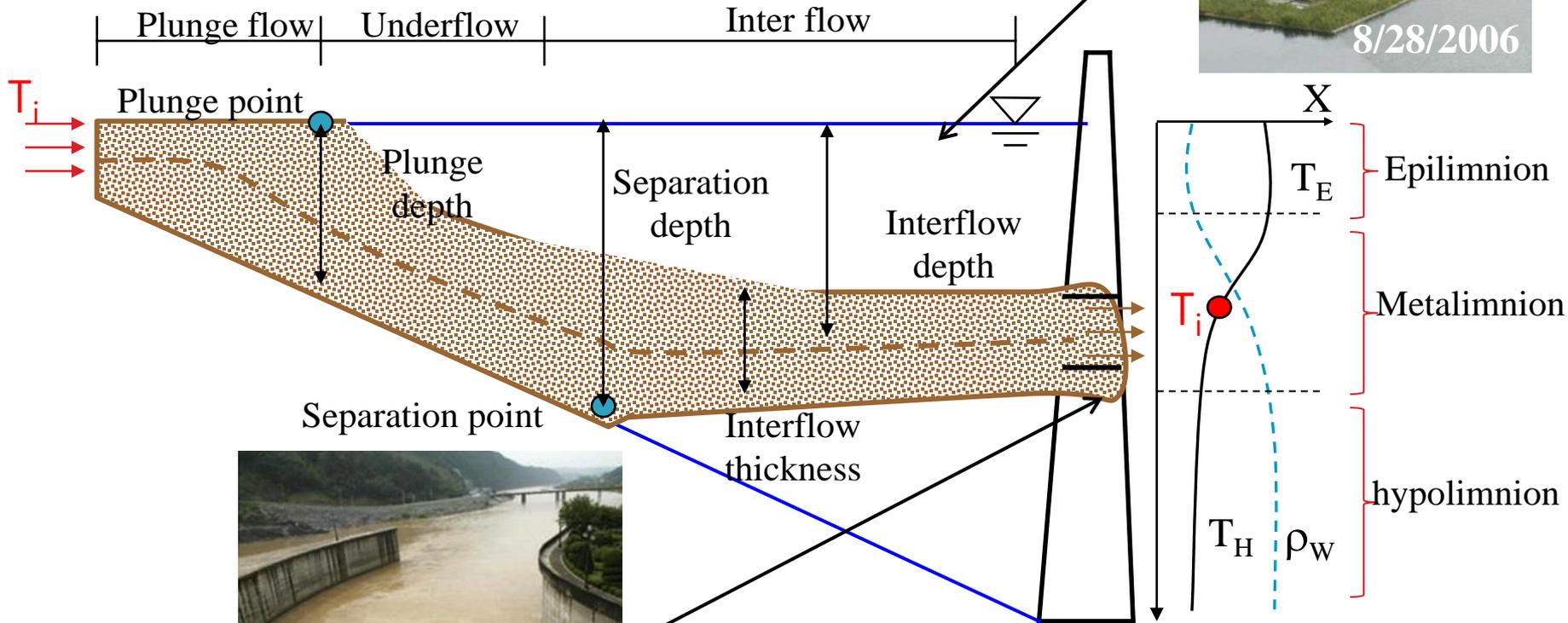
from Hyeonsik Kim and Julien, JKWRA (2006)

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



A general type of turbid density currents during summer

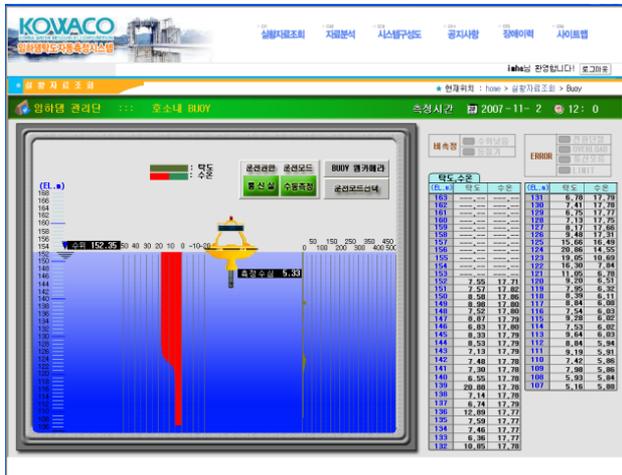


from Sangdo An (2011)

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

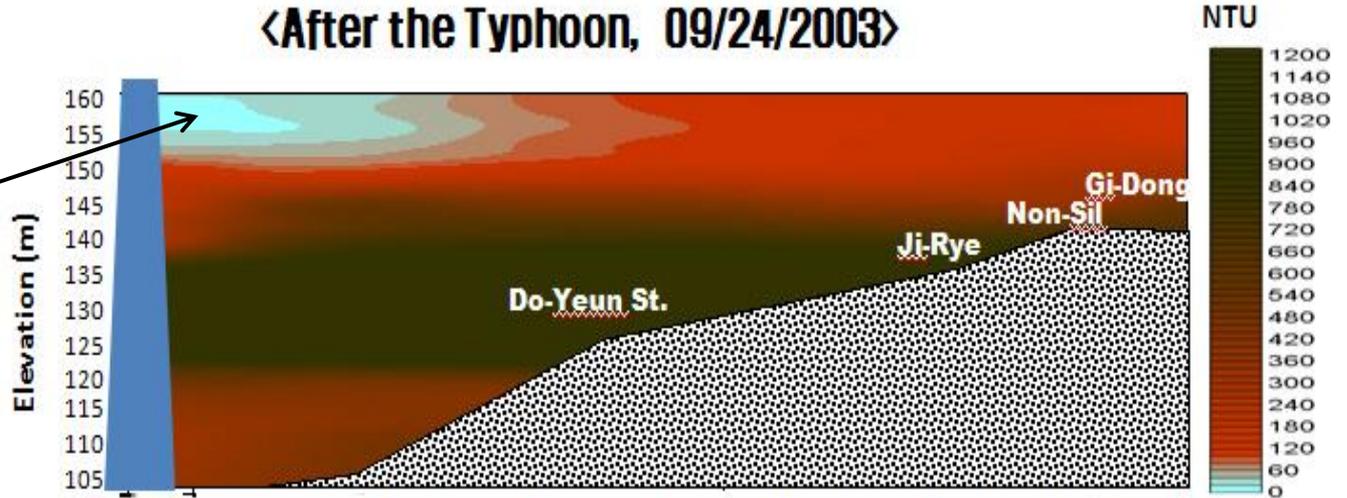


Real-time monitoring system for Imha Reservoir; installed and has been operating by K-water since 2006

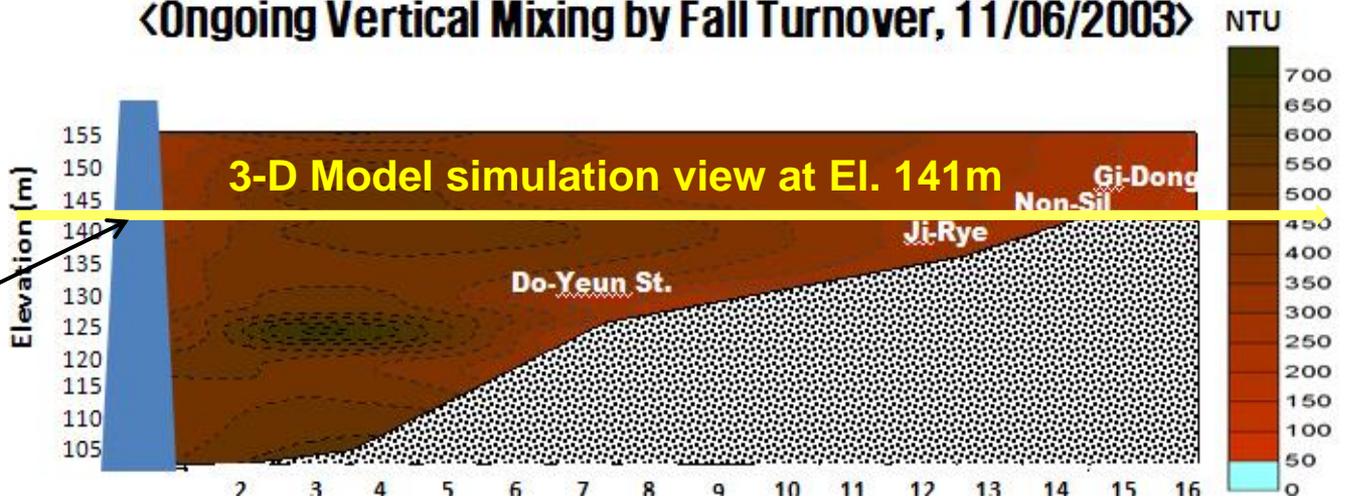
from K-water and Sangdo An (2011)

Turbidity Measurements

<After the Typhoon, 09/24/2003>



<Ongoing Vertical Mixing by Fall Turnover, 11/06/2003>



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) :

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

: i = 1, 2, 3

• Scalar transport equation :

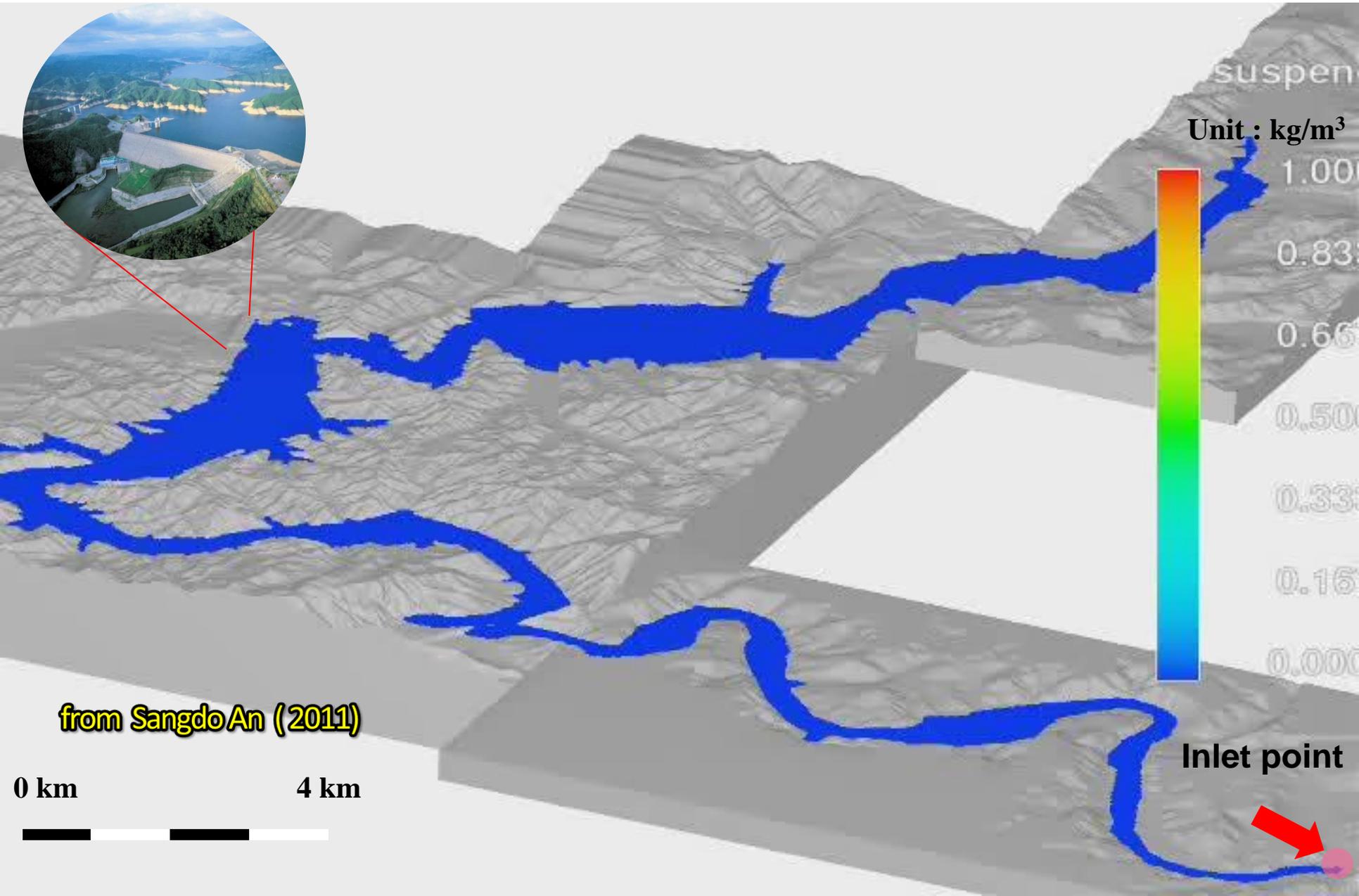
$$\frac{\partial \Phi}{\partial t} + \sum_{j=1}^3 \frac{\partial}{\partial x_j} (U_j \Phi) = \sum_{j=1}^3 \frac{\partial}{\partial x_j} \left(\Gamma \frac{\partial \Phi}{\partial x_j} - \overline{u_j \Phi} \right)$$

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

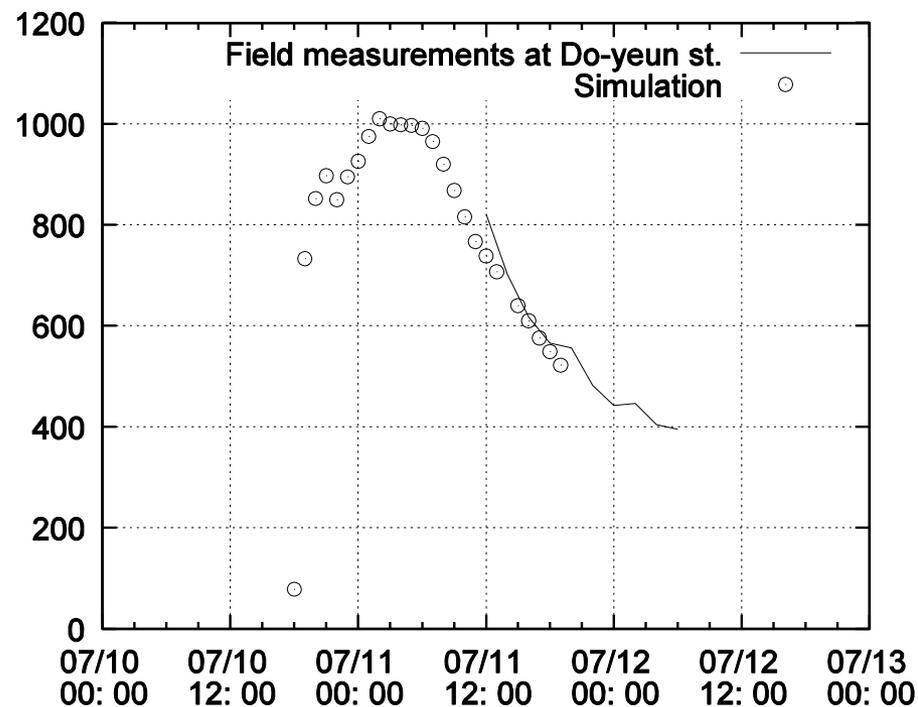
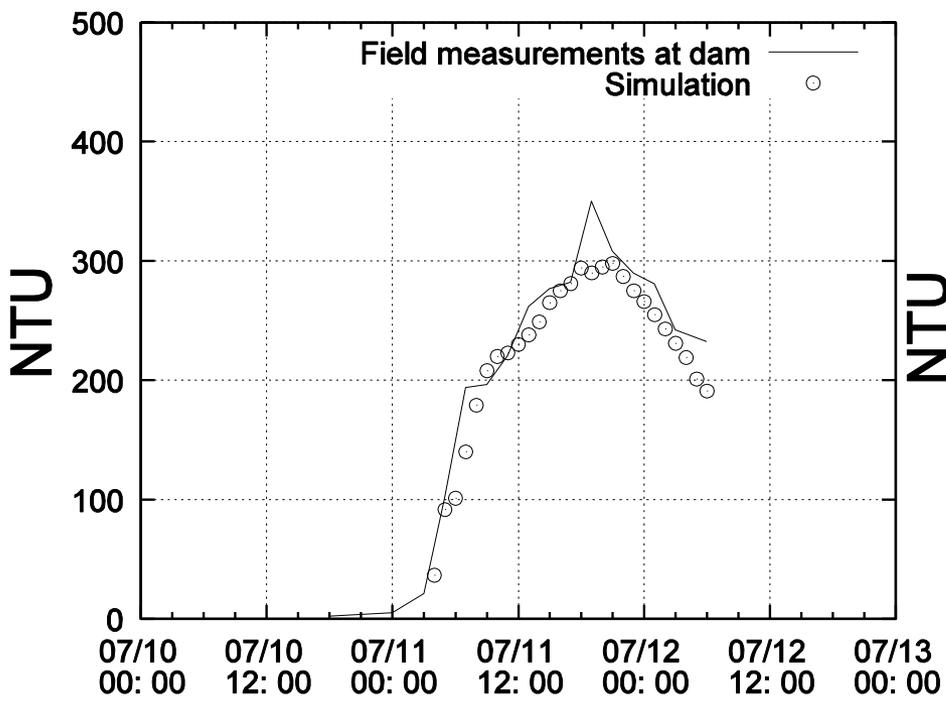
$\Gamma_t \frac{\partial \Phi}{\partial x_i}$

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,
 $\overline{\quad}$: (Overbar) averaging of fluctuating quantities.

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



Comparison with time series measurements



from Sangdo An (2011)

July 11, 04:00

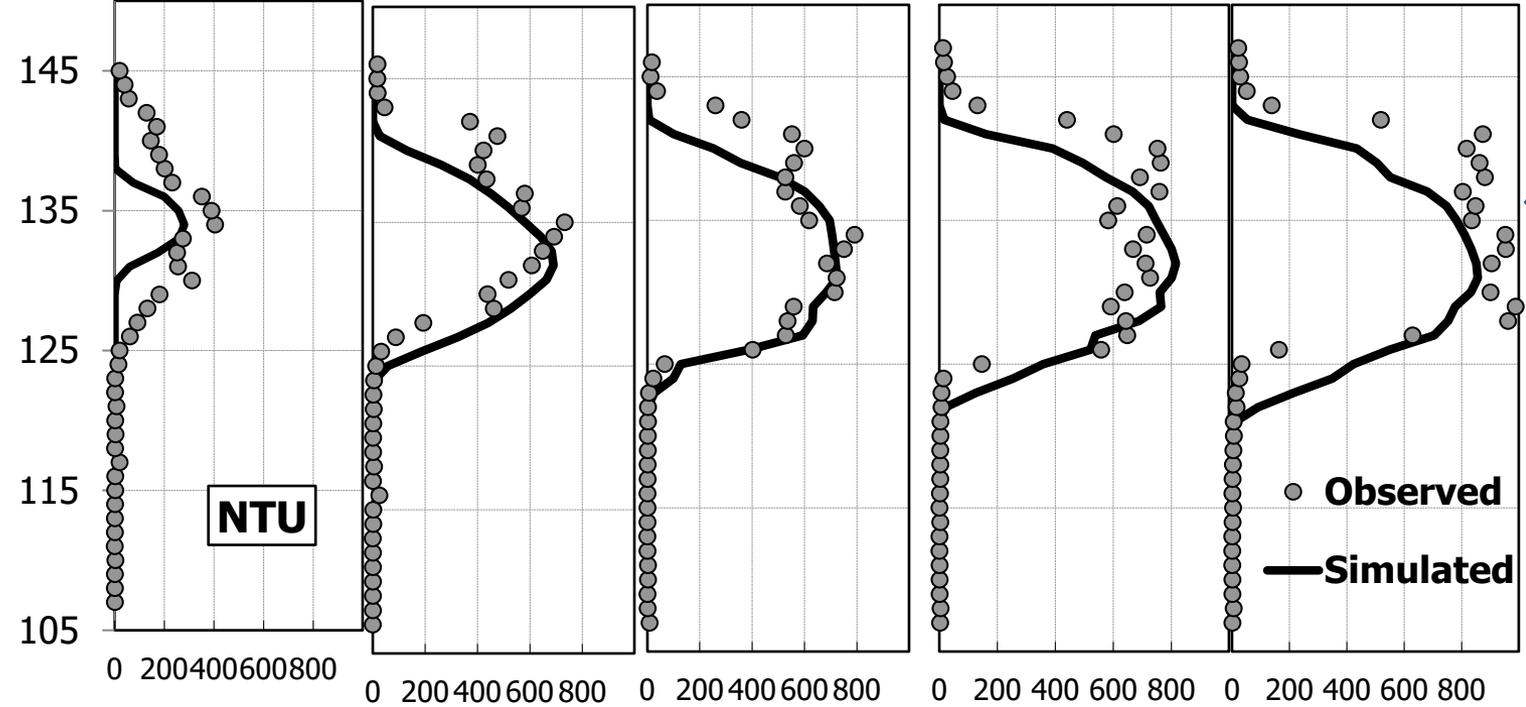
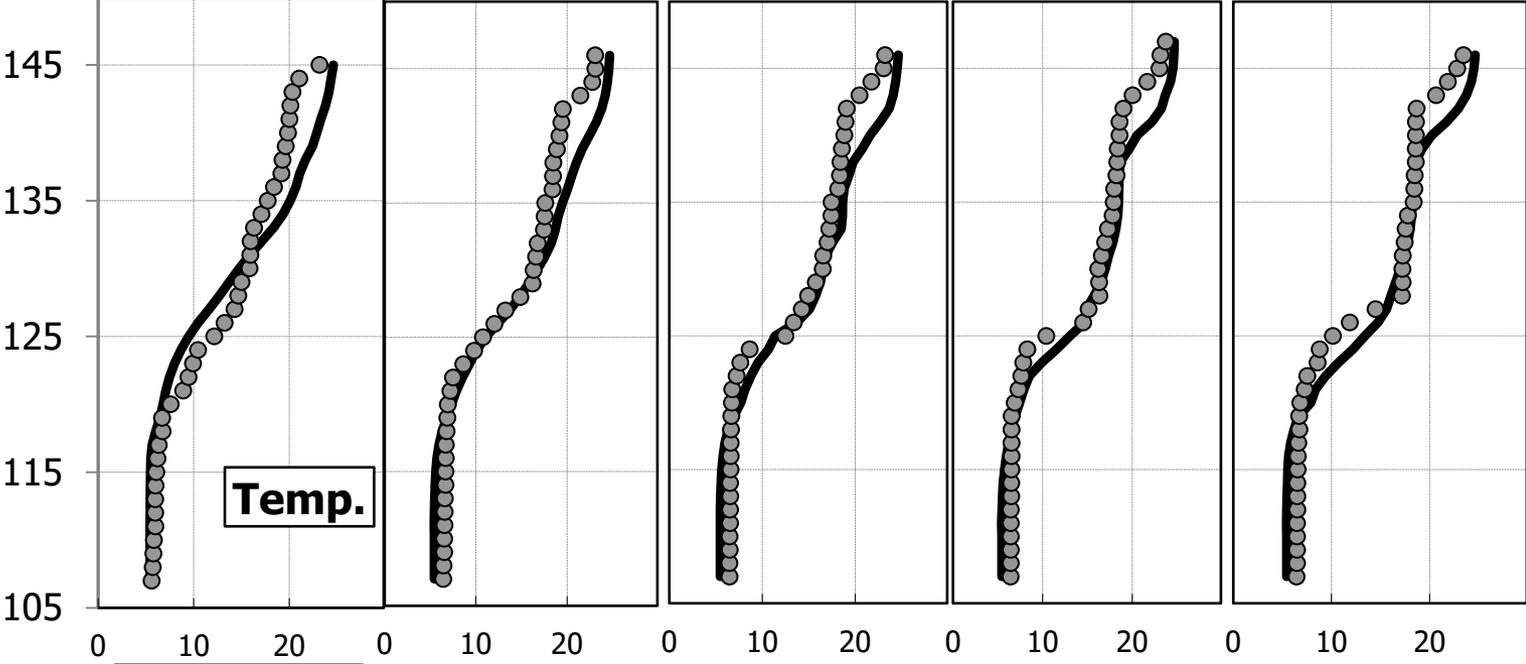
July 11, 08:00

July 11, 12:00

July 11, 16:00

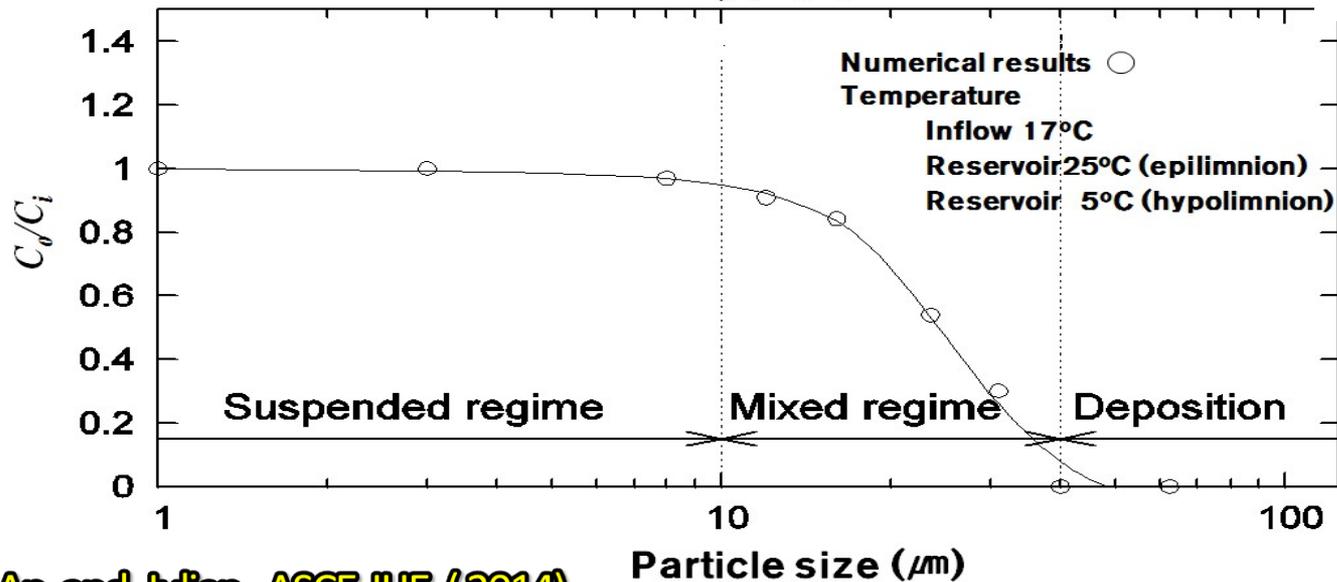
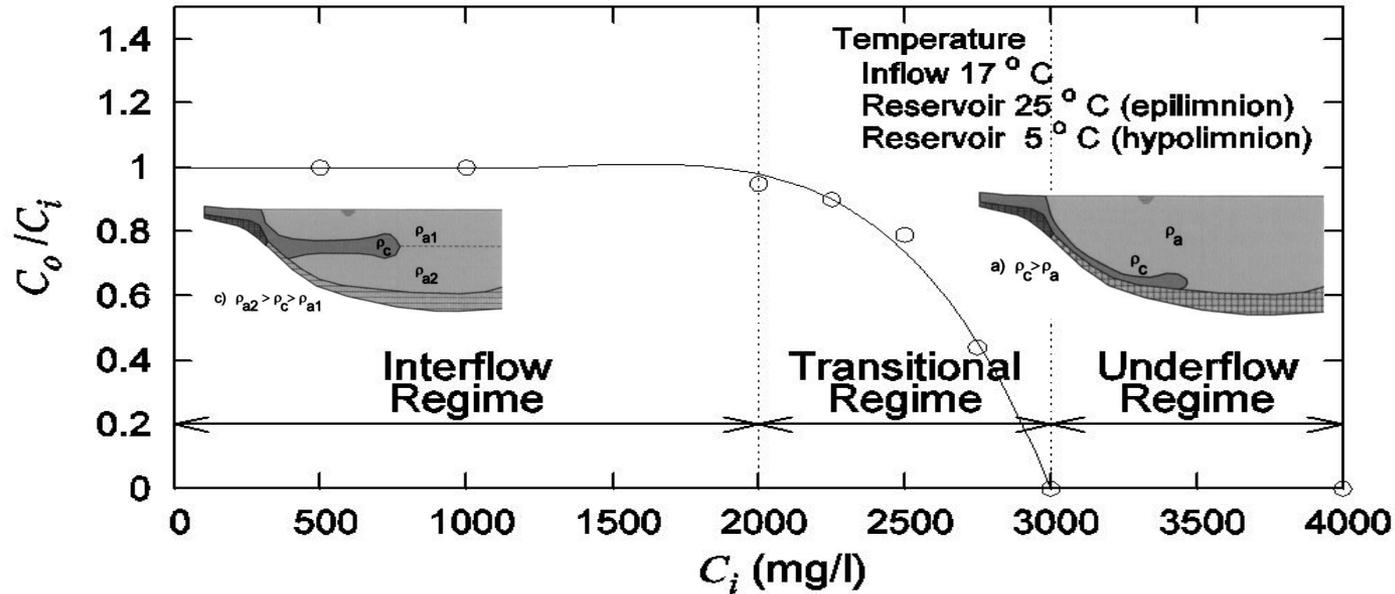
July 11, 18:00

at near dam



**An and Julien,
ASCE-JHE (2014)**

NEW Results on Density Currents!



River Environment

1. Upland Contamination
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4. **Aquatic Habitat**





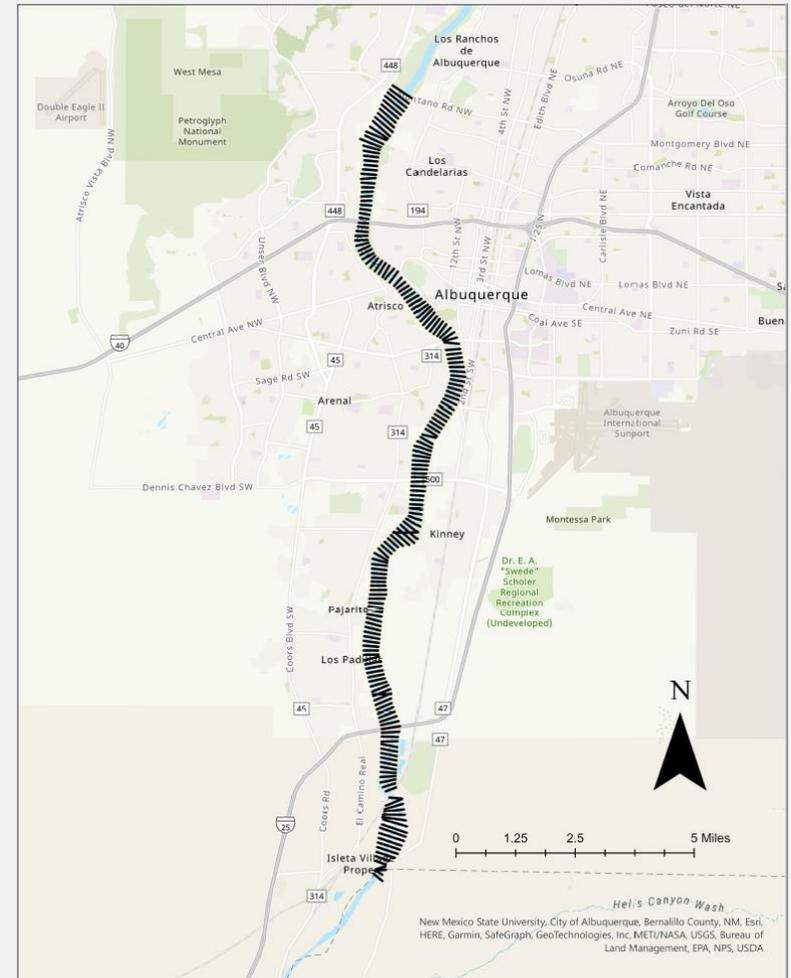
Cochiti Dam

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



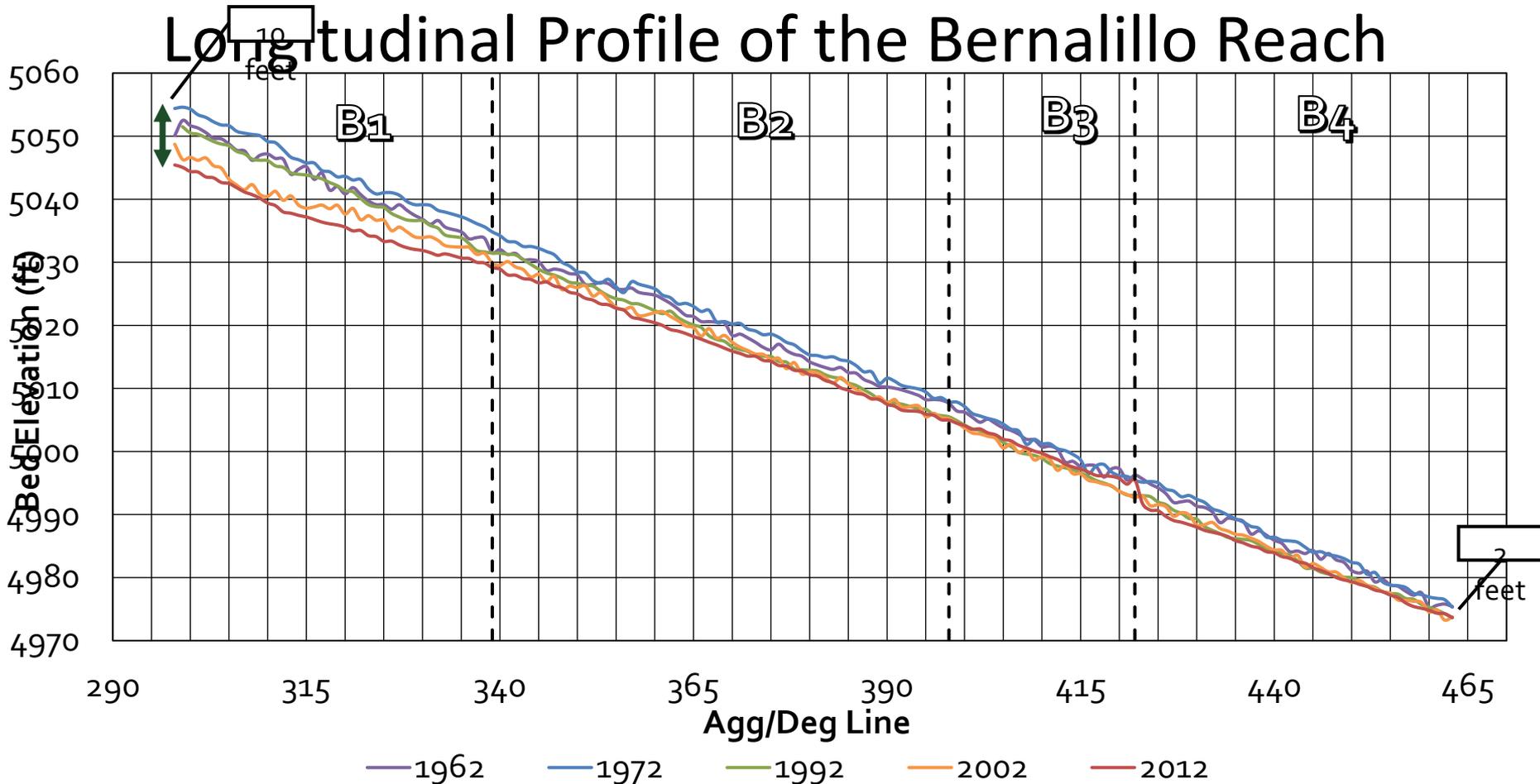
Methodology

- 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)

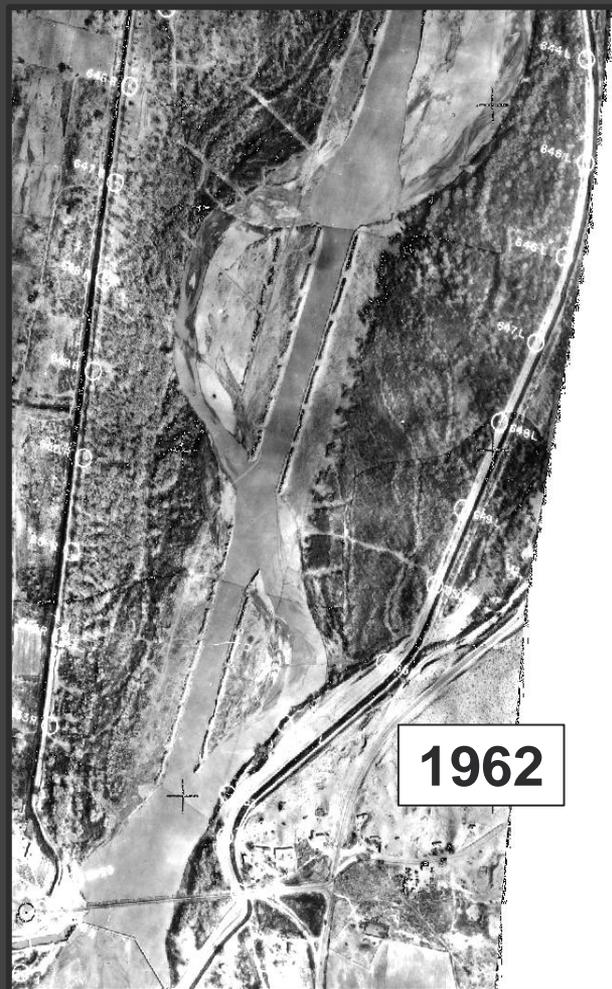


from T. Anderson, B. Corsi, C. Radobenko

Longitudinal Profile of the Bernalillo Reach

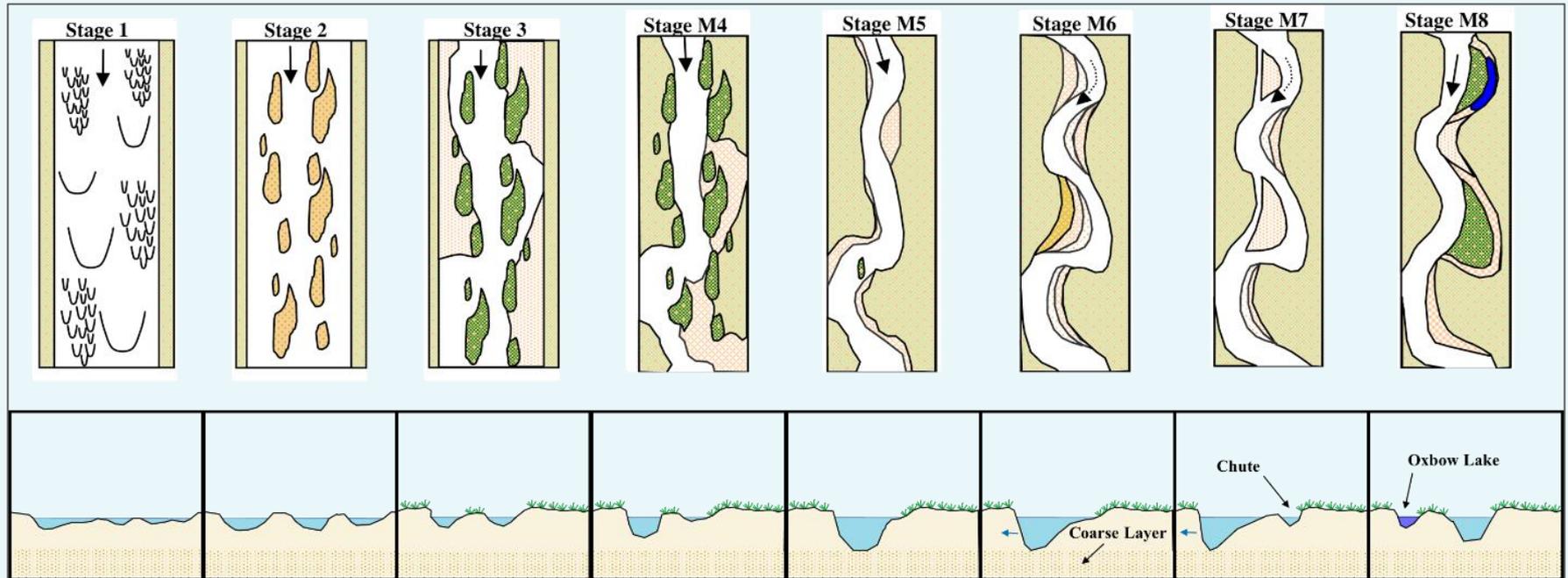


from T. Anderson, B. Corsi, C. Radobenko



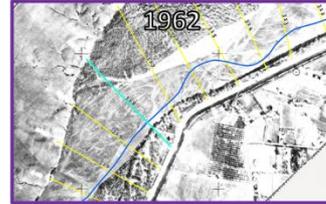
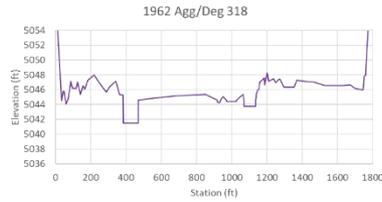
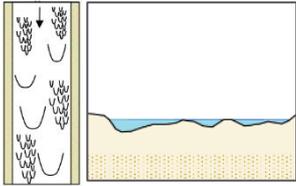
from T. Anderson, B. Corsi, C. Radobenko

Massong Conceptual Planform Model

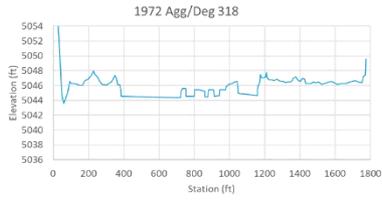
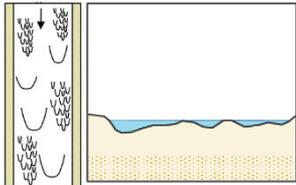


from T. Anderson, B. Corsi, C. Radobenko

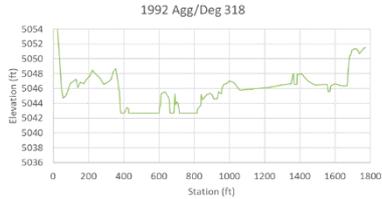
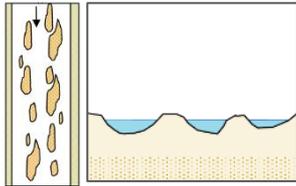
Stage 1



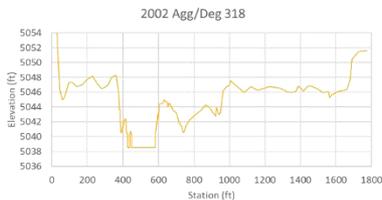
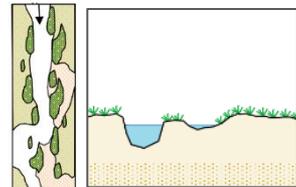
Stage 1



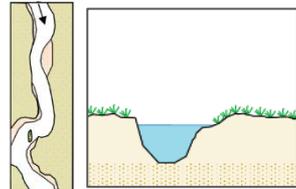
Stage 2



Stage M4



Stage M5



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

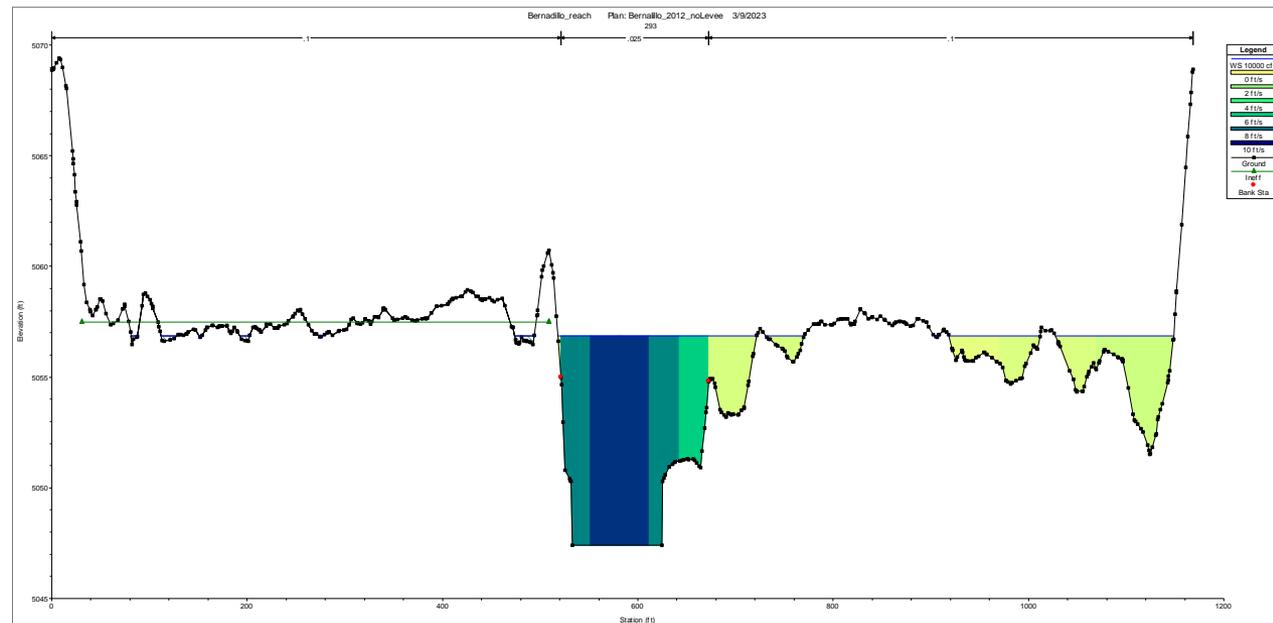
Subreach B1

Planform Classification

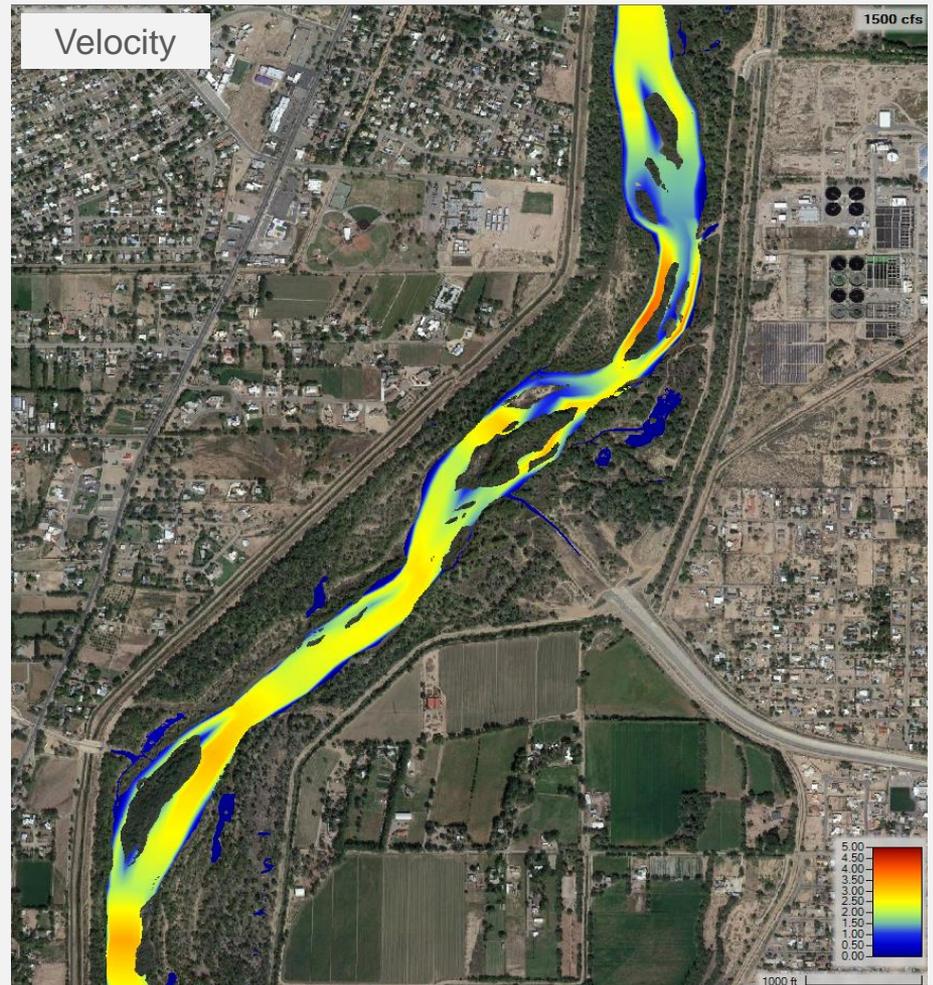
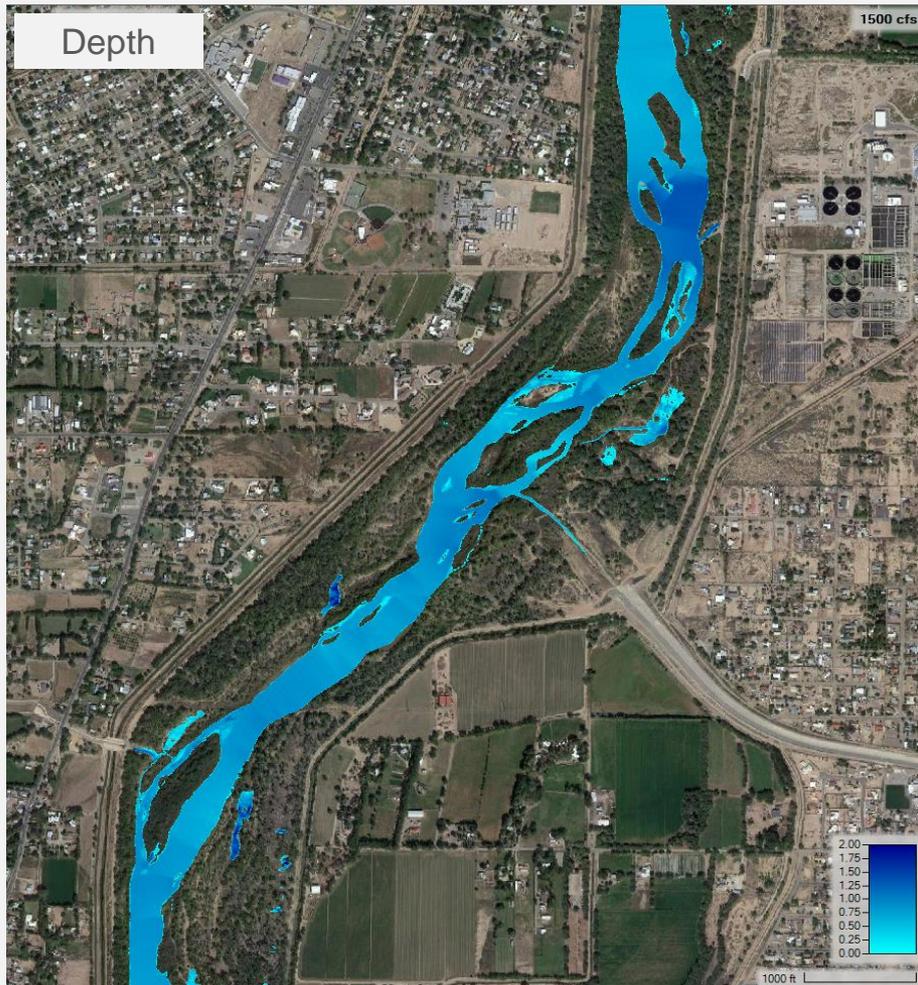


1D Model Methods

- 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



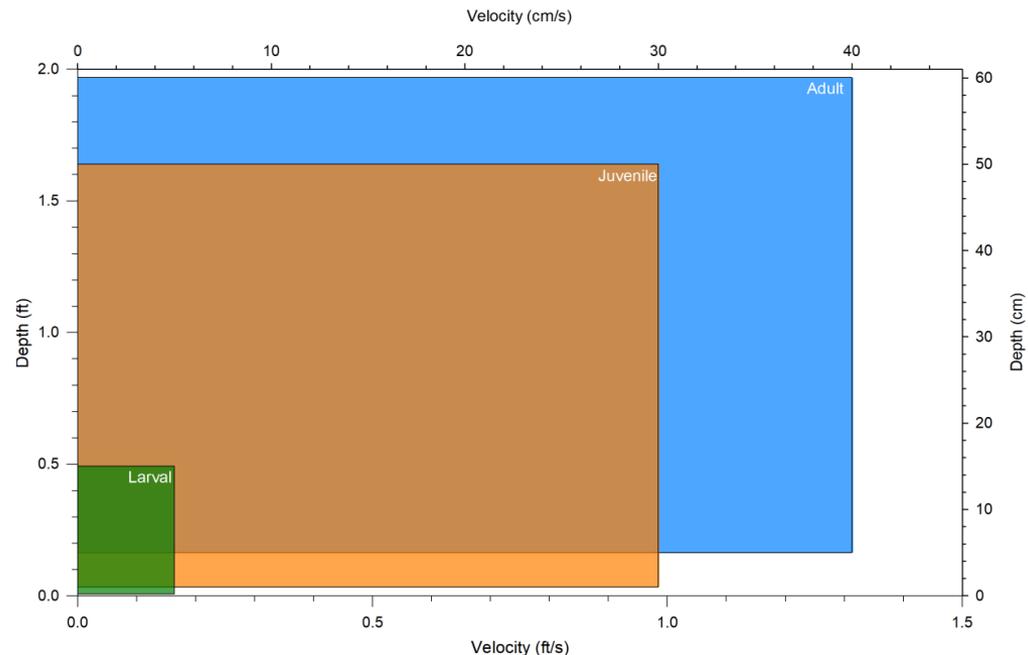
from T. Anderson, B. Corsi, C. Radobenko

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



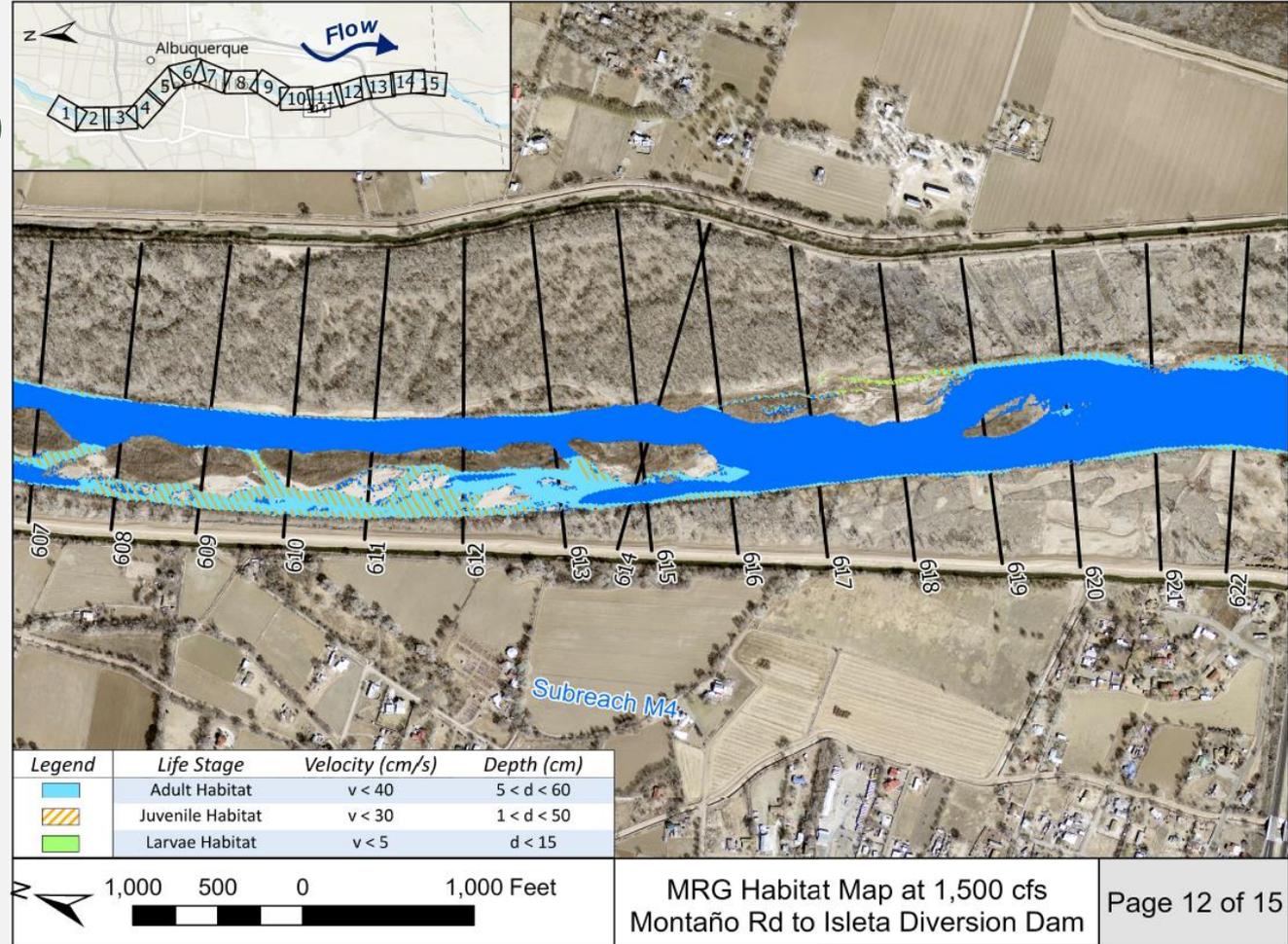
(Rio Grande silvery minnow. (2023, February 20). In *Wikipedia*)



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

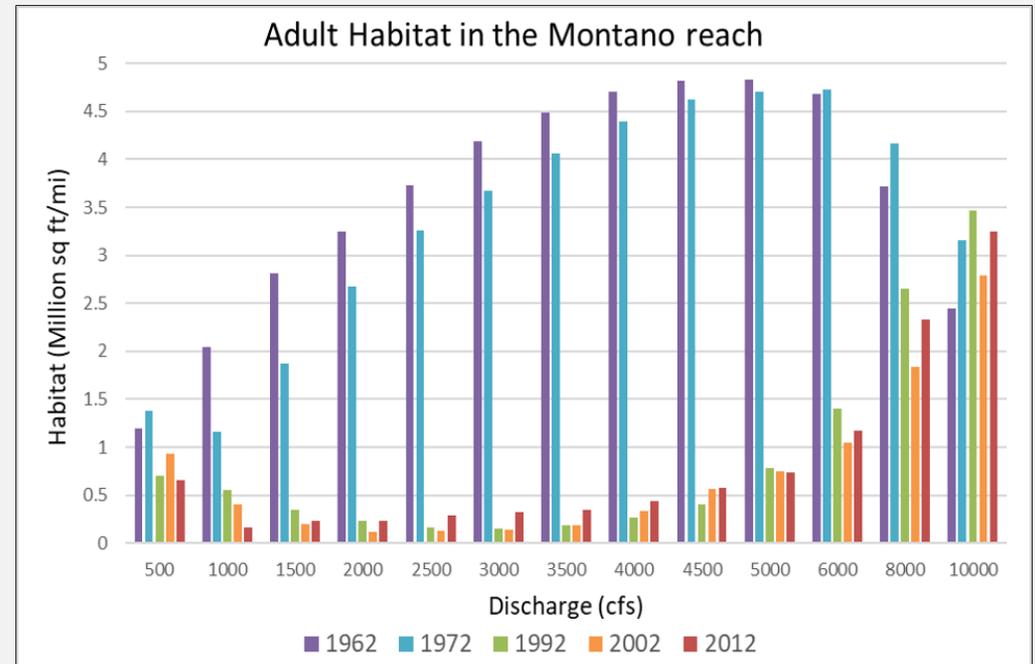


MRG Habitat Map at 1,500 cfs
Montañero Rd to Isleta Diversion Dam

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



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

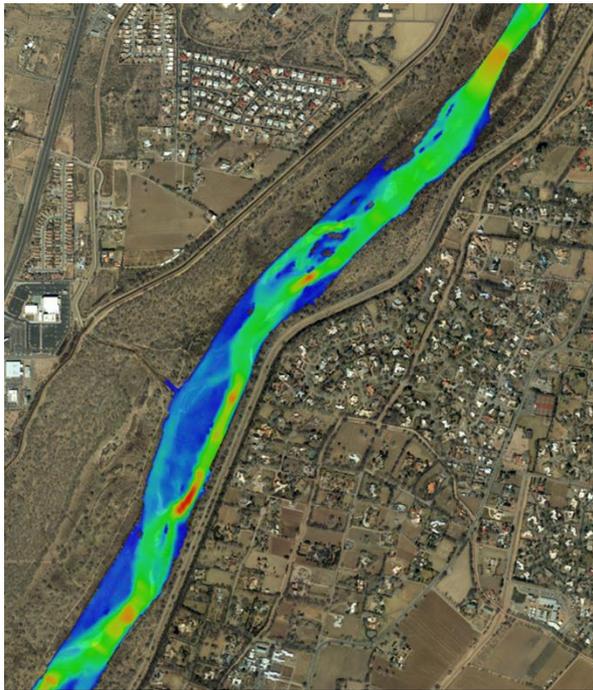
2D Model Comparison Study



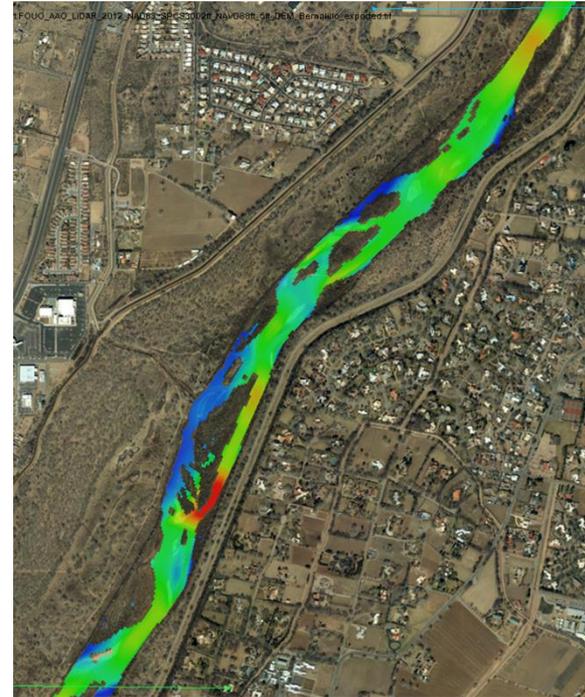
2D hydraulics vs
“pseudo” 2D
hydraulics created
from 1D HEC-RAS and
RasMapper

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

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



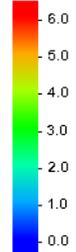
SRH-2D

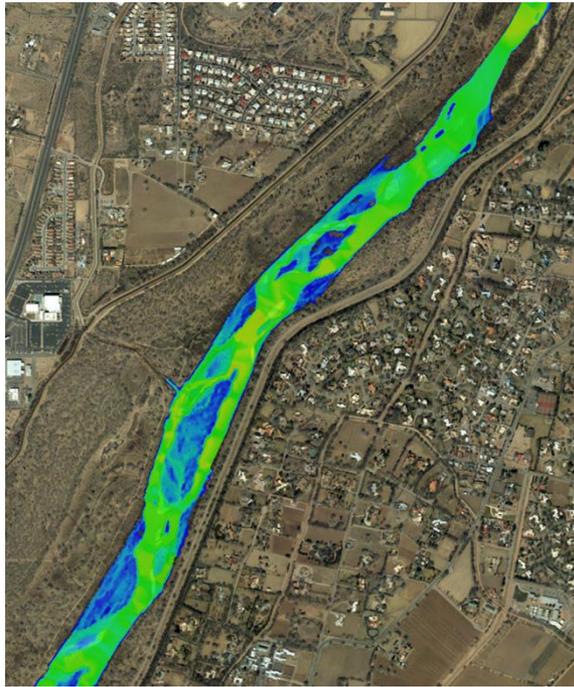


1D HEC-RAS "pseudo" 2D

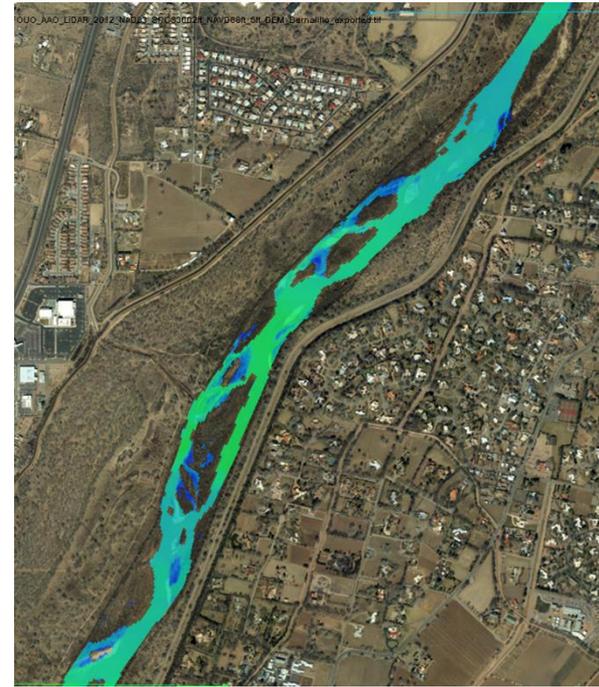
3,000 cfs Velocity Results

Mesh Module Vel_Mag_ft_p_s 0 10:00:00



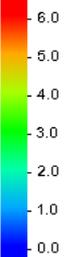


SRH-2D



1D HEC-RAS "pseudo" 2D

Mesh Module Water_Depth_ft 0 10:00:00



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

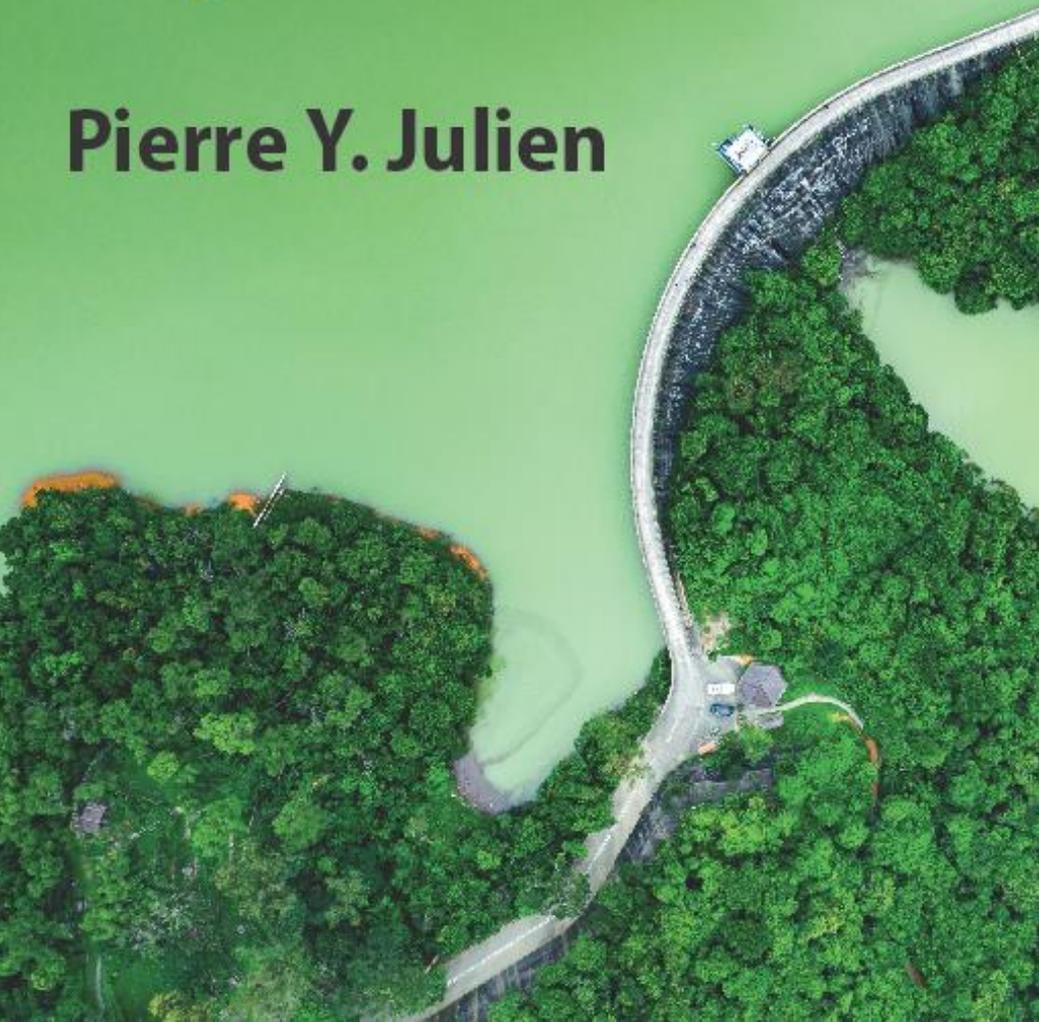
4. Aquatic Habitat

New models define mapping of suitable aquatic habitat



Essentials of Hydraulics

Pierre Y. Julien



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Dr. Drew Baird, USBR
Nathan Holste, USBR
Nate Bradley, USBR
Apologies if I forgot anyone ...



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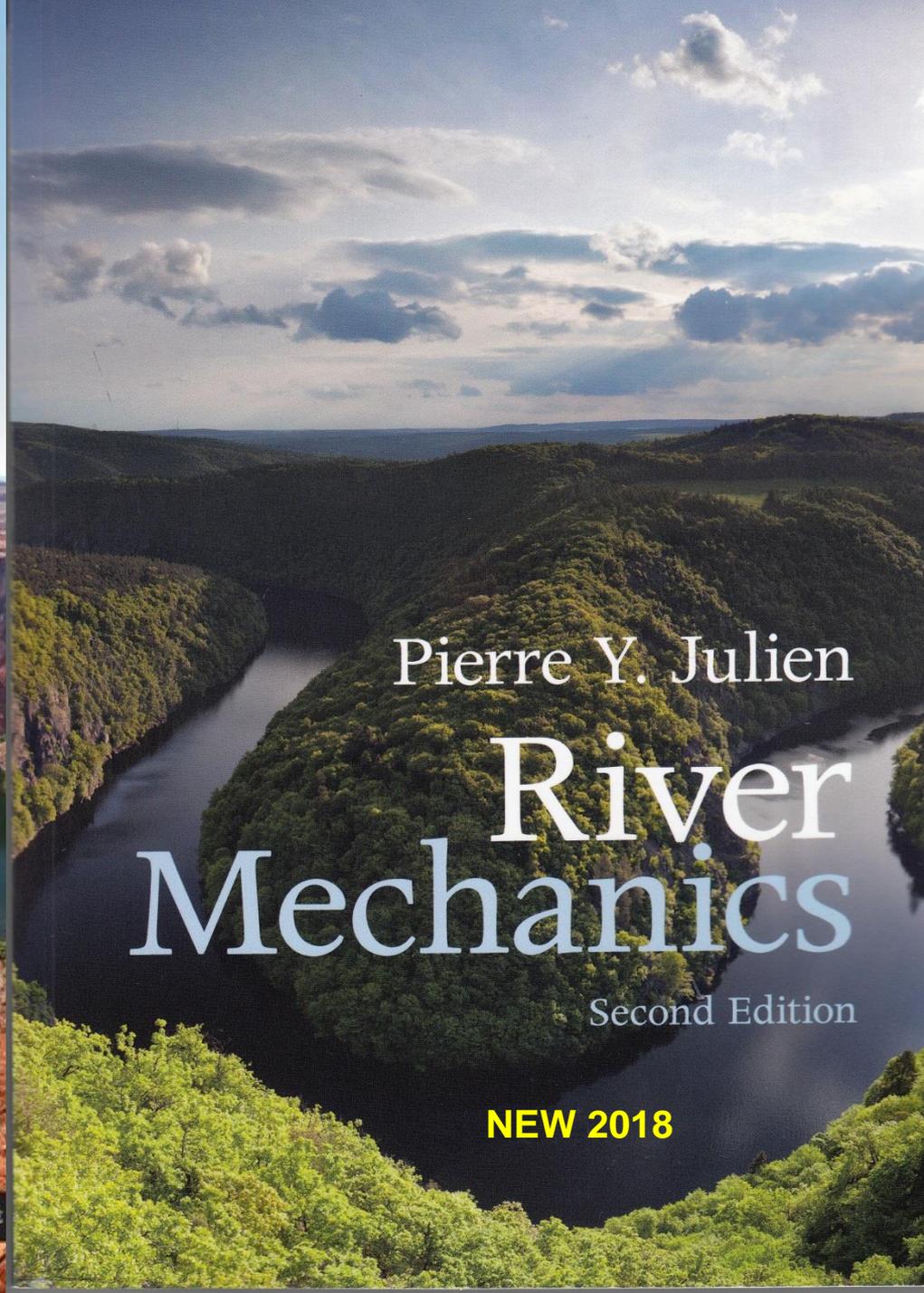
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