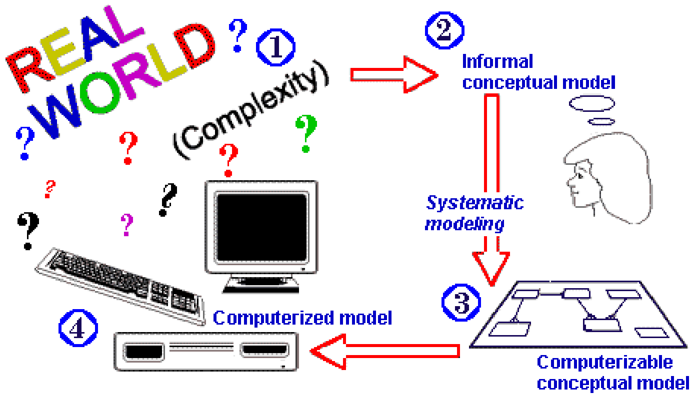
Chapter 9

Numerical Models for River Mixing



Chapter 9 Numerical Models for River Mixing

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8.4 River Modeling

Objectives

- Introduce concept of river modeling
- Study fundamentals of river hydraulics
- Introduce rivers models and case studies of river modeling

Introduction

Open channel hydraulics (Fixed-bed)

- Analysis of free surface flows

River study

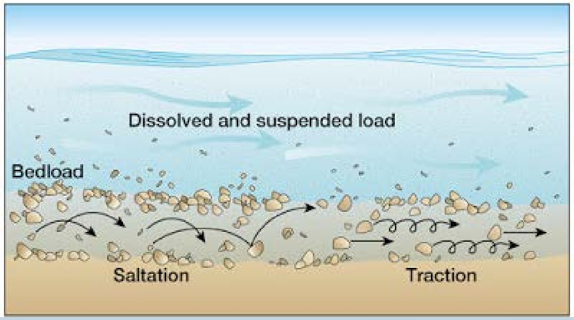
Artificial channel

Lab experiment in fixed-bed

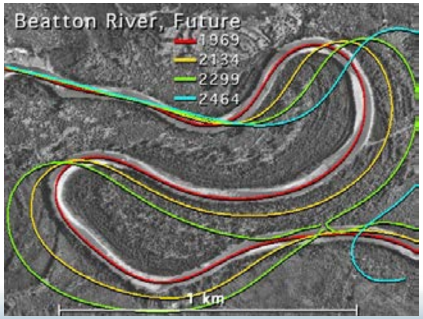
Fluvial hydraulics (Movable-bed, Sediment transport + Geomorphology)

- Flow analysis in a river and sediment transport

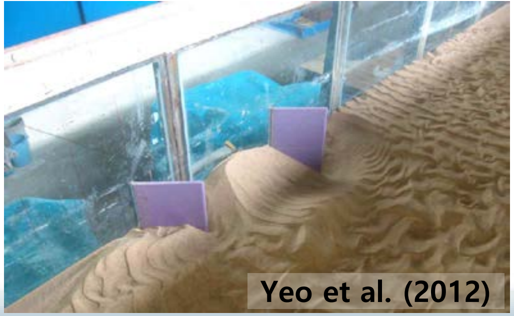
Sediment transport



River bed change



Lab experiment in moving-bed



Yeo et al. (2012)

1. Introduction

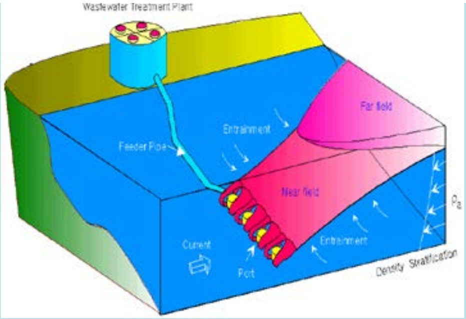
River Hydraulics

Environmental hydraulics

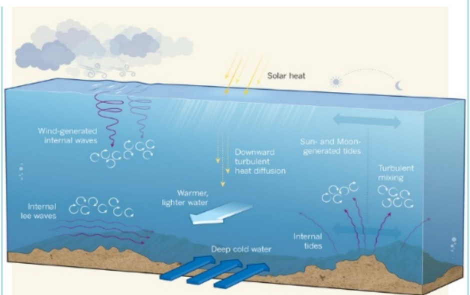
- Study of flow dynamics in the water body to handle environmental problems by human activities

Contaminant mixing

Thermal diffuser



Stratified flow



Source: Mackinnon (2013)

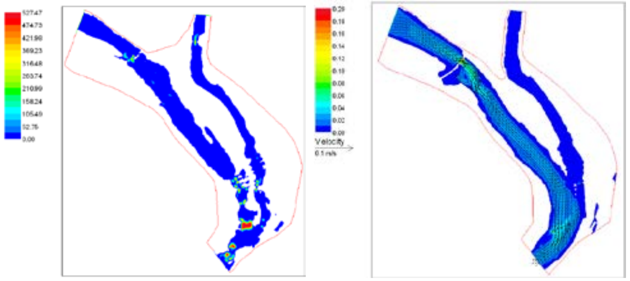
Ecological hydraulics

- Combined study of hydraulics and biological dynamics to understand the ecosystem

River restoration

Fish way

Evaluation of fish habitat



River Modeling

Definition

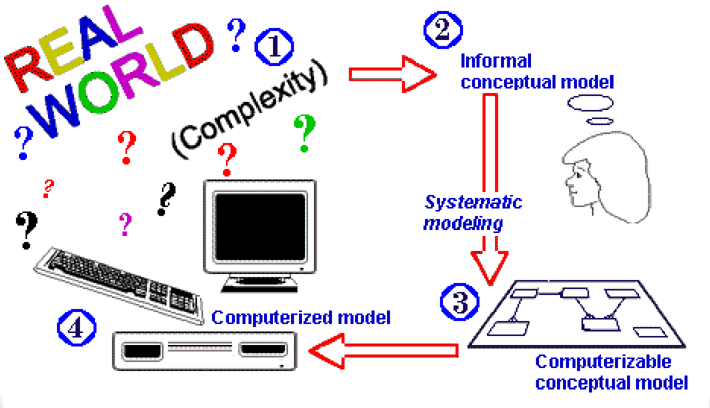
- Describe the real system of river dynamics using physical or mathematical approach

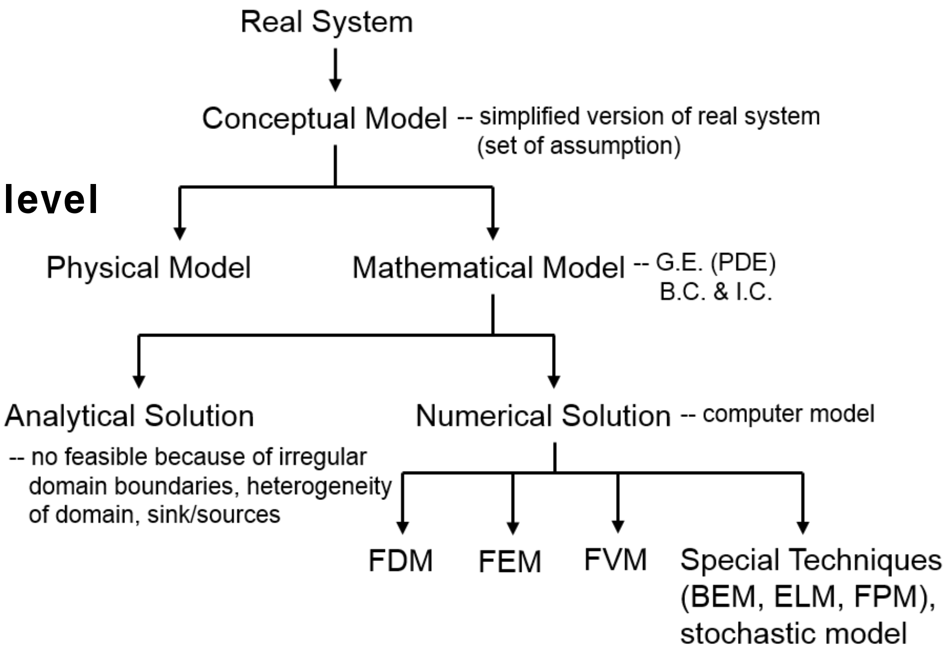
Purpose

- Understanding and prediction of river dynamics

Limitation

- Accuracy depending on simplification level





Real System

Conceptual Model -- simplified version of real system (set of assumption)

Physical Model

Mathematical Model -- G.E. (PDE) B.C. & I.C.

Analytical Solution -- no feasible because of irregular domain boundaries, heterogeneity of domain, sink/sources

Numerical Solution -- computer model

FDM

FEM

FVM

Special Techniques (BEM, ELM, FPM), stochastic model

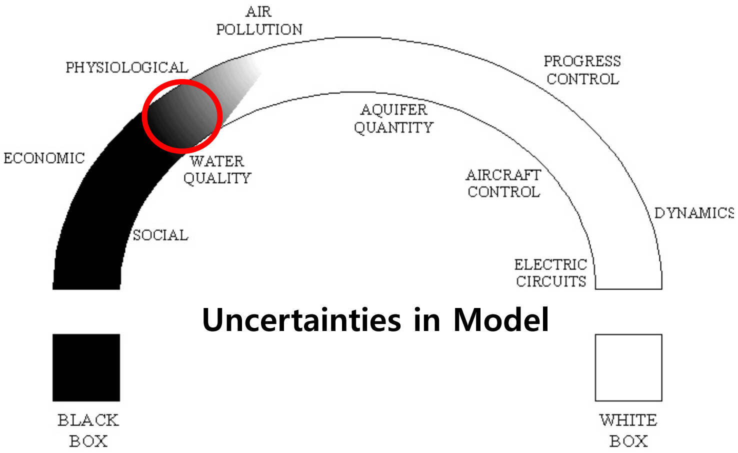
Modeling Process

Uncertainty

- Most models are intermediate forms between physical-based models and empirical models.

Parameter

- Model have its own parameters to represent their characteristics.



Uncertainties in Model

Calibration

- Comparison of model output with observations to tune the model parameters

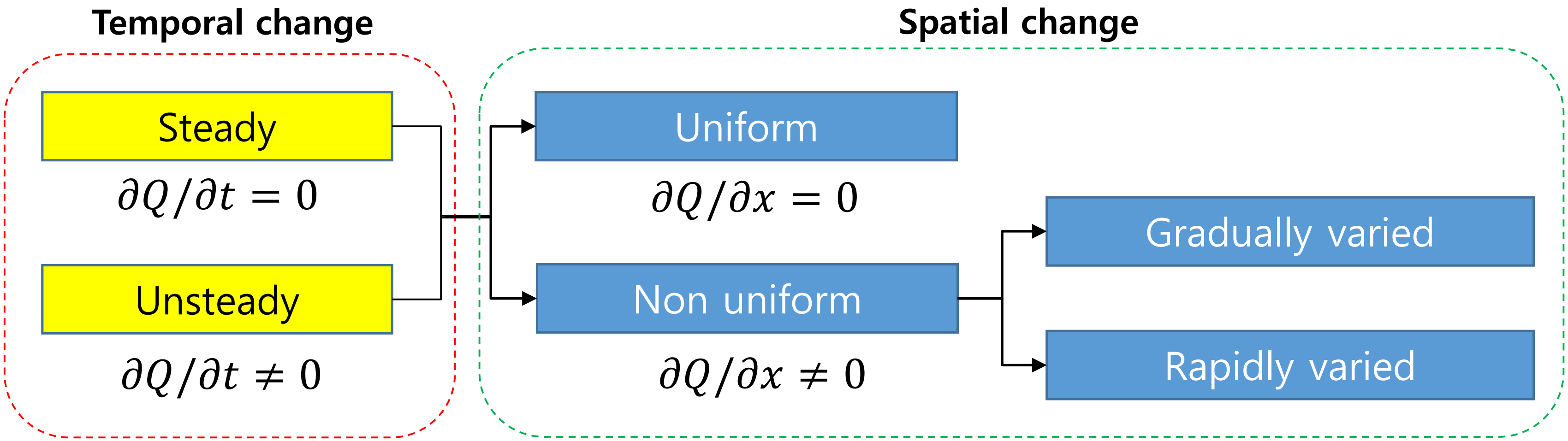
  → The calibrated models can be called empirical models

Validation

- Comparison of output from the calibrated models with observations to evaluate validity of the calibrated models.

Open Channel Hydraulics

Classification of open channel flow



Temporal change

Steady

$$\partial Q/\partial t = 0$$

Unsteady

$$\partial Q/\partial t \neq 0$$

Spatial change

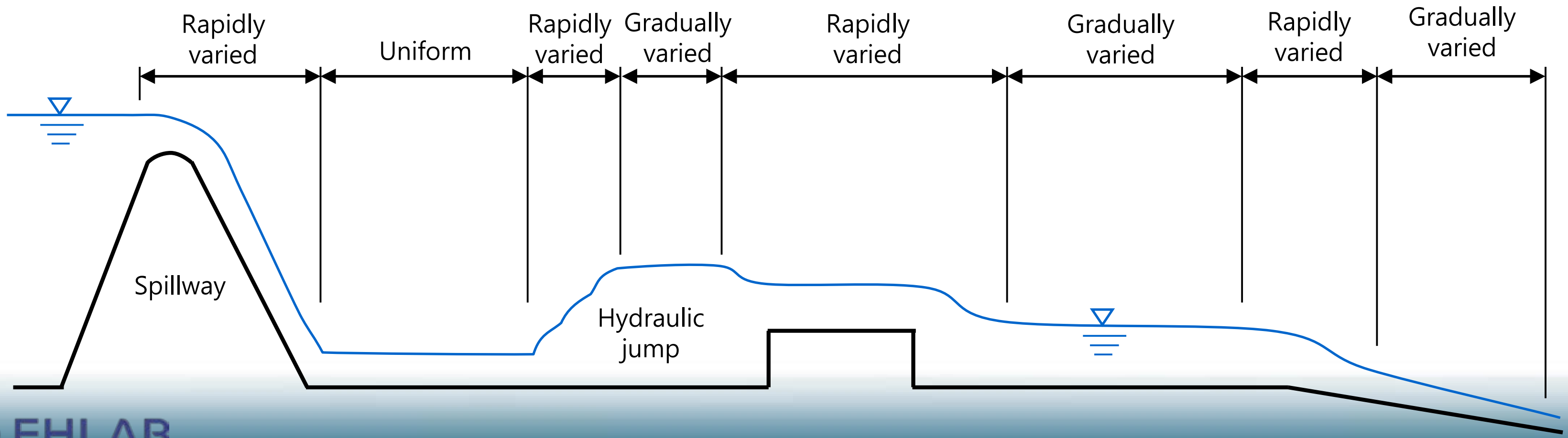
Uniform

$$\partial Q/\partial x = 0$$

Non uniform

$$\partial Q/\partial x \neq 0$$

- Gradually varied
- Rapidly varied

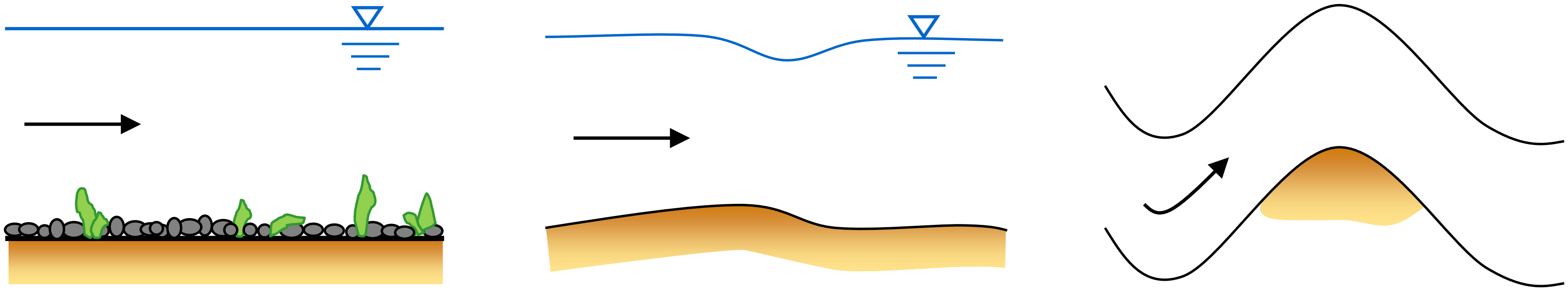


Open Channel Hydraulics

Flow resistance

- Consistently working on the water flow as opposite to drag force

Geomorphological characteristics on the flow resistance



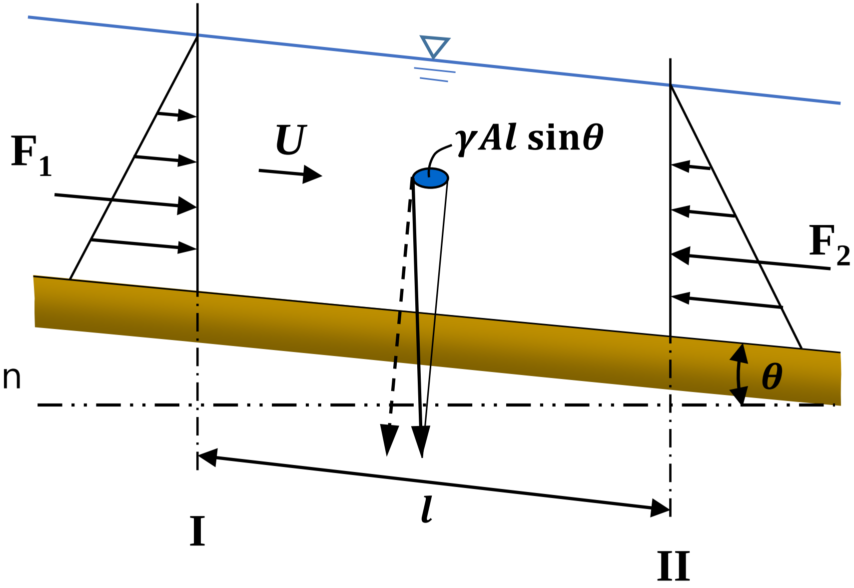
a) Bed material b) Bed forms c) Meander and sand bar

~ Frictional resistance on the boundary between the water flow and bed material and form resistance facing the water flow by the bed forms and obstacles

Open Channel Hydraulics

Flow resistance

Shear stress in uniform flow



~ Flow with constant cross section and slope

→ Uniform flow, $\dfrac{\partial U}{\partial t} = 0$

~ Hydrostatic assumption $F_1 = F_2$ as opposite direction

$$\rightarrow F_1 = F_2$$

~ Momentum equation about entire water flow

$$\rightarrow \gamma Al\frac{\partial U}{\partial t} = \gamma Alsin\theta - \tau_0 Pl$$

~ Flow direction due to gravity parallel to wall shear stress

$$\rightarrow \tau_0 = \gamma\frac{A}{P}\sin\theta = \boldsymbol{\gamma RS}$$

Open Channel Hydraulics

Flow resistance equation – Uniform flow equation

- Calculate uniform flow with geometric characteristics and resistance on the boundary

Chezy's equation

~ Set Darcy - Weisbach equation

= Shear stress equation

$$\rightarrow \ \tau_0 = \gamma RS \equiv \left(\frac{f}{8}\right)\rho U^2$$

$$\rightarrow U = C\sqrt{RS}$$

where, f = friction factor,

C = Chezy's coefficient $\left(C = \sqrt{8g/f}\,\right)$

Manning's equation

~ Empirical equation from the experimental data to determine C

$$\rightarrow C = \frac{R^{1/6}}{n}$$

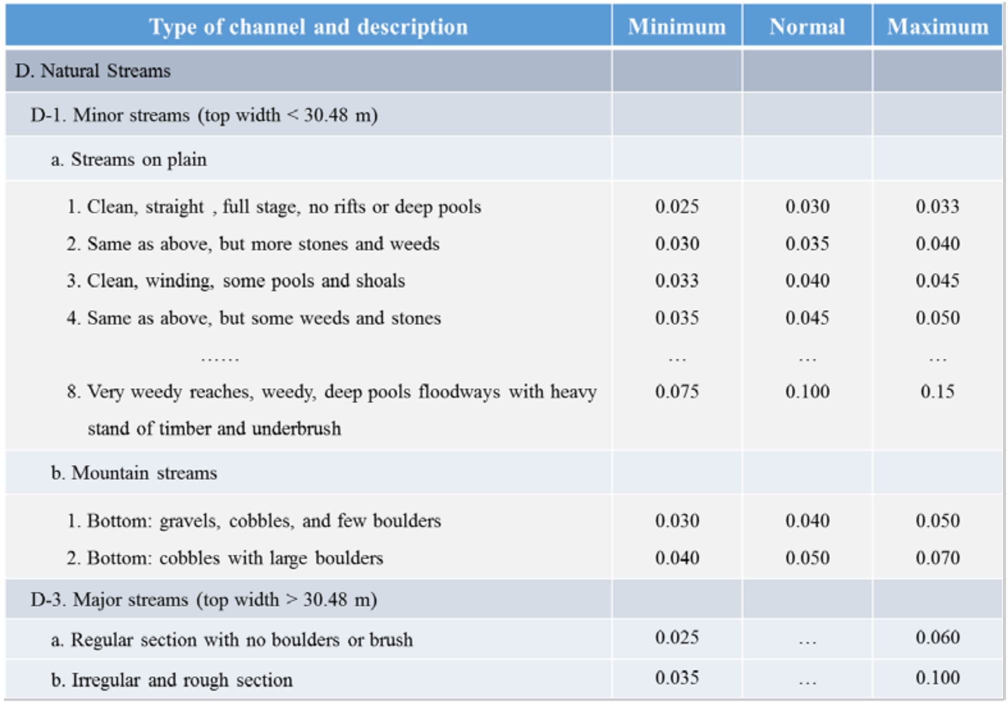
$$\rightarrow U = \frac{1}{n}R^{2/3}S^{1/2}$$

where, n = Manning's coefficient

Open Channel Hydraulics

Manning's roughness coefficient

~ Average values of *n* proposed by Chow (1959), considering various bed surface conditions



Type of channel and description	Minimum	Normal	Maximum
D. Natural Streams			
D-1. Minor streams (top width < 30.48 m)			
a. Streams on plain			
1. Clean, straight , full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
……	…	…	…
8. Very weedy reaches, weedy, deep pools floodways with heavy stand of timber and underbrush	0.075	0.100	0.15
b. Mountain streams			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
D-3. Major streams (top width > 30.48 m)			
a. Regular section with no boulders or brush	0.025	…	0.060
b. Irregular and rough section	0.035	…	0.100

Ref.: Chow (1959)

Estimation of roughness coefficient in the open channel (USGS, 1989)

~ Cowan's equation (1956)

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

where, n_b = Bed material

n_1 = Irregularity

n_2 = Cross-sectional shape

n_3 = Obstructions

n_4 = Vegetation

m = Channel meandering

Open Channel Hydraulics

Gradually-varied flow

Derivation

Bernoulli equation

$$H = z + y + \alpha\frac{V^2}{2g}$$

+

Specific energy

$$E = y + \frac{V^2}{2g}$$

⇨

Water surface curve

$$\frac{dy}{dx} = \frac{S_0 - S_f}{(1 - Fr^2)}$$

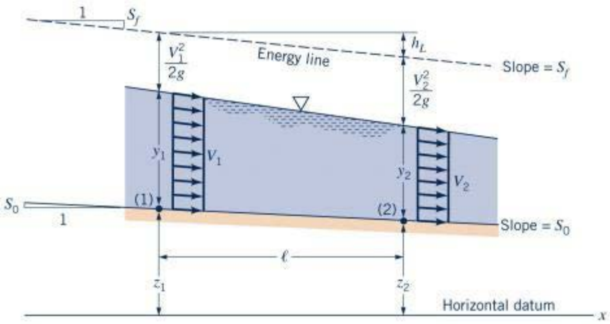
S_0 : channel slope

S_f : friction slope

Fr : Froud number $\left(= \frac{V}{\sqrt{gy}}\right)$

Calculation of the water surface curve with the standard step method

- **Solve unknowns in the non-linear equation, apply the energy equation into upstream and downstream of the channel with the trial & error method or numerical analysis**
- **Trial & error method commonly used for water surface curve in rivers (ex. HEC-RAS)**



Trial & error method

$$H_1 = H_2 + \frac{1}{2}(S_{f1} + S_{f2})\Delta x$$

Solve **unknown total energy** (H_1) of the upstream using **total energy** (H_2) of the downstream and assuming **unknown water elevation** (y_1) of the upstream

Numerical analysis

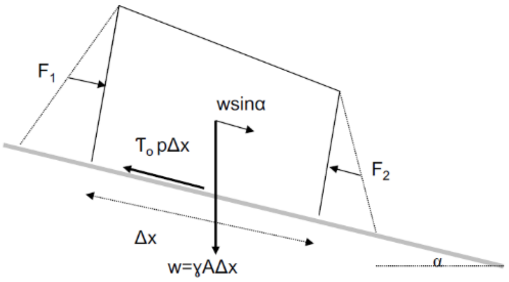
$$f(y_1) = y_1 + \alpha_1\frac{Q^2}{2gA_1^2} - \frac{1}{2}\Delta x S_{f1} + \left(z_1 - z_2 - y_2 - \alpha_2\frac{Q^2}{2gA_2^2} - \frac{1}{2}\Delta x S_{f2}\right) = 0$$

Solve the non-linear equation about **unknown water depth** (y_1) of the upstream using **bisection method** or **Newton method**

Open Channel Hydraulics

Unsteady flow

Derivation



$$F_1 = \gamma h_c A$$

$$F_2 = \gamma h_c A + \frac{\partial}{\partial x}\left(\gamma h_c A\right)\Delta x$$

Applying **Newton's second law** into the control volume

$$\Sigma F = ma = \rho A \Delta x \frac{dV}{dt} = \rho A \Delta x \left[\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x}\right]$$

$$F_1 - F_2 + W\sin\alpha - \tau_0 p \Delta x = \rho A \Delta x \left[\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x}\right]$$

$$\Rightarrow \frac{\partial Q}{\partial t} + \frac{\partial (VQ)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0$$ **(St.Venant Equation)**

1-D models for unsteady flow analysis

Model	Developer	Properties
HEC-RAS	US Army Corps of Engineers	- Widely used in international research institutes - Compatible with evaluation of various hydraulic structures
SWMM	US EPA	- Developed for rainfall-runoff in urban areas - Effective in pipe flow analysis considering hydrological properties
MIKE 11	DHI	- Commercial software for flood simulations - Hydrodynamic and water quality simulation with user-friendly GUI

Shallow Water Hydraulics

Shallow water equation

Time-averaged Navier-Stokes equation

$$\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u_i' u_j'}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} - g\delta_i + \nu_L \frac{\partial^2 \overline{u}_i}{\partial x_j \partial x_j}$$

Depth-averaging the 3-D Navier-Stokes equation with hydrostatic assumption

$$\frac{\partial u_i}{\partial t} + u_j\frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial p_a}{\partial x_i} - g\frac{\partial (H+h)}{\partial x_i} - \frac{g}{\rho_0}\frac{\partial}{\partial x_i}\int_z^{H+h}\rho' dz - g\delta_{3i} + (\nu_L+\nu_T)\frac{\partial^2 u_i}{\partial x_j\partial x_j} + \nu_T\frac{\partial}{\partial x_j}\left(\frac{\partial u_j}{\partial x_i}\right)$$

(Bottom: $z = H(x,y)$ **Surface:** $z = H + h(x,y,t)$ **)**

Applying the kinematic free surface condition and non-slip boundary on the bottom

Local acceleration

Bed slope

Turbulent stress

$$\frac{\partial u_i}{\partial t} + u_j\frac{\partial u_i}{\partial x_j} = -g\frac{\partial H}{\partial x_i} - g\frac{\partial h}{\partial x_i} + \nu_T\frac{\partial^2 u_i}{\partial x_j \partial x_j} - gn^2\frac{u_i\sqrt{u_j u_j}}{h^{4/3}}$$

Advective acceleration

Pressure

Bed friction

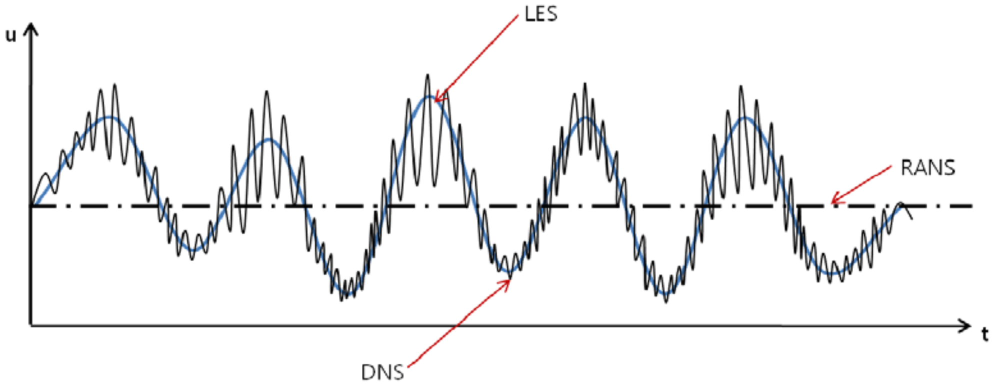
Shallow Water Hydraulics

Turbulence modeling

- Hydrodynamic model – RANS(Reynolds Averaged Navier-Stokes Equation)

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + g_i + \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right)\right] - \frac{\partial}{\partial x_j}\boxed{\overline{u_i' u_j'}}$$

Reynolds stress term



Modeling the Reynolds stress term from time-averaging of 3-D Navier-Stokes equation, using turbulence models

Shallow Water Hydraulics

- Turbulence modeling
  - Turbulence models

Introducing the concept of turbulent viscosity by Boussinesq approximation

$$-\overline{u_i' u_j'} = \nu_t \left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i} \right) + \frac{2}{3} k \delta_{ij}$$

Zero-Equation Model

$$\nu_t = l_m^{\ 2} \left| \frac{\partial u}{\partial z} \right|$$

Determine mixing length,

No PDE equation to describe the transport of turbulent flux

One-Equation Model

$$\nu_t = c_\mu \sqrt{k} L$$

Determine *k* from one transport equation

Two-Equation Model

$$\nu_t = c_\mu \frac{k^2}{\varepsilon}$$

Determine *k* and ε from two transport equations (*k*- ε model)

- k-Ω, SST, RNG, …

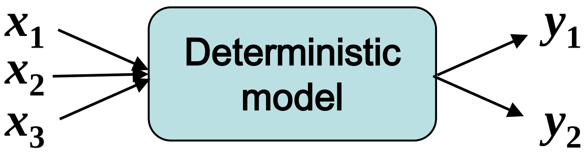
Model Classification

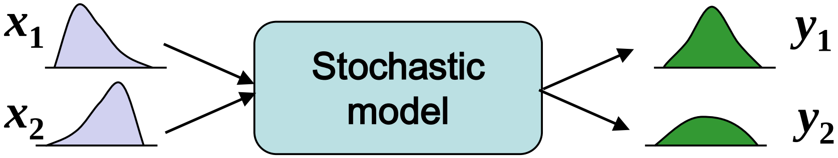
Dimensions of model

- 3-D: DNS, RANS (Time-averaged model)
- 2-D: Depth-averaged or horizontally averaged models
- 1-D: Cross-sectional averaged model

Input & output data

- Deterministic model : Model output fully determined by parameters and input data
- Stochastic model : Parameters and input data leading to randomized output





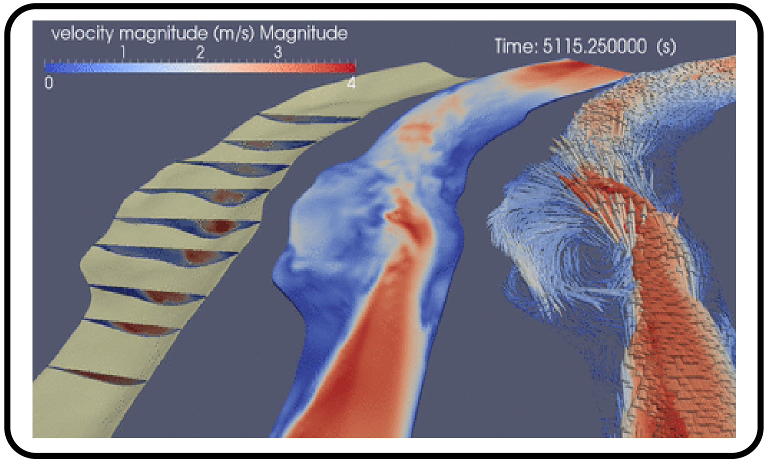
Analysis method

- Physics-based model : Represents the physical process in the real world
- Data-based model : Estimates the phenomenon based on the acquired data

Model Classification

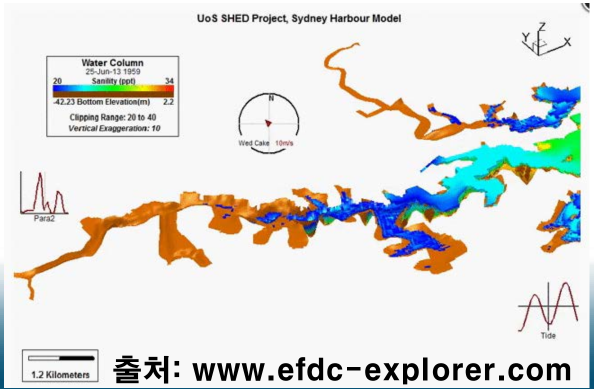
3D Model

- **OpenFOAM**
  - C++ based Open Source CFD toolbox
  - Uses Linux OS
  - Calculate PDE with FVM method
  - Supports parallel computing



출처: Mark Schmeeckle, Arizona State Univ.

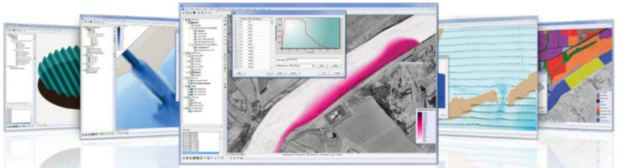
- **EFDC (Environmental Fluid Dynamics Computer code)**
  - Developed in 1992 by Virginia Institute of Marine Science
  - Applicable to various surface flows as rivers, lakes, wetlands, estuaries etc
  - Physical model based on Blumberg and Mellor(1987)
  - RANS computation with Boussinesq approximation and hydrostatic pressure



출처: www.efdc-explorer.com

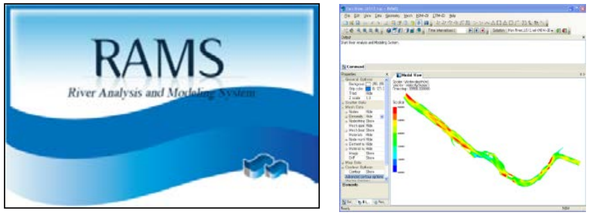
Model Classification

2D Model



Ref: www.aquaveo.com

- **SMS (Surface-water Modeling Solution)**
  - Numerical model based on FEM and depth-averaging
  - River flow and transport modeling in rivers, lakes
  - Consists of flow model(RMA2), transport model (RMA4), sediment transport model(FESWMS), particle tracing model (PTM) etc



Ref: Seo, etc(2014) "RAMS tech manual"

Homepage: http://ehlab.snu.ac.kr

- **RAMS(River Analysis and Modeling System)**
  - Conservative and non-conservative transport modeling, mass injection modeling assuming contaminant accidents
  - Various mixing analysis of river and lake variables such as BOD/DO, Temperature, Algal bloom, etc

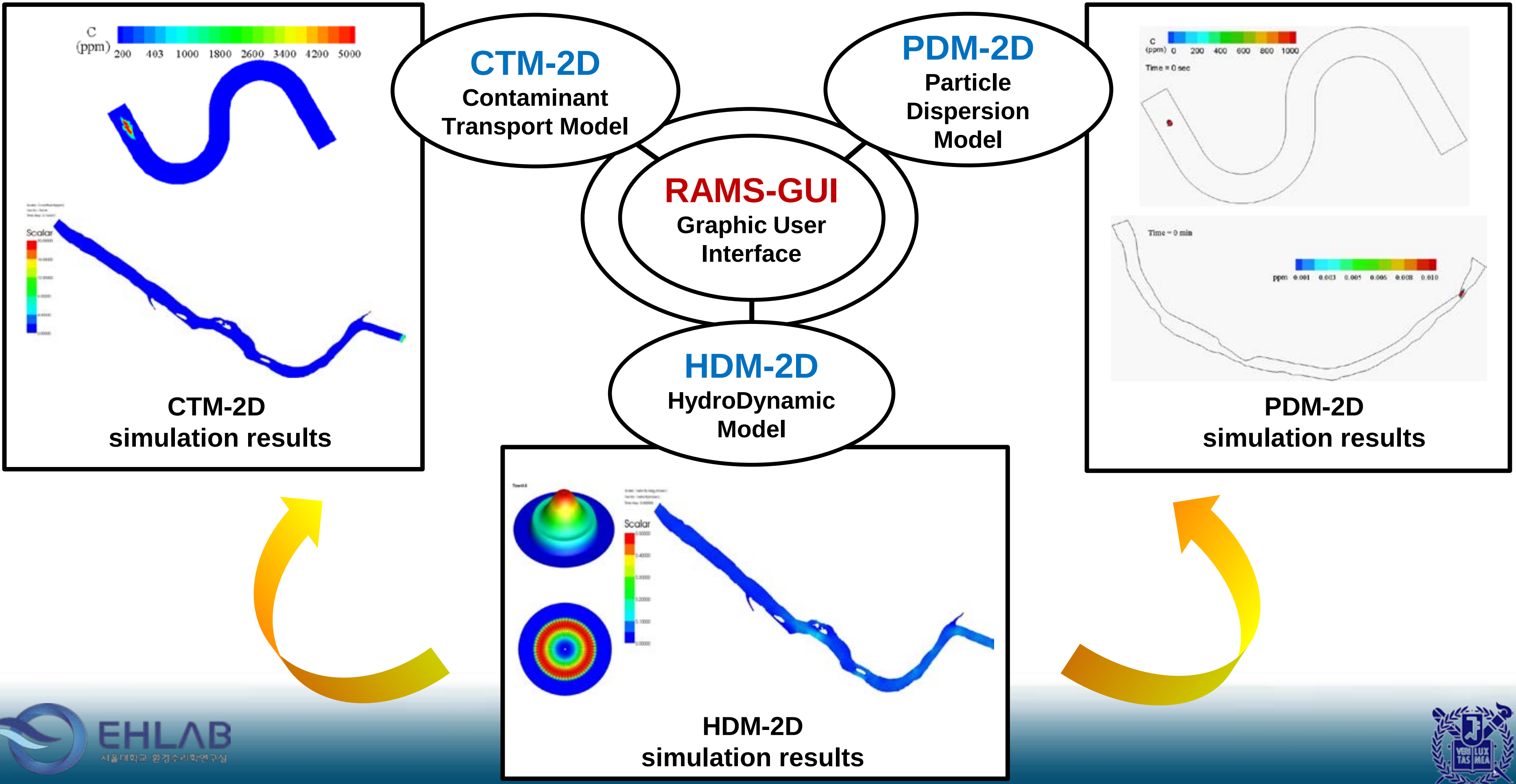
RAMS (River Analysis and Modeling Systems)

RAMS Software

- Able to simulate physical phenomena in natural rivers with complex topography by 2D finite element calculations
- RAMS consists of river flow model (HDM-2D), pollutant transport model (CTM-2D), particle dispersion model (PDM-2D)
- Graphic User Interface is combined with computing engines
- Increased accuracy for the pollutant transport model with dispersion linked with flow direction and various pollutant input
- Web: http://ehlab.snu.ac.kr
- E-mail: seoilwon@snu.ac.kr

RAMS

- **RAMS program consists of a 2D flow analysis model and a pollutant transport model that is combined with a GUI for user convenience**



CTM-2D
Contaminant Transport Model

PDM-2D
Particle Dispersion Model

RAMS-GUI
Graphic User Interface

HDM-2D
HydroDynamic Model

CTM-2D simulation results

PDM-2D simulation results

HDM-2D simulation results

RAMS

Governing eq. of HDM-2D

Continuity eq. : $\frac{\partial h}{\partial t}+h\frac{\partial u_j}{\partial x_j}+u_j\frac{\partial h}{\partial x_j}=0$

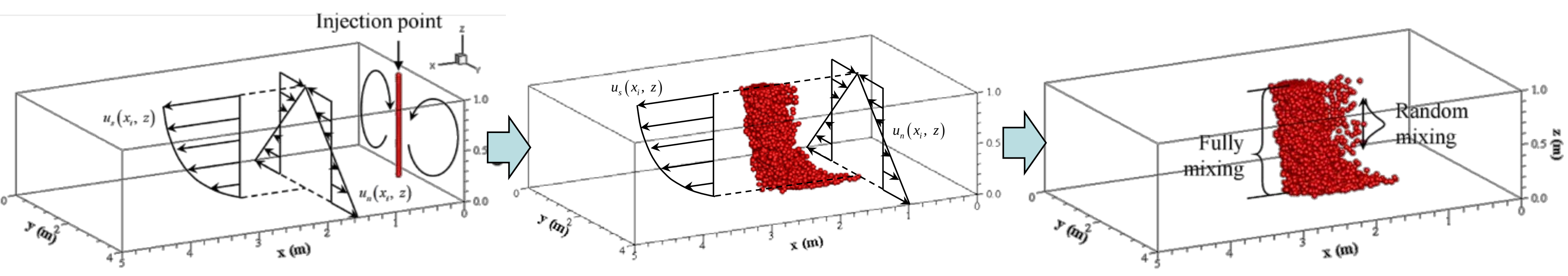
Momentum eq. : $\frac{\partial u_i}{\partial t}+u_j\frac{\partial u_i}{\partial x_j}=-g\frac{\partial H}{\partial x_i}-g\frac{\partial h}{\partial x_i}+\nu_T\frac{\partial^2 u_i}{\partial x_j\partial x_j}-gn^2\frac{u_i\sqrt{u_j u_j}}{h^{4/3}}-\frac{\partial S_{ij}}{\partial x_j}$

Governing eq. of CTM-2D

$$\frac{\partial(h\overline{C})}{\partial t}+\frac{\partial\left(\overline{u}_i h\overline{C}\right)}{\partial x_i}=\frac{\partial}{\partial x_i}\left(hD_{ij}\frac{\partial\overline{C}}{\partial x_j}\right)+Q+kh\overline{C}$$

Governing eq. of PDM-2D

$$dx_i=\left(\frac{1}{hC}\int_0^h u_i c\,dz\right)dt+\sqrt{2\varepsilon_h\Delta t}\,RN=\text{shear dispersion}\ +\ \text{random translation}$$



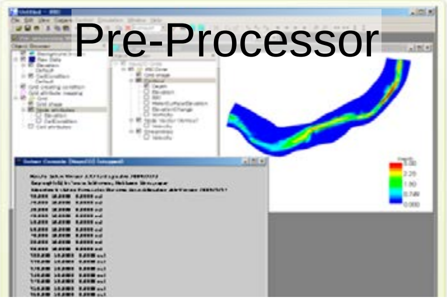
Particles injection Shear advection Vertical diffusion

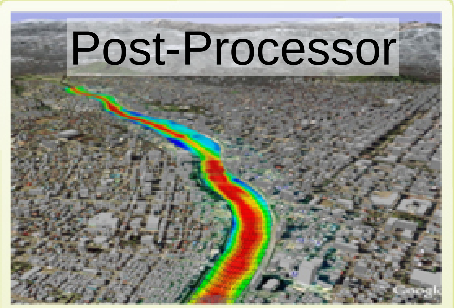
Model Classification

Two dimensional model

- iRIC (international River Interface Cooperative)
  - GUI interface software package for flow and sediment transport models developed by Hokkaido University and United States Geological Survey
  - Consists of pre-processor, post-processor, and model

Nays2DH	Hokkaido Univ, Flow and sediment transport model
Nays2DFlood	Hokkaido Univ, Flow model for floods
ELIMO	Hokkaido Univ, Tsumami wave and reach time model
HDM-2D	Seoul National Univ, Transient/steady flow model
FaSTMECH	USGS, Flow and sediment transport model
StoRM	USGS, Flow model with wet/dry, sub/supercritical flow
River2D	Alberta Univ, Flow model and habitat simulations





Ref: http://i-ric.org

Model Classification

1D Model

Hydrodynamic model – 1 dimensional Saint Venant equation

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial h}{\partial x}-g\left(S_0-S_f\right)=0$$

Transport model – 1 dimensional advection-transport equation

$$\frac{\partial C}{\partial t}+U\frac{\partial C}{\partial x}=\frac{\partial}{\partial x}\left(K\frac{\partial C}{\partial x}\right)$$

Model	Developer	Characteristics
HEC-RAS	US Army Corps of Engineers	- Used worldwide in many institutions - Capable of assessment of various riverine structures
SWMM	US EPA	- Developed for urban rainfall runoff analysis - Hydrologic characteristics applied to rainfall events, specialized for water distribution network design
MIKE 11	DHI	- Commercial software model for flood modeling - User friendly GUI with various hydraulic / advection models

4. River Modeling

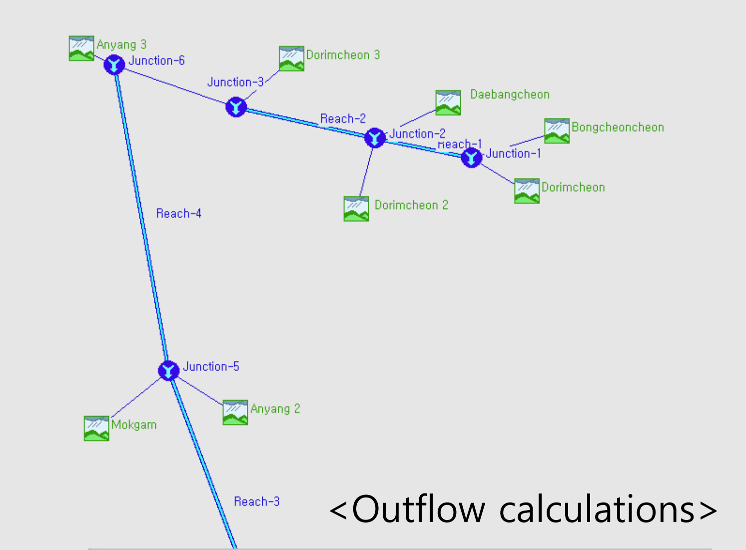
-HEC-RAS application-

Water surface elevation modeling with HEC-RAS

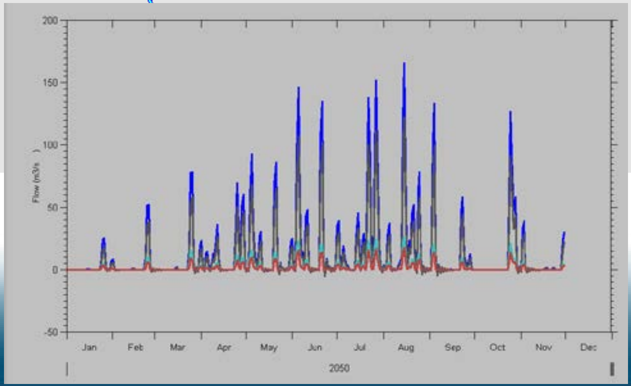
Anyang-cheon water surface elevation changes

- HEC-HMS hydrologic processes

<Anyang-cheon creek area >

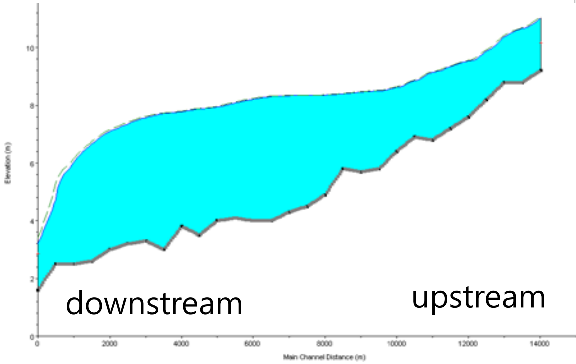


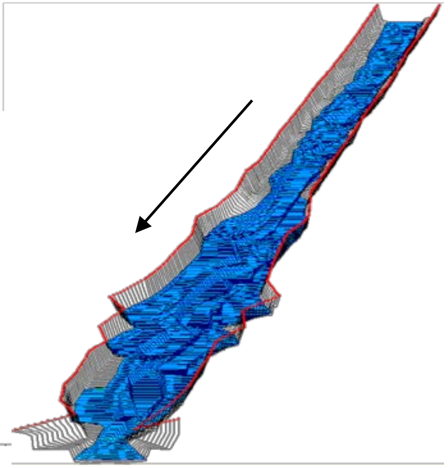
<Outflow calculations>



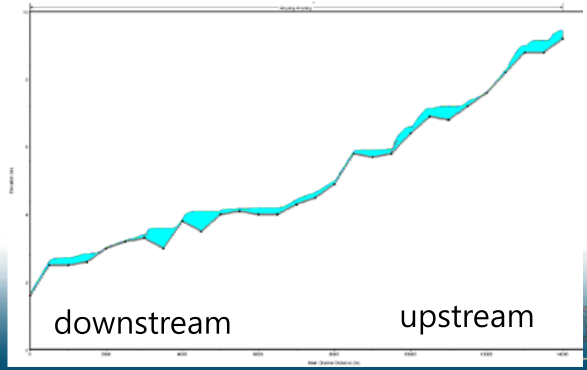
- 2008 simulation using HEC-RAS

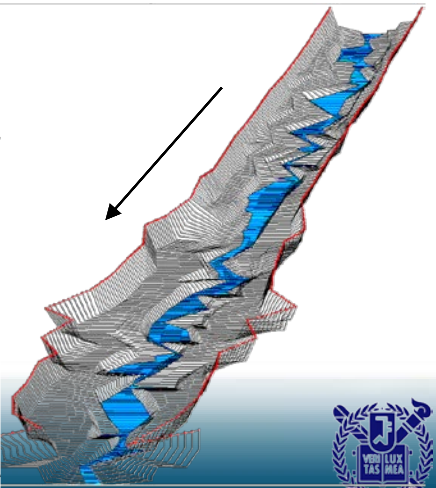
< Anyang-cheon at floods>





< Anyang-cheon at drought >

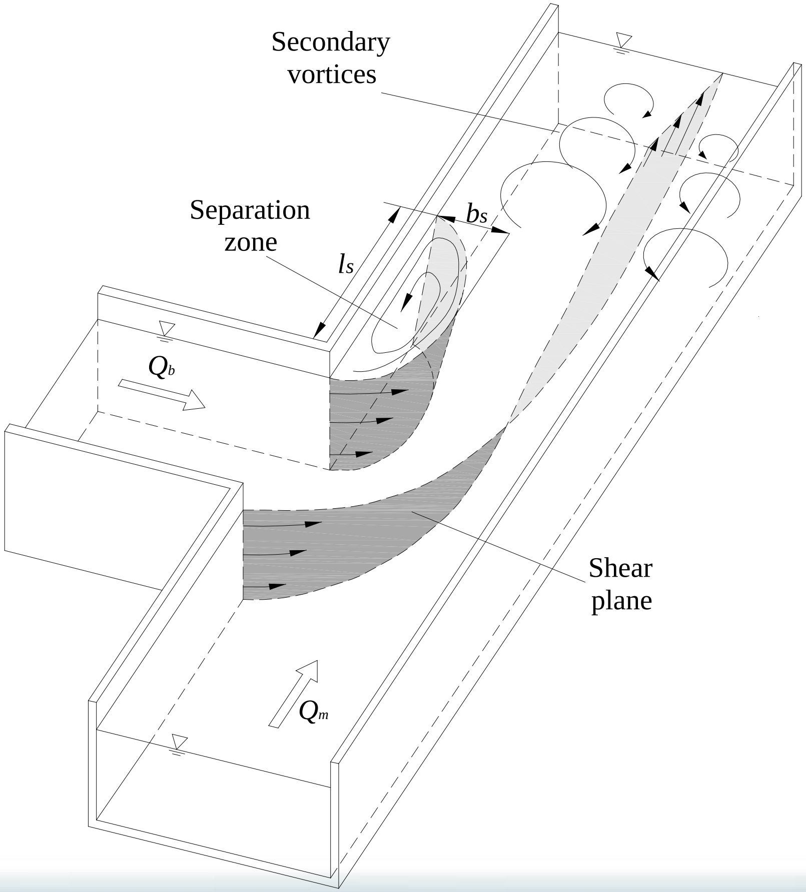




Flow modeling in confluent channel

Confluent channel modeling boundary conditions

- Flow characteristics (Weber etc, 2001)



- HDM-2D boundary conditions

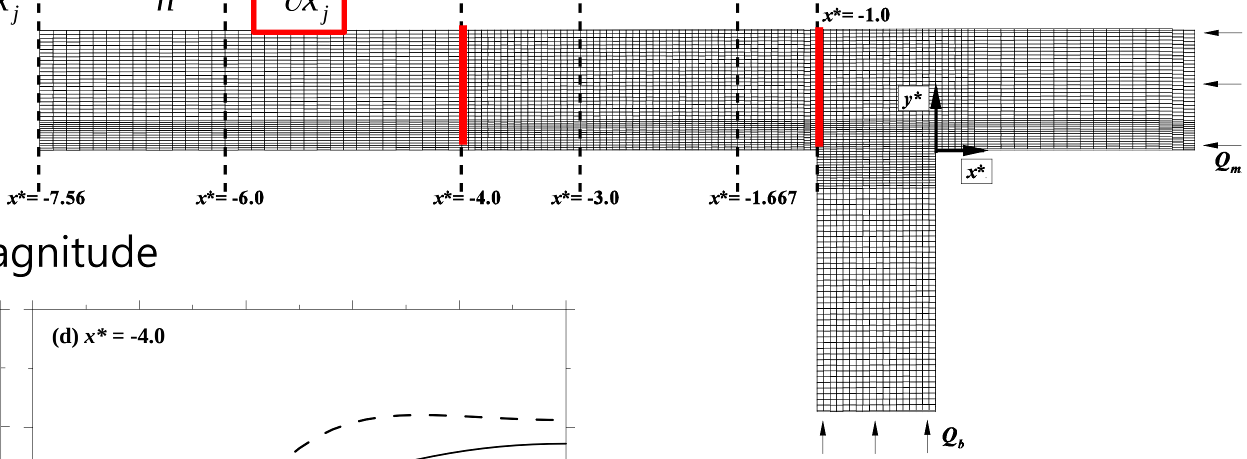
Q_m (m^3/s)	0.043
Q_b (m^3/s)	0.127
h (m)	0.296
B (m)	0.914
U_∞ (m/s)	0.628
Fr	0.37

Flow modeling in confluent channel

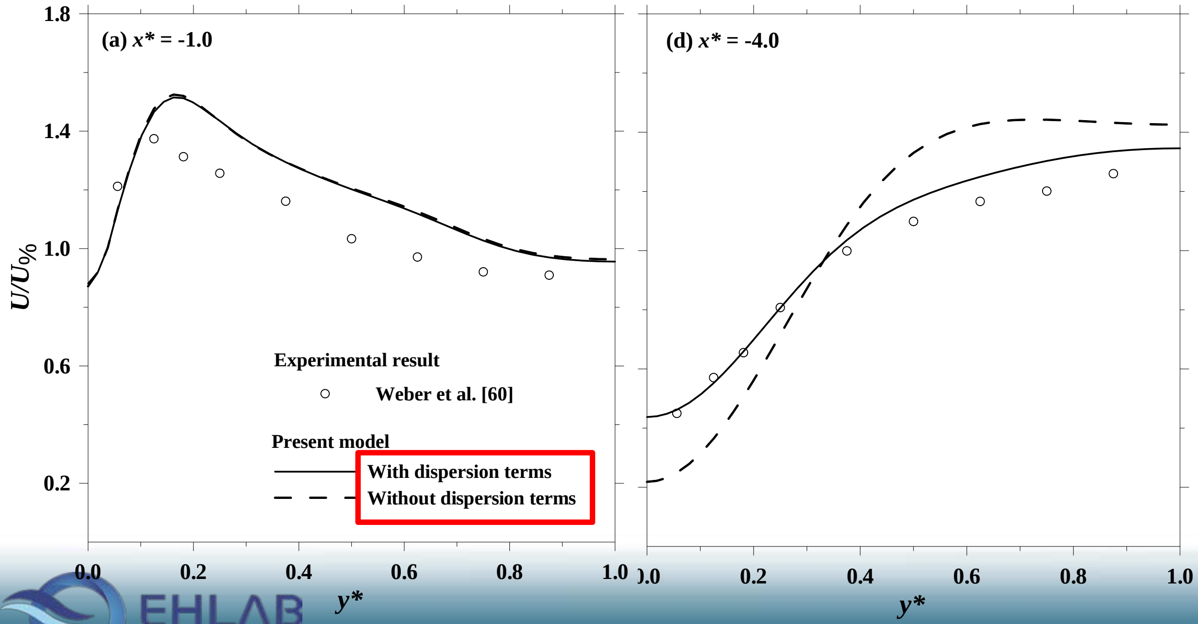
HDM-2D numerical modeling results

$$\frac{\partial u_i}{\partial t}+u_j\frac{\partial u_i}{\partial x_j}+g\frac{\partial H}{\partial x_i}+g\frac{\partial h}{\partial x_i}-\nu\frac{\partial^2 u_i}{\partial x_j\partial x_j}+gn^2\frac{u_i\sqrt{u_ju_j}}{h^{4/3}}+\boxed{\frac{\partial S_{ij}}{\partial x_j}}=0$$

Dispersion stress : $S_{ij}=\int_H^{H+h}\left(u_i(z)-u_i\right)\left(u_j(z)-u_j\right)dz$



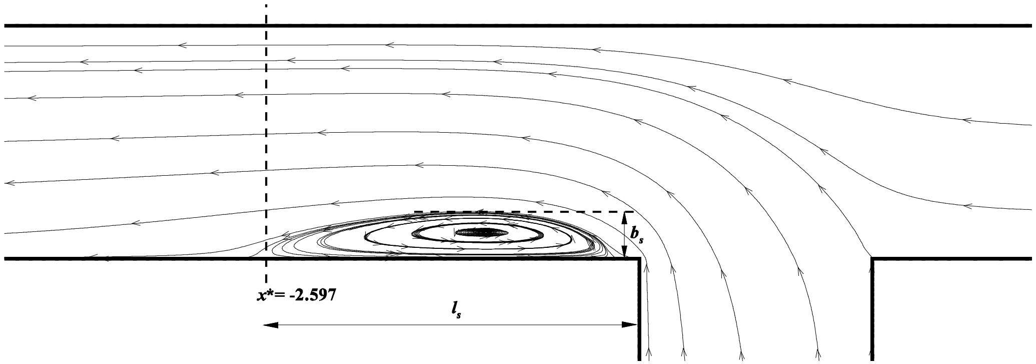
Comparison of velocity magnitude



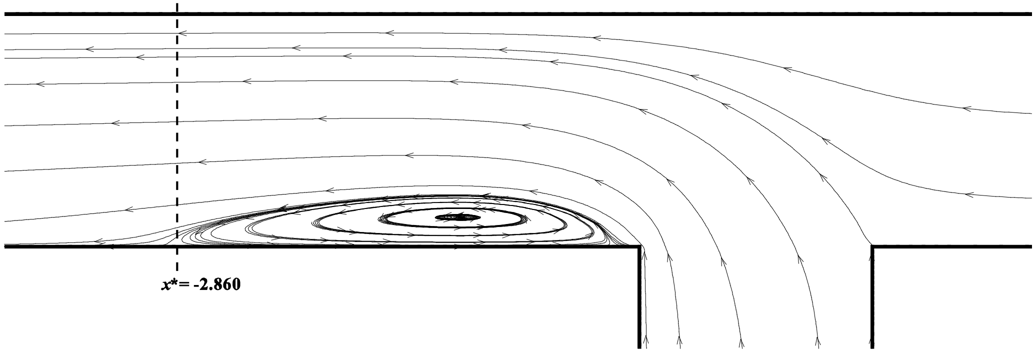
Flow modeling in confluent channel

- Separation zone changes with application of dispersion stress

(a) With dispersion terms



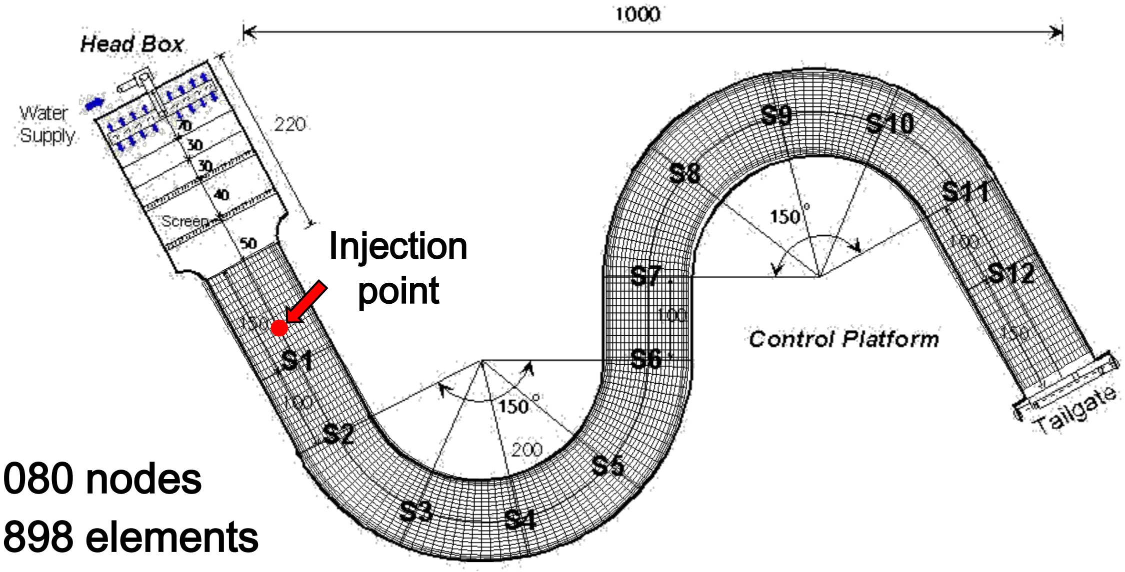
(b) Without dispersion terms



	l_s (m)	b_s (m)
w/ dispersion	1.46	0.188
w/o dispersion	1.70	0.227
Shumate (1998)	1.22	0.190
Gurram etc (1997)	-	0.195

Flow modeling in meandering channel

Meandering channel modeling boundary conditions



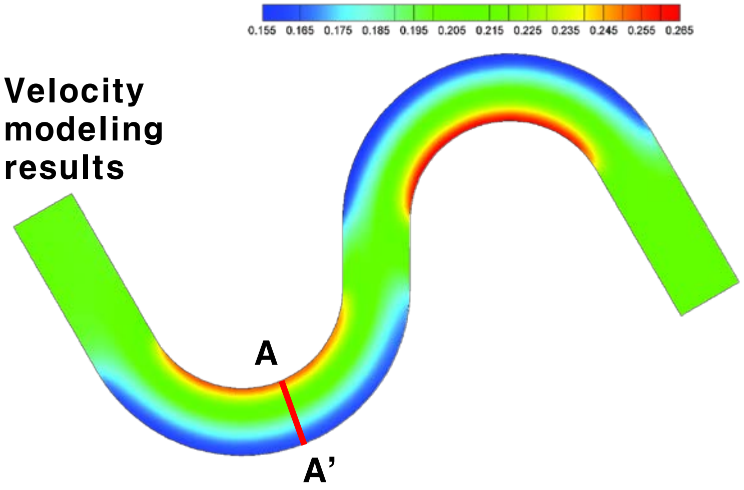
4,080 nodes
3,898 elements

Case	U.B.C. (cms)	D.B.C. (m)	ν_{xx} (m²/s)	ν_{xy} (m²/s)	ν_{yy} (m²/s)	n ($m^{-1/3}s$)
M1	0.03	0.15	10^{-3}			0.013
M2		0.40				

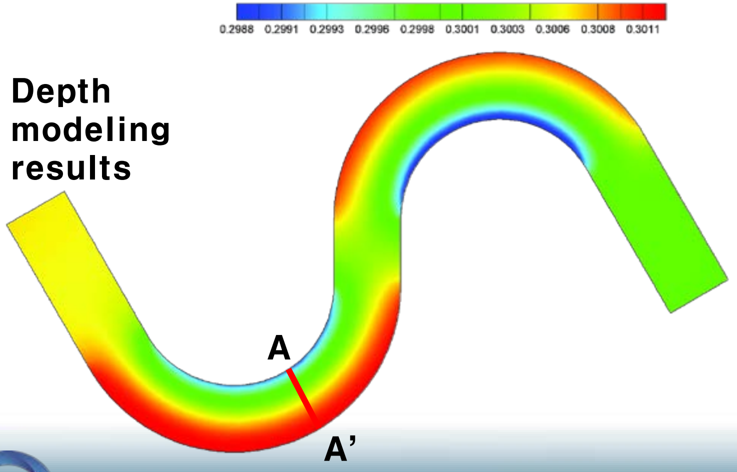
Flow modeling results in meandering channel

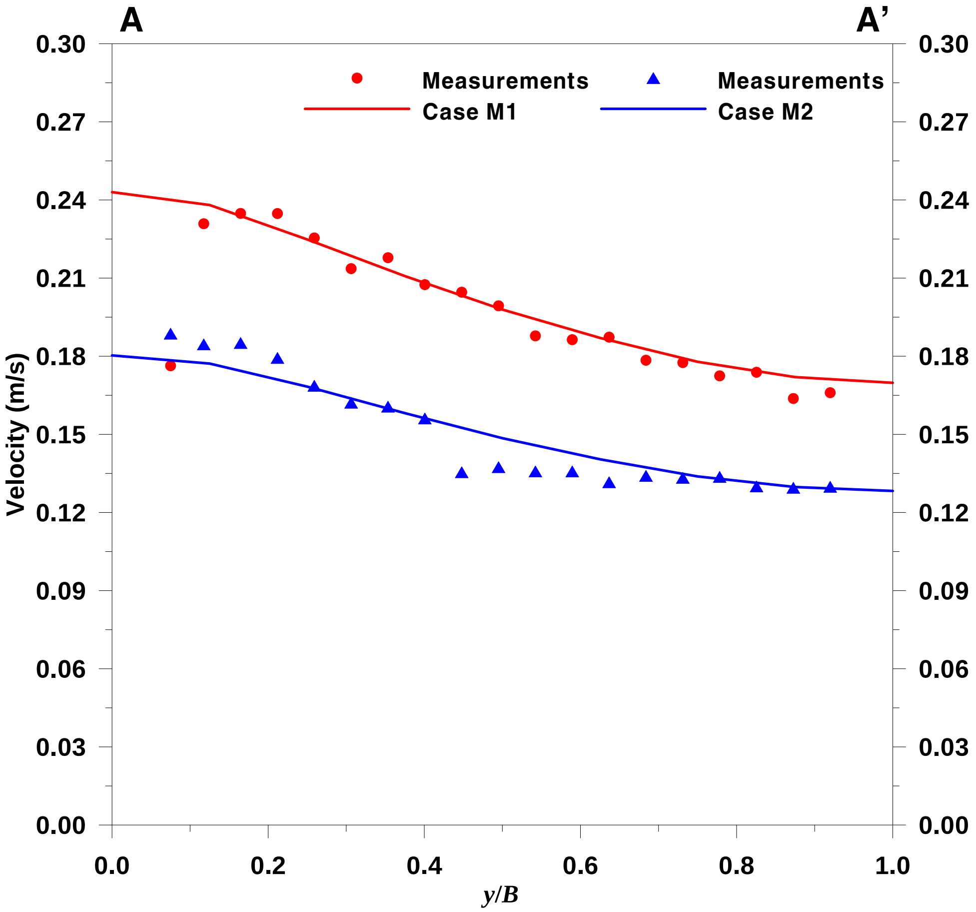
HDM-2D model results

Velocity modeling results



Depth modeling results

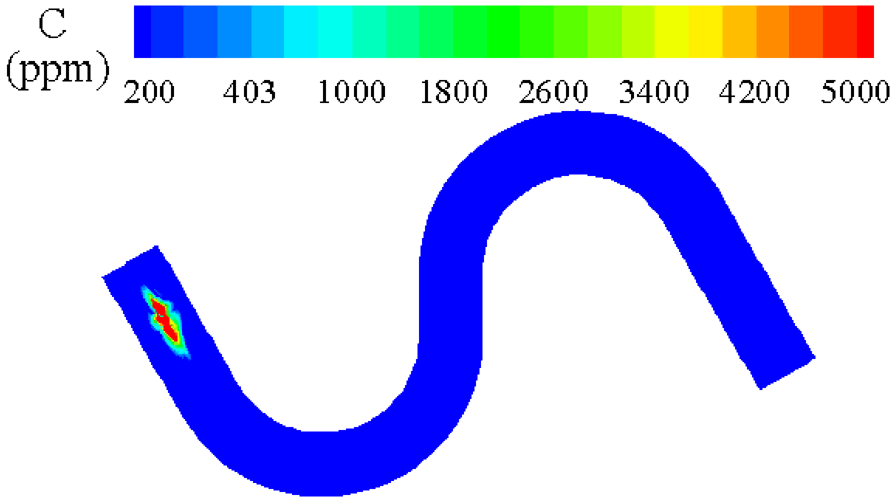


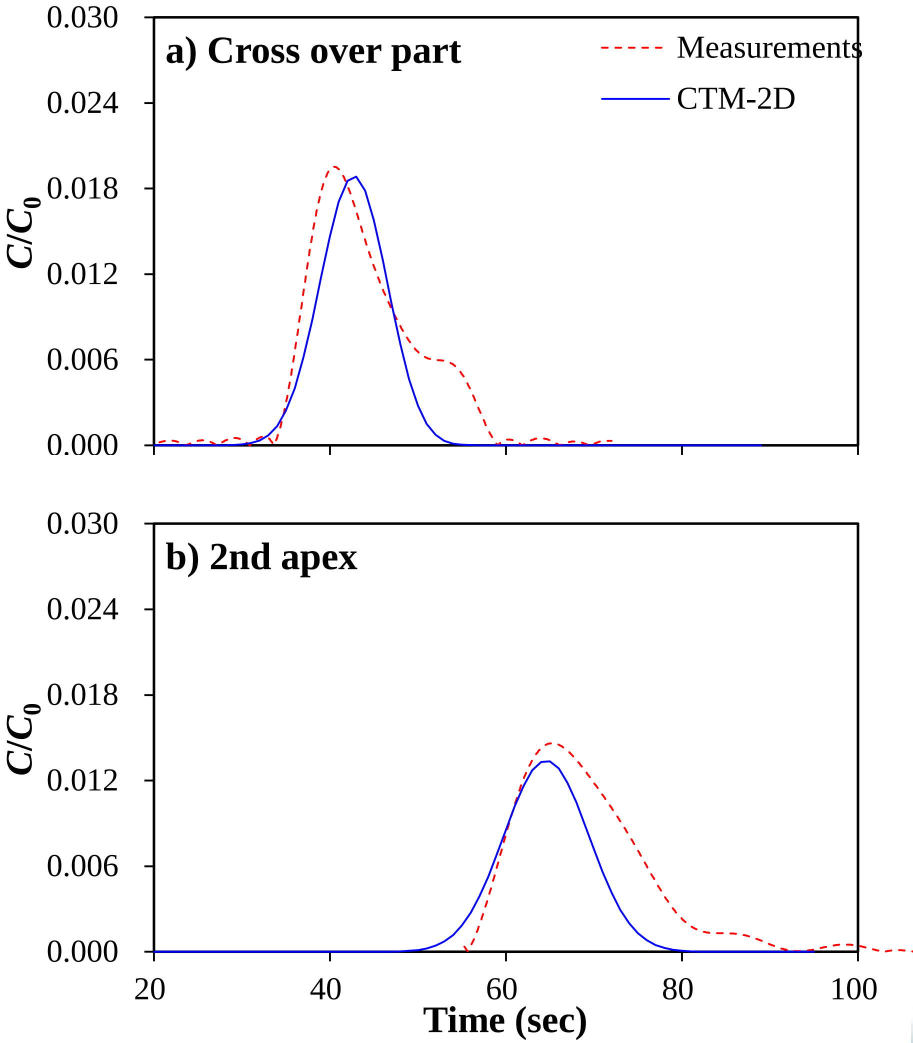


Transport modeling results in meandering channel

CTM-2D modeling results

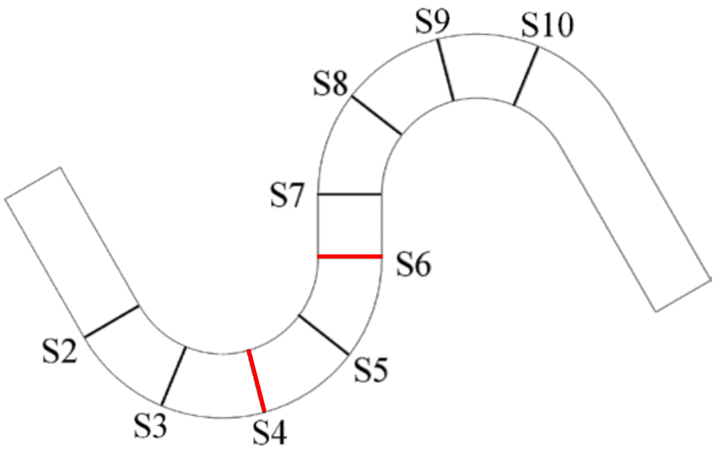
- Comparison of NaCl input experiment results and CTM-2D instantaneous mass injection modeling

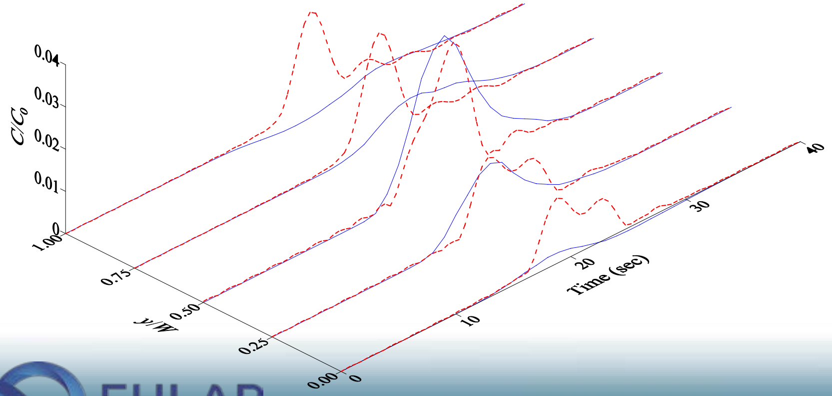




Tracer tests in the meandering channel

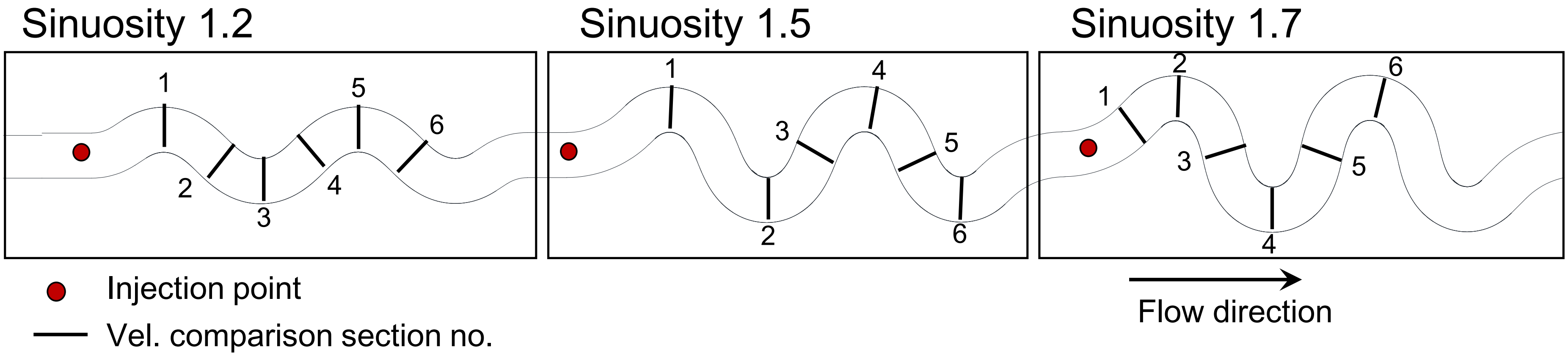
- **Results of PDM-2D**





Andong River Experiment Center

Simulation conditions



No. of elements: 5565
No. of nodes: 5852

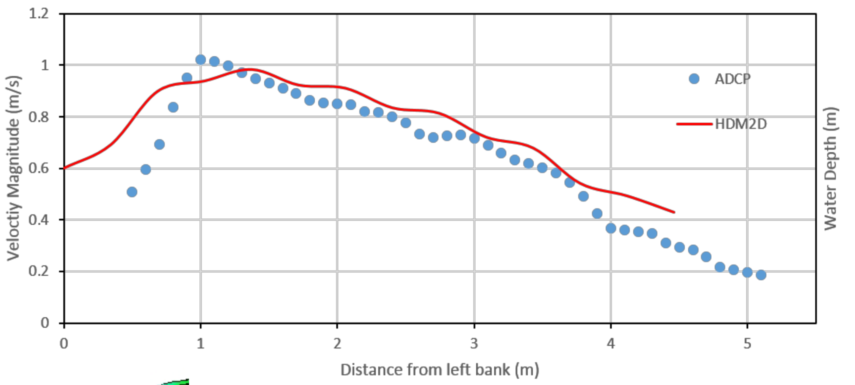
No. of elements: 6846
No. of nodes: 7194

No. of elements: 8316
No. of nodes: 8734

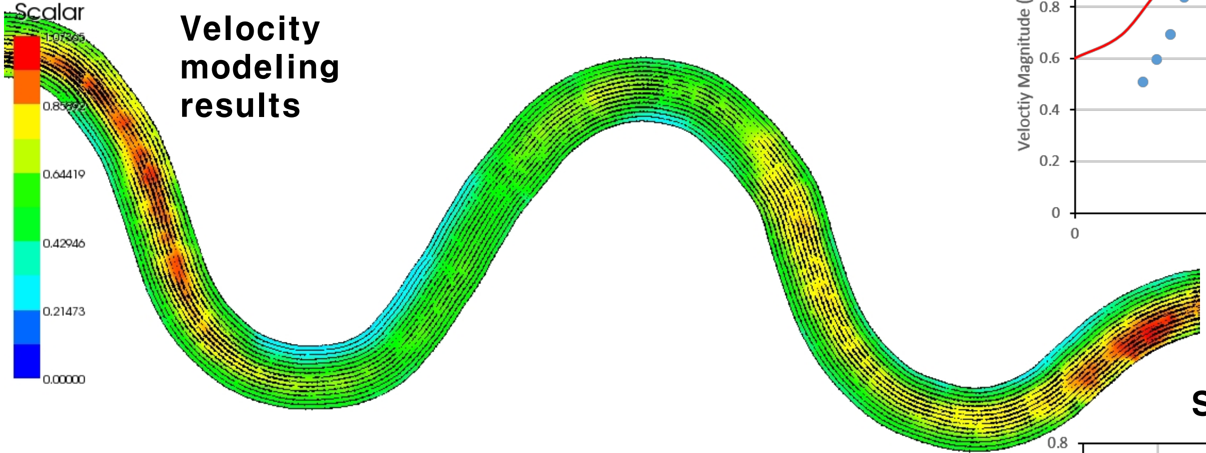
Andong River Experiment Center

Simulation results of HDM-2D

Section 1 data comparison

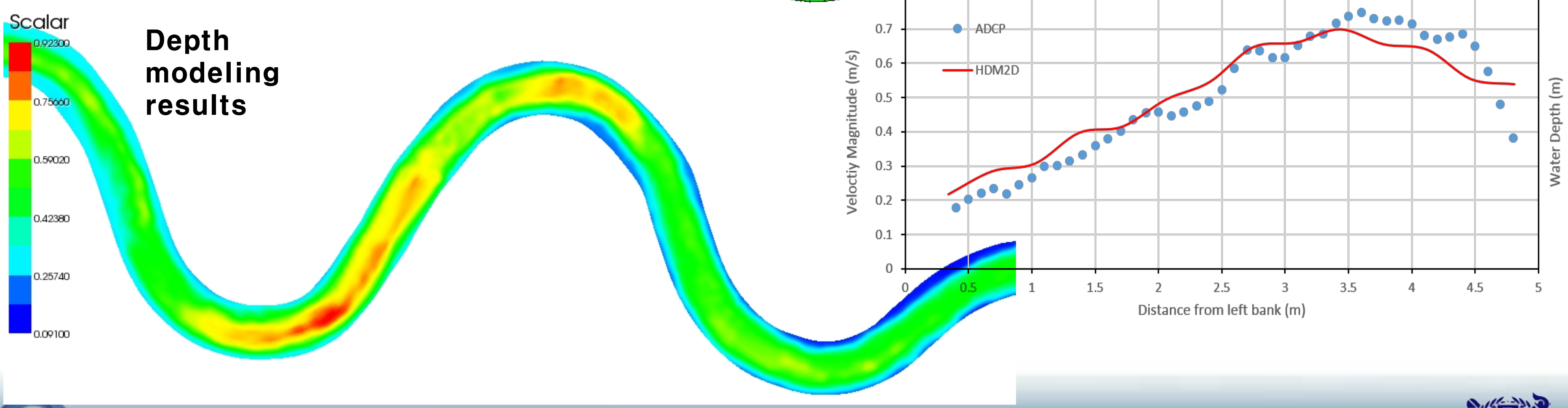


Velocity modeling results



Section 2 data comparison

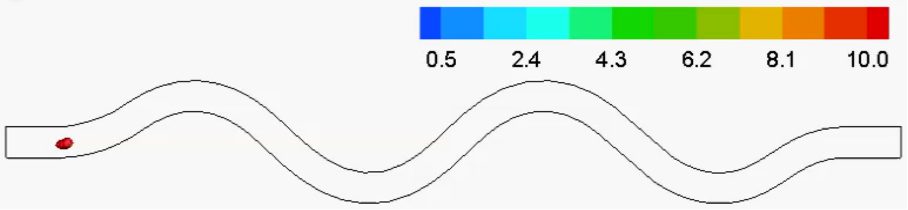
Depth modeling results



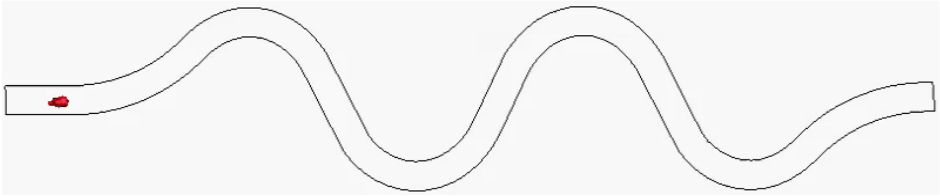
Andong River Experiment Center

Simulation results of PDM-2D

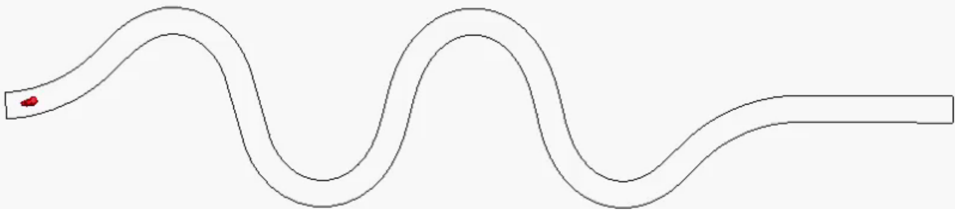
Case AMC12



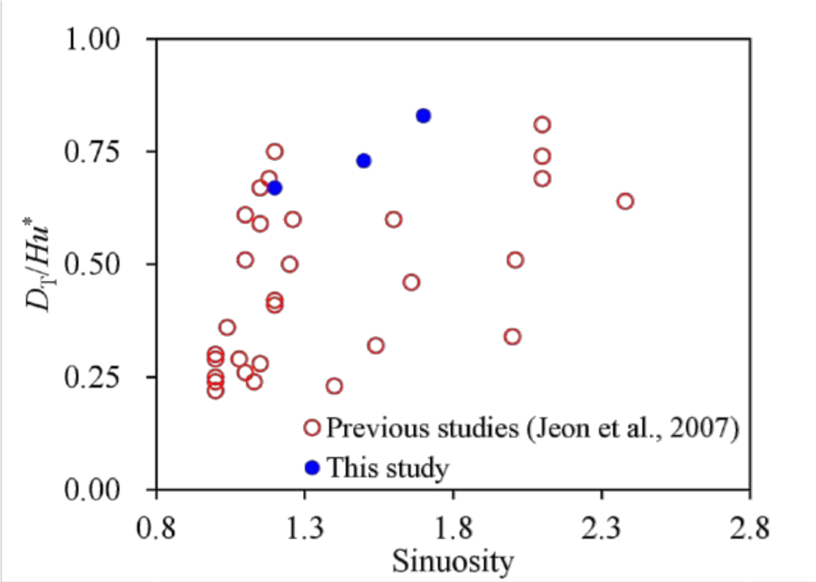
Case AMC15



Case AMC17



Calculation results of D_T with sinuosity change



Rutherford (1994)

- D_T/Hu^* = 0.30 ~ 0.90, for meandering channels

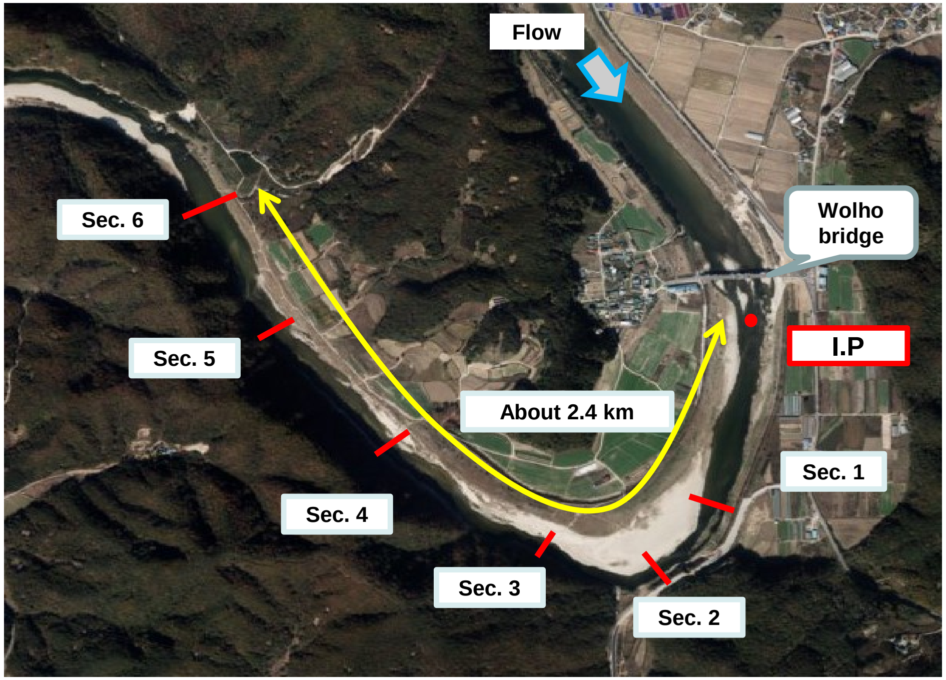
Case	AMC12	AMC15	AMC17
D_T/hu^*	0.67	0.73	0.83
Sinuosity	1.2	1.5	1.7

Sum River two dimensional tracer experiment modeling

Sum River tracer test

Test outline

**Rhodamine WT 20% solution
1900 mL(20,000 ppm) injection**



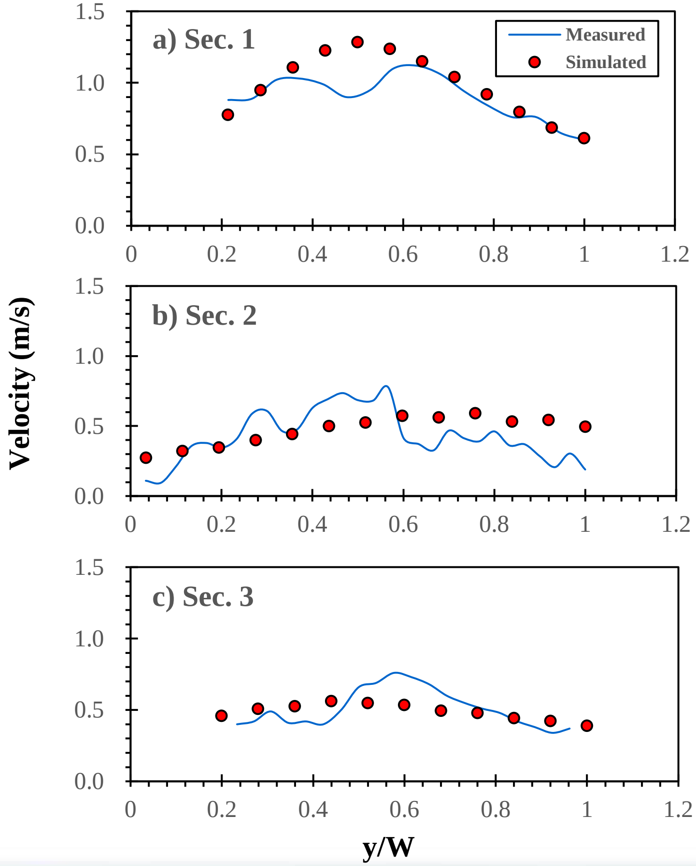
Simulation condition

Model	HDM-2D			CTM-2D	
Variable	Q (m^3/s)	h (m)	n	D_L (m2/s)	D_T (m2/s)
Value	5.9	63.2	0.03	0.84	0.019

- RAMS application -

Sum River two dimensional tracer experiment modeling

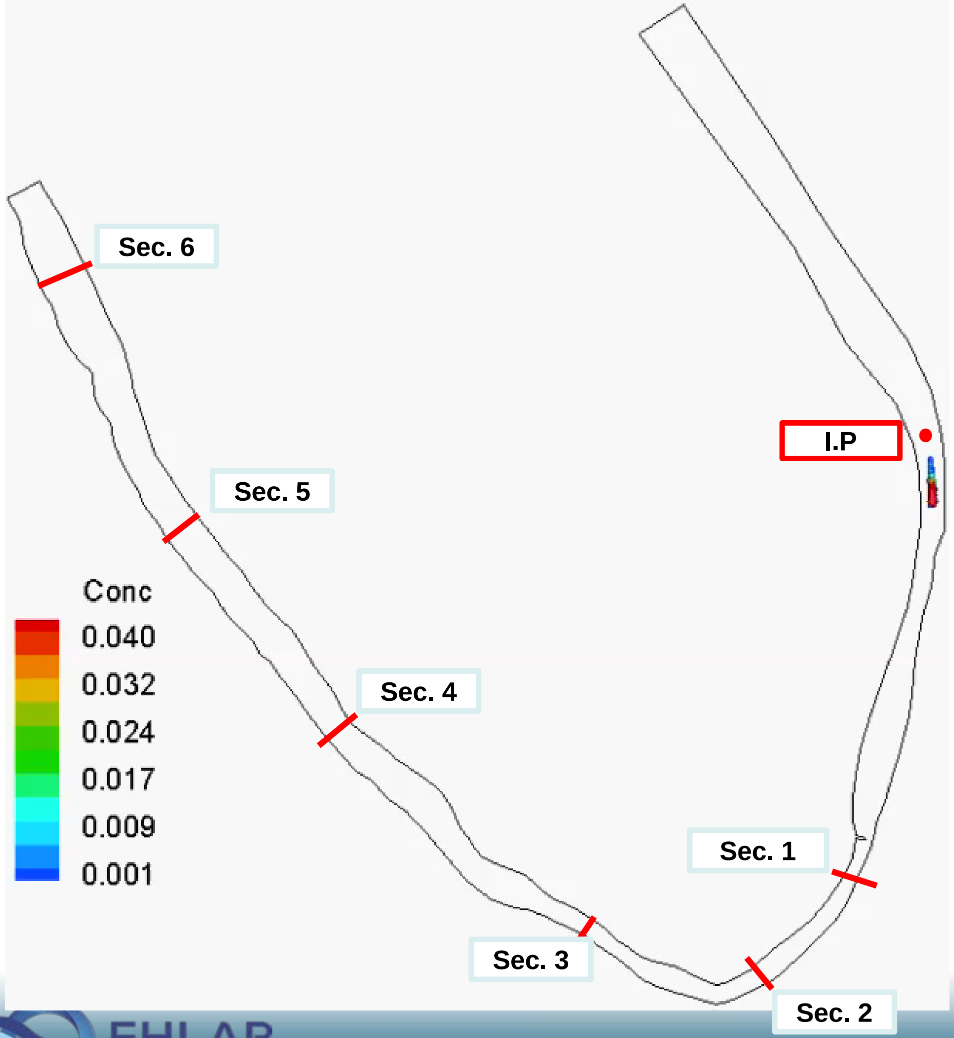
- HDM-2D comparisions
  - Velocity results



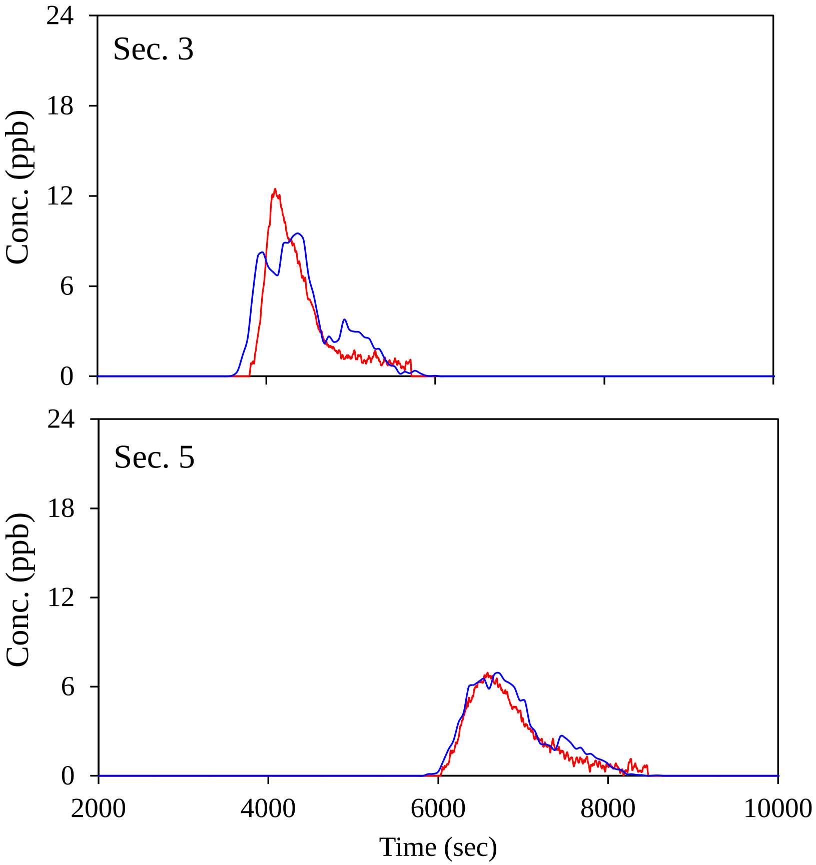
- CTM-2D comparisons

Sum River two dimensional tracer experiment modeling

Simulation results of PDM-2D



Comparison with tracer test results



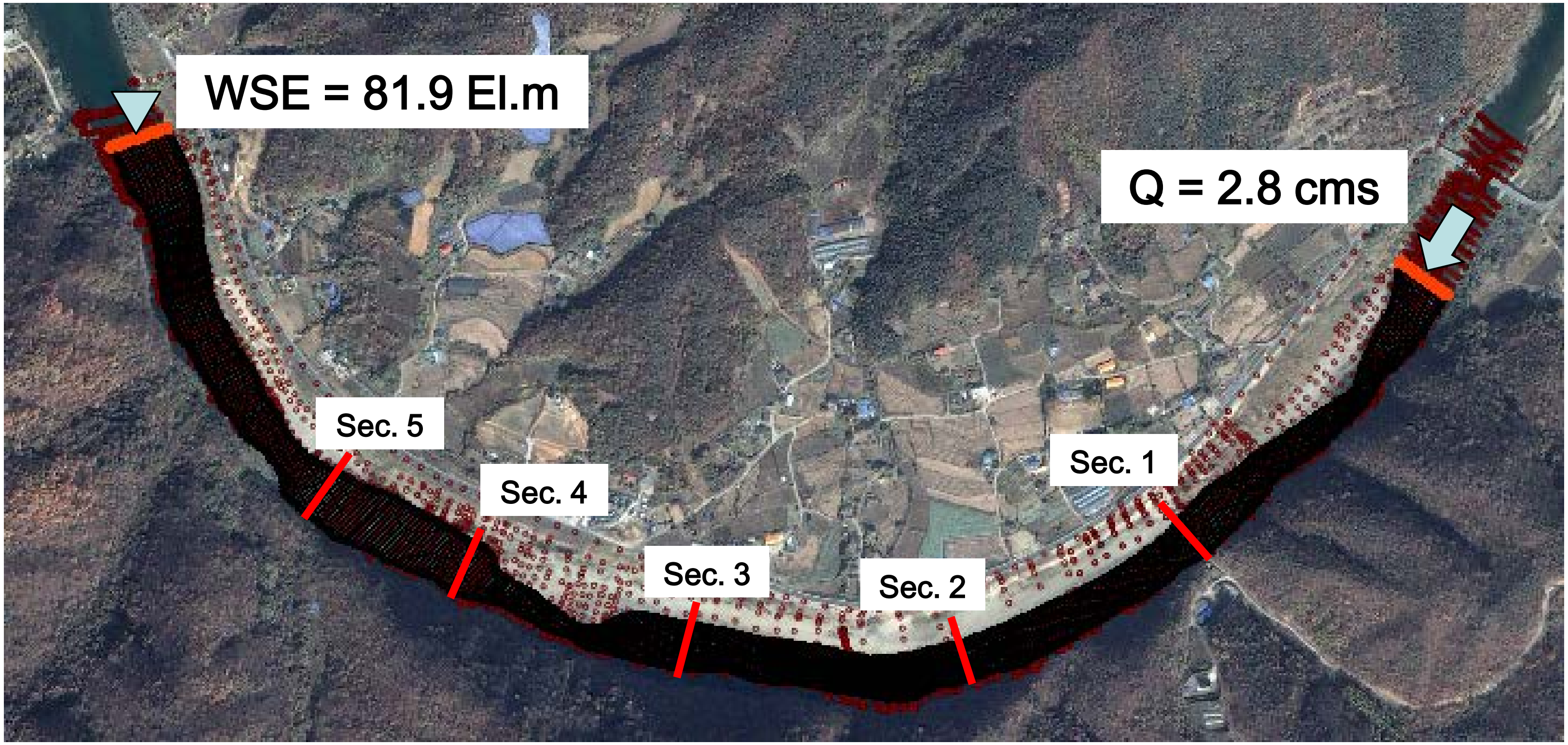
- RAMS application -

Hongcheon River

Simulation conditions

No. of Node : 8162
No. of Element : 7770

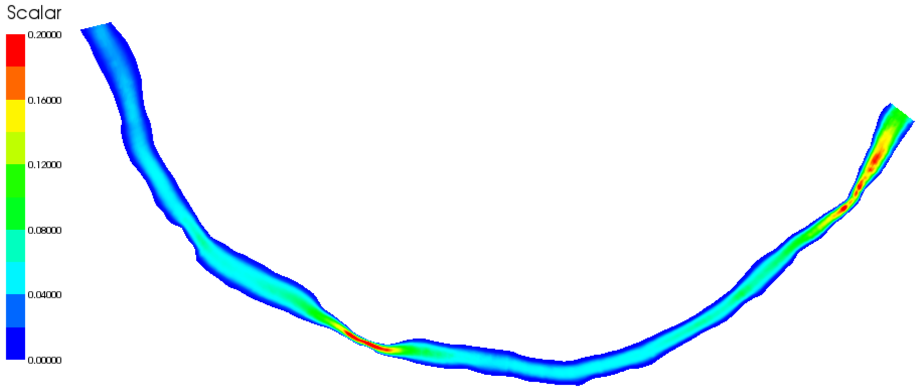
Wall boundary condition: no slip
Inflow vel. profile : parabolic distribution



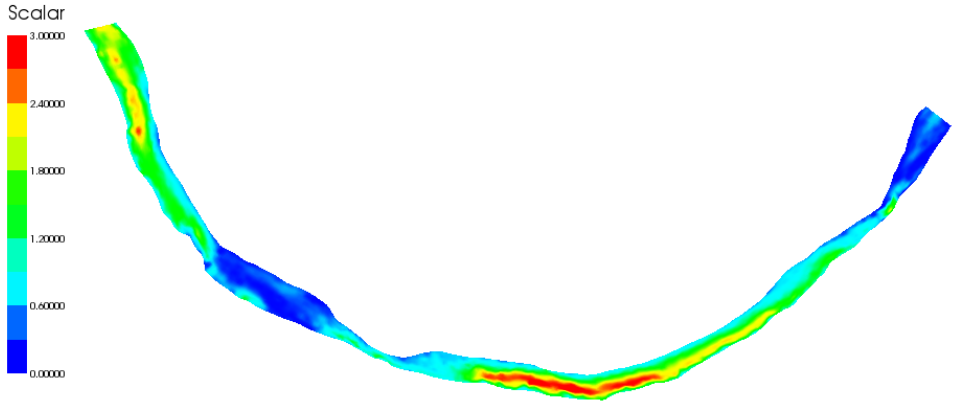
Hongcheon River

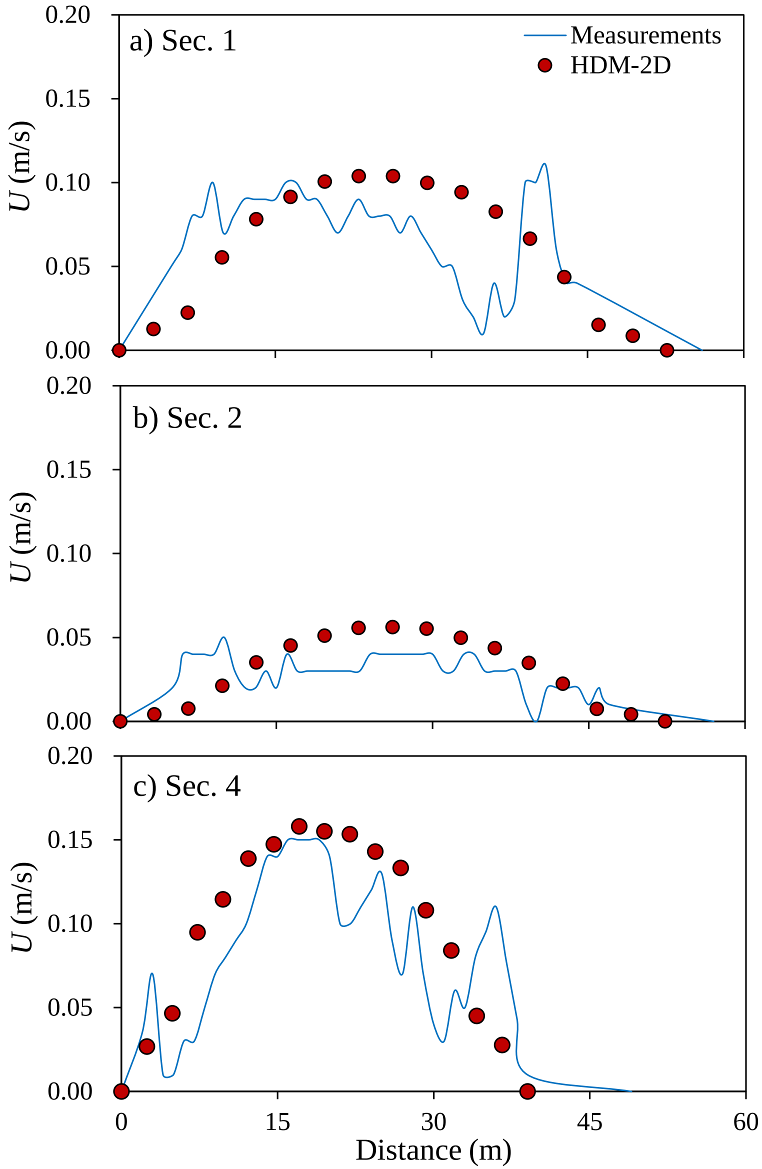
Simulation results of HDM-2D

Velocity magnitude



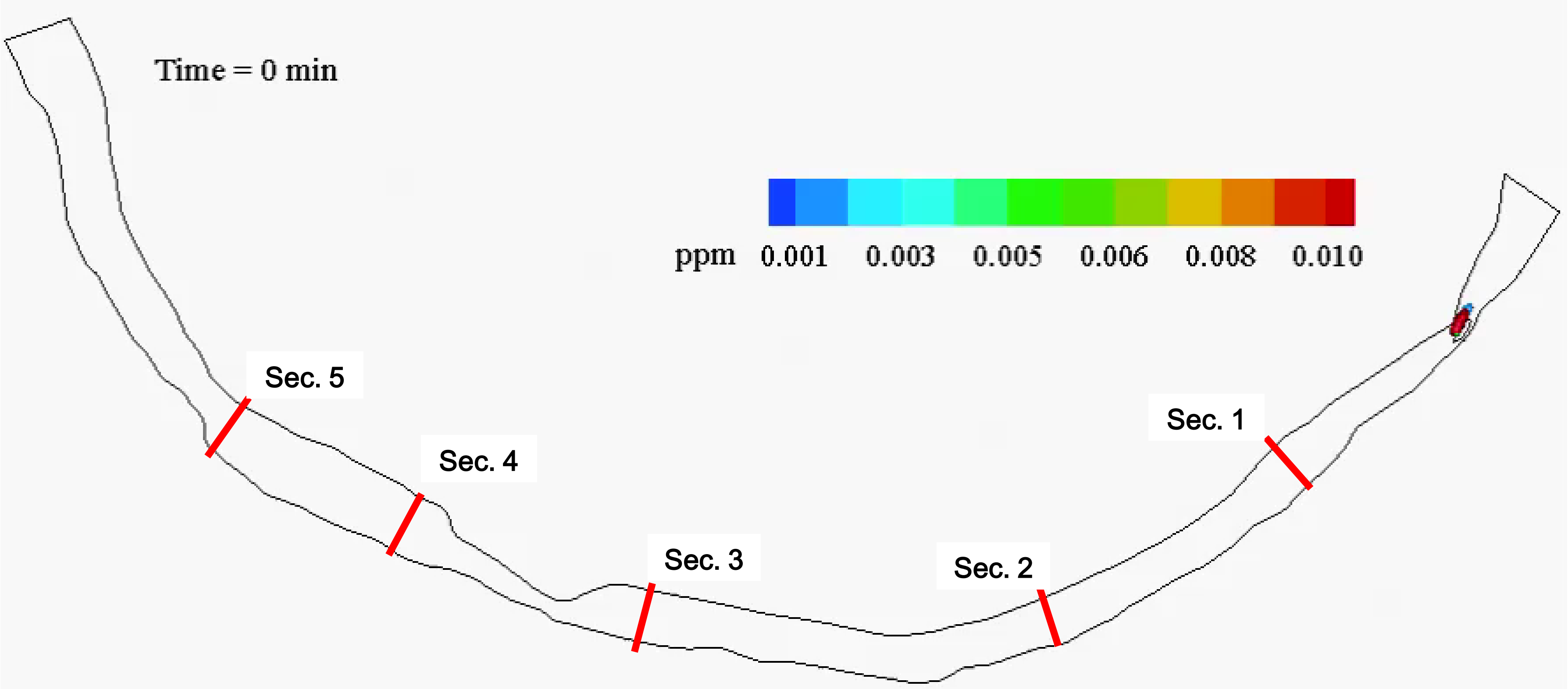
Water depth



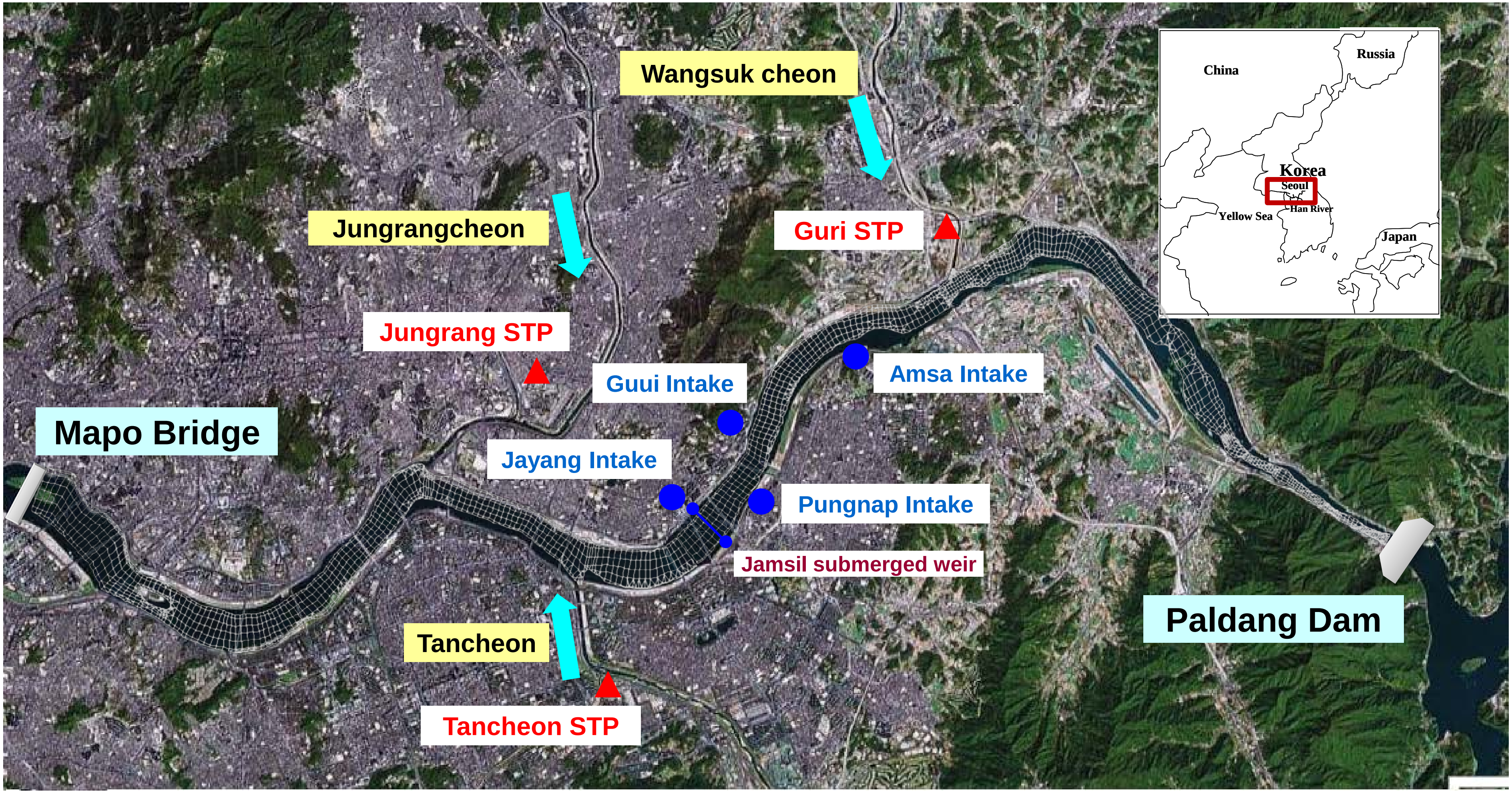


Hongcheon River

Simulation results of PDM-2D

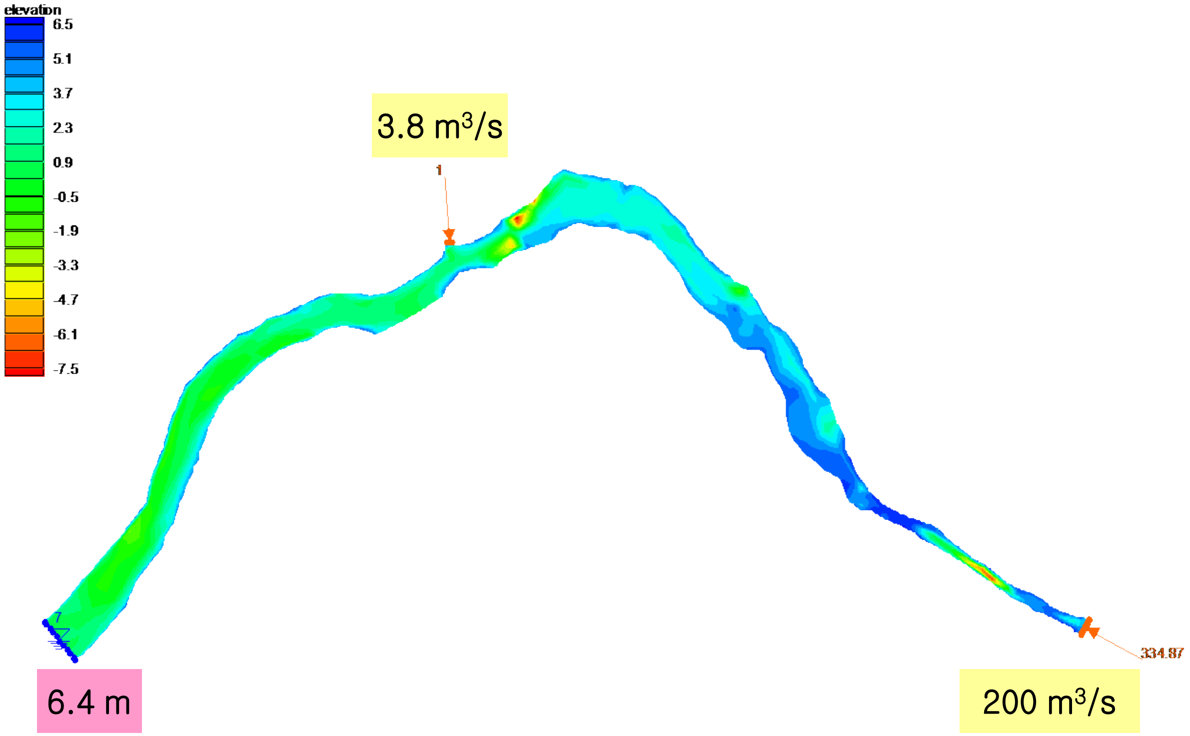


Pollutant mixing in the Han River



Upstream of Jamsil submerged weir : BOD scenario simulation

- **BOD mixing simulation conditions**



3.8 m^3/s

6.4 m

200 m^3/s

Scenario	Injection point	BOD effluent	BOD influent in Han River
1-1	Wangsuk Stream	20 ppm	12.5 ppm
1-2		150 ppm	75.8 ppm
1-3		150 ppm for 1st day, 20 ppm for remaining period	

4. River Modeling

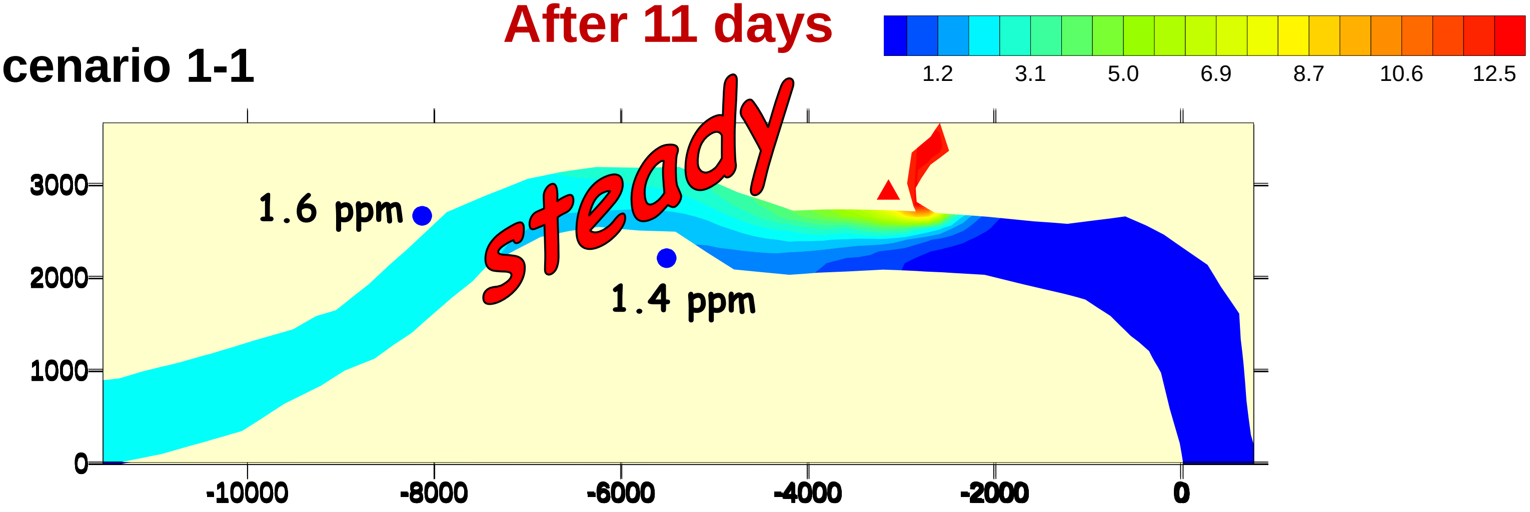
- RAMS application -

Upstream of Jamsil submerged weir : BOD scenario simulation

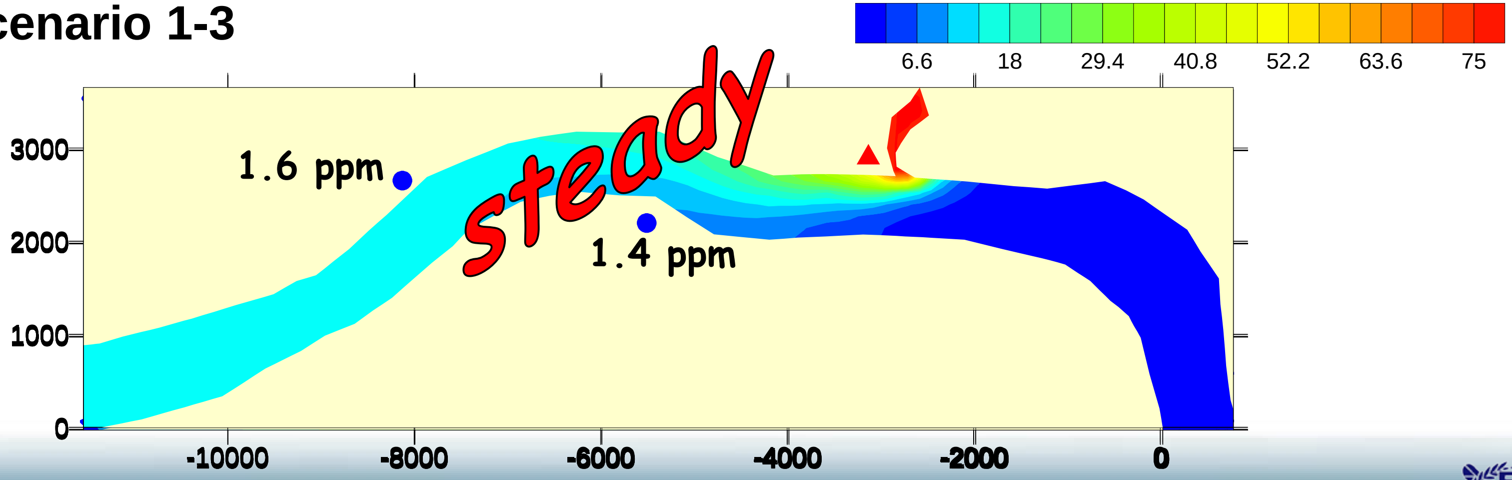
Concentration mixing results

After 11 days

- **Scenario 1-1**



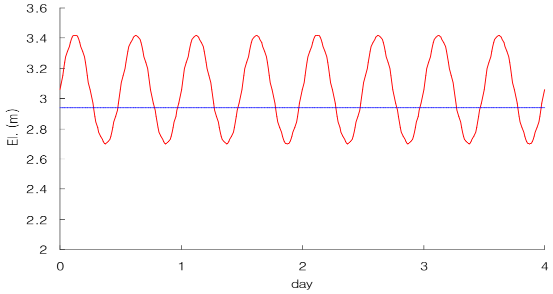
- **Scenario 1-3**

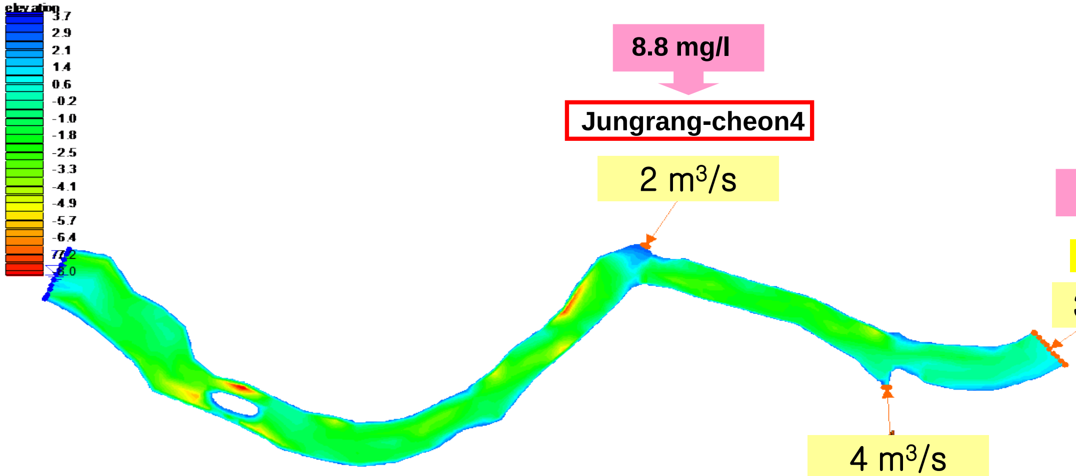


Downstream of Jamsil submerged weir : BOD scenario simulation

Flow and transport concentration simulation condition

Considering tidal datum vs. rest elevation





8.8 mg/l

Jungrang-cheon4

2 m^3/s

1.4 mg/l

Jamsil

336 m^3/s

4 m^3/s

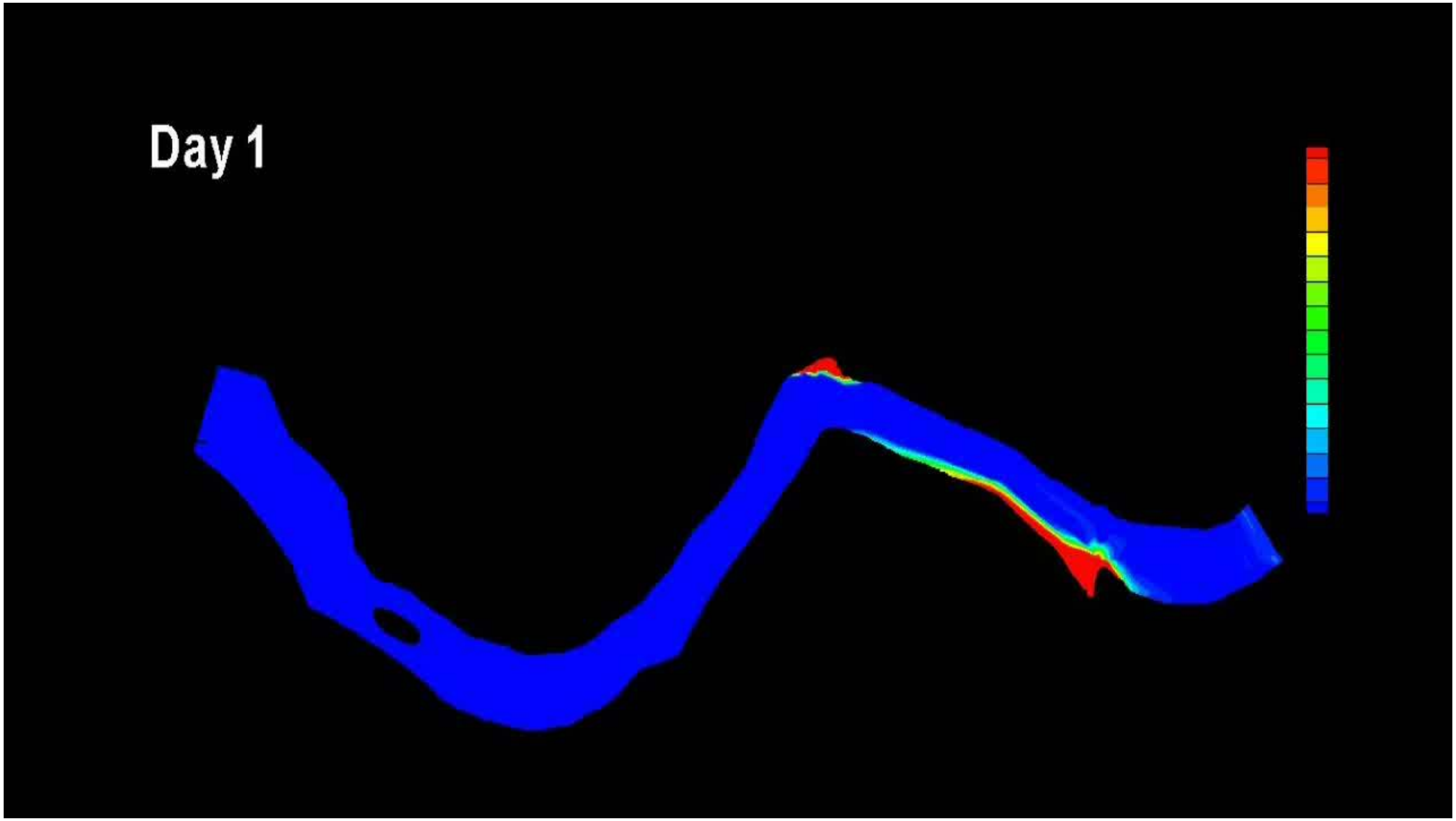
10.6 mg/l

Tan-cheon5

- RAMS application -

Downstream of Jamsil submerged weir : BOD scenario simulation

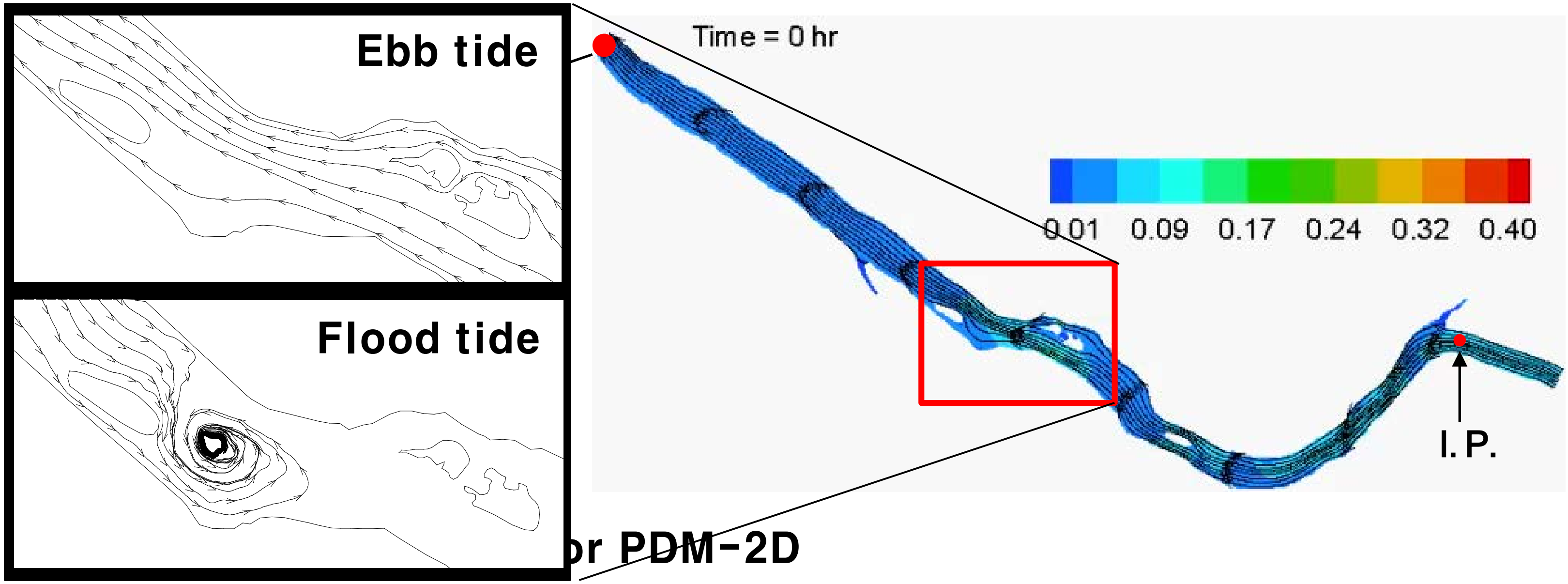
- **Concentration simulation results**



Downstream of Jamsil submerged weir : Phenol scenario simulation

- **Simulation of conservative pollutant mixing using PDM-2D**

Flow conditions (HDM-2D simulation results)

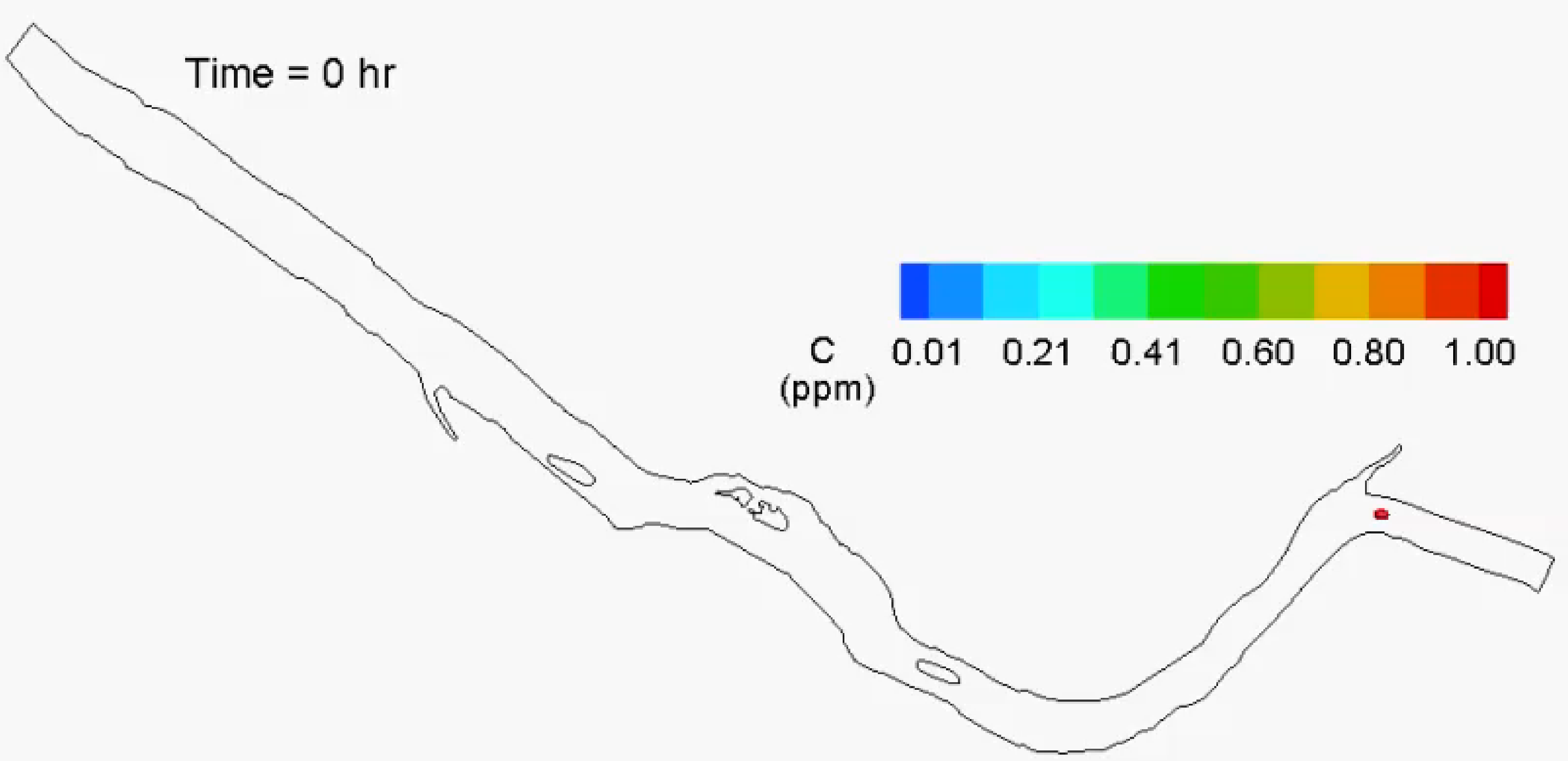


or PDM-2D

Q (m³/s)			Pollutant	Mass (kg)	No. of particles
Han River	Jurang Creek	Anyang Creek			
183.9	1.4	2.2	Phenol	1,000	10,000

Downstream of Jamsil submerged weir : Phenol scenario simulation

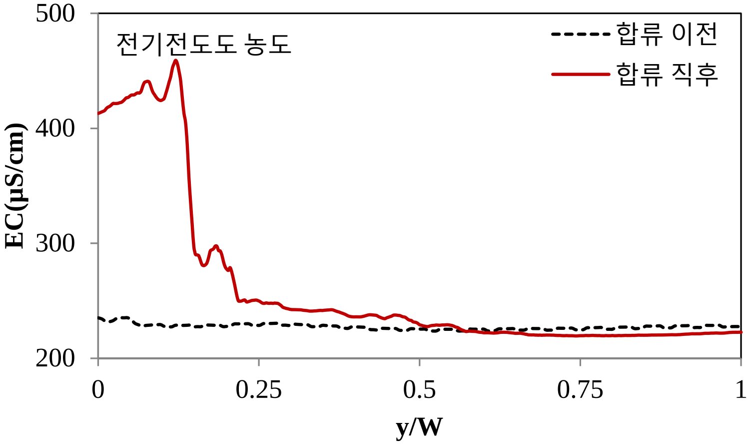
- **Simulation results using PDM-2D**



Nakdong River : Conservative pollutant mixing

Simulation conditions

- Capacity of plant : 80,000 tons/day
- 4th largest WWTP (waste water treatment plant) in Korea.



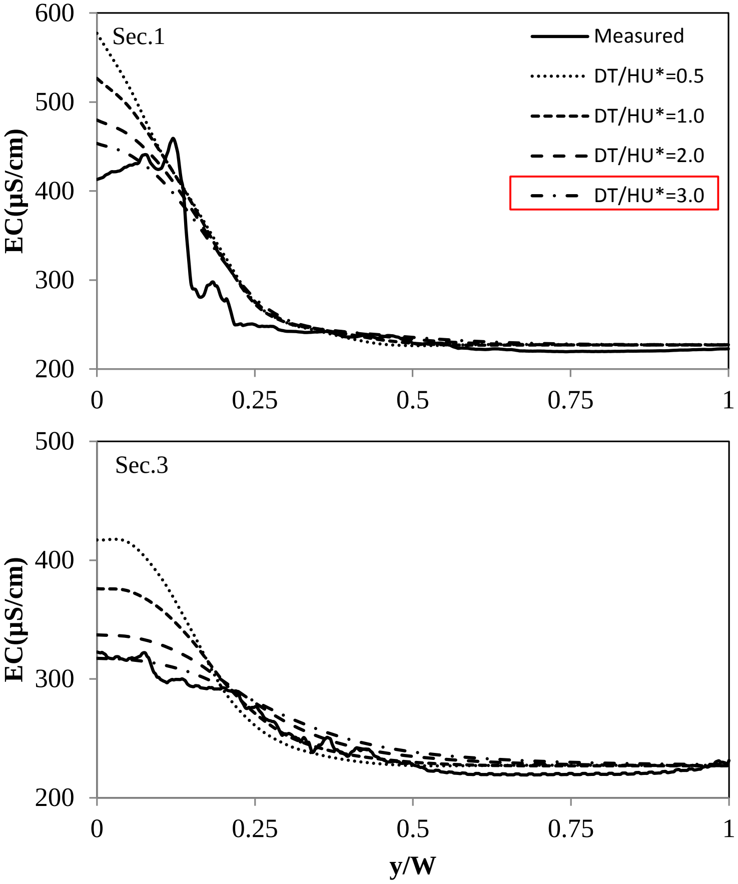
Contaminants from 2 tributaries cause high conductivity value in left bank

- Field tracer test conducted at downstream of confluence
- 2 tributaries are merging from left side of Nakdong River

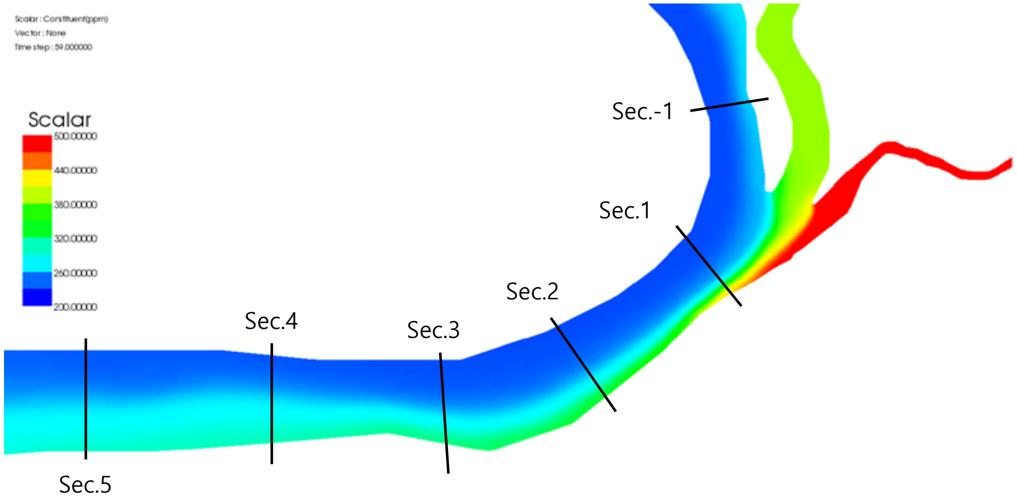
Nakdong River : Conservative pollutant mixing

Simulation results using CTM-2D

- Model calibrations with changing D_T



- Concentration distribution



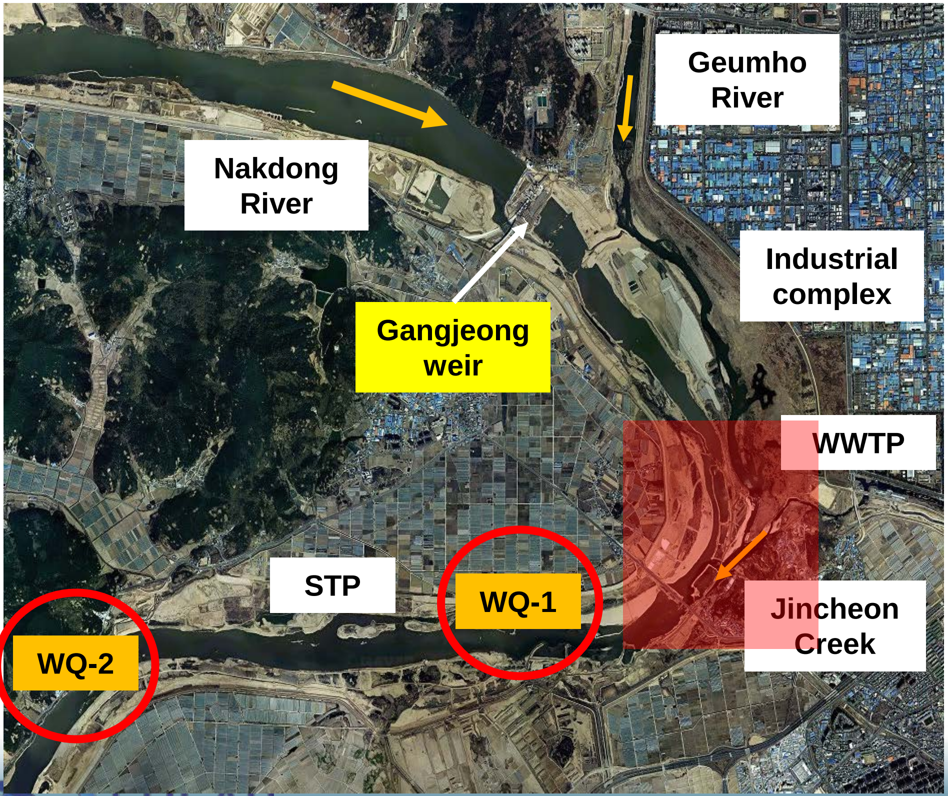
- Initial field of confluence (Sec.1) showed high conductivity value in left

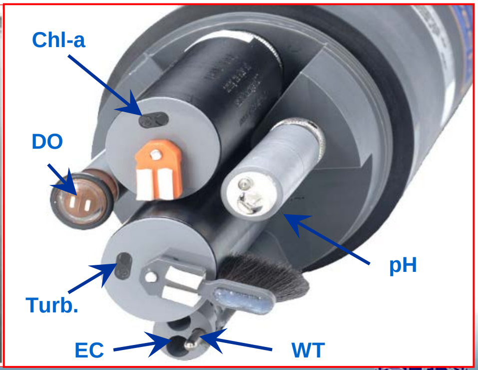
- As cloud moving further downstream, conductivity gradient decreased

Diatom Prediction

Diatom bloom in the Nakdong River, South Korea

- Diatom blooms in spring and winter to impact on water quality deterioration
- Model calibration and validation using daily observation data





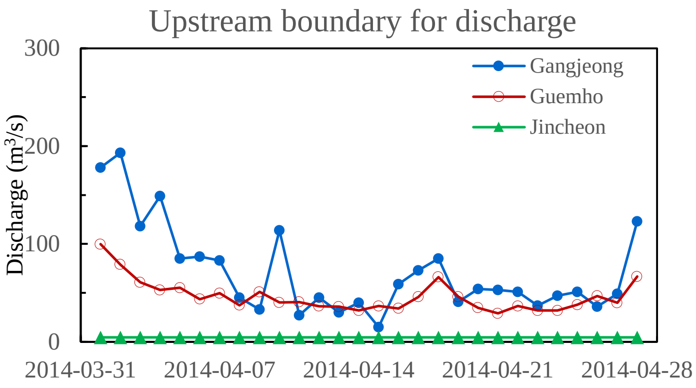
Diatom Prediction

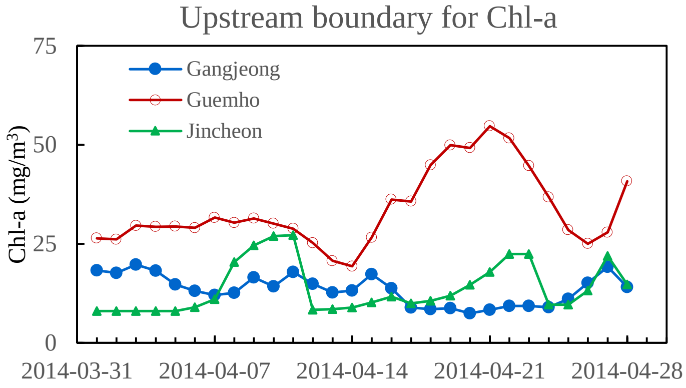
Continuous injection on unsteady regime

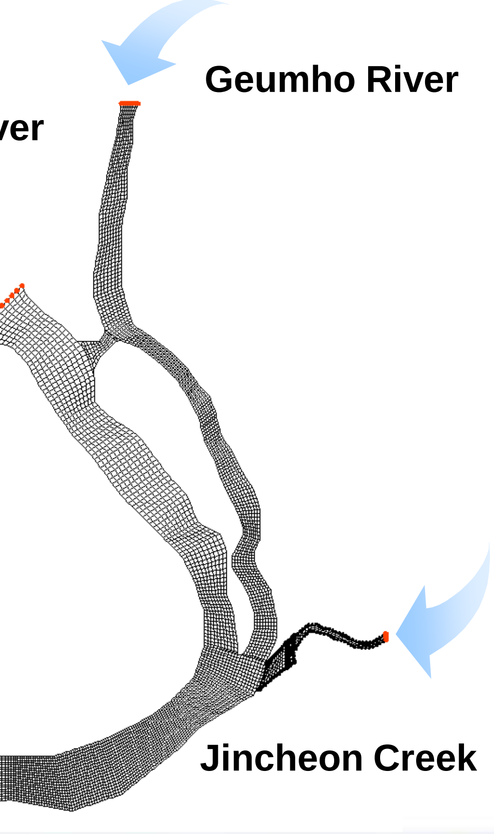
- Daily concentration and discharge used for initial and boundary condition

WQ inputs	D_L (m²/s)	D_T (m²/s)	# of node	△t (hr)
Chl-a, Temp, TP, TN	4.9	0.23	19,902	1

- Model calibration period: 2014.04.01 – 04.28
- Model validation period: 2014.11.01 – 11.28

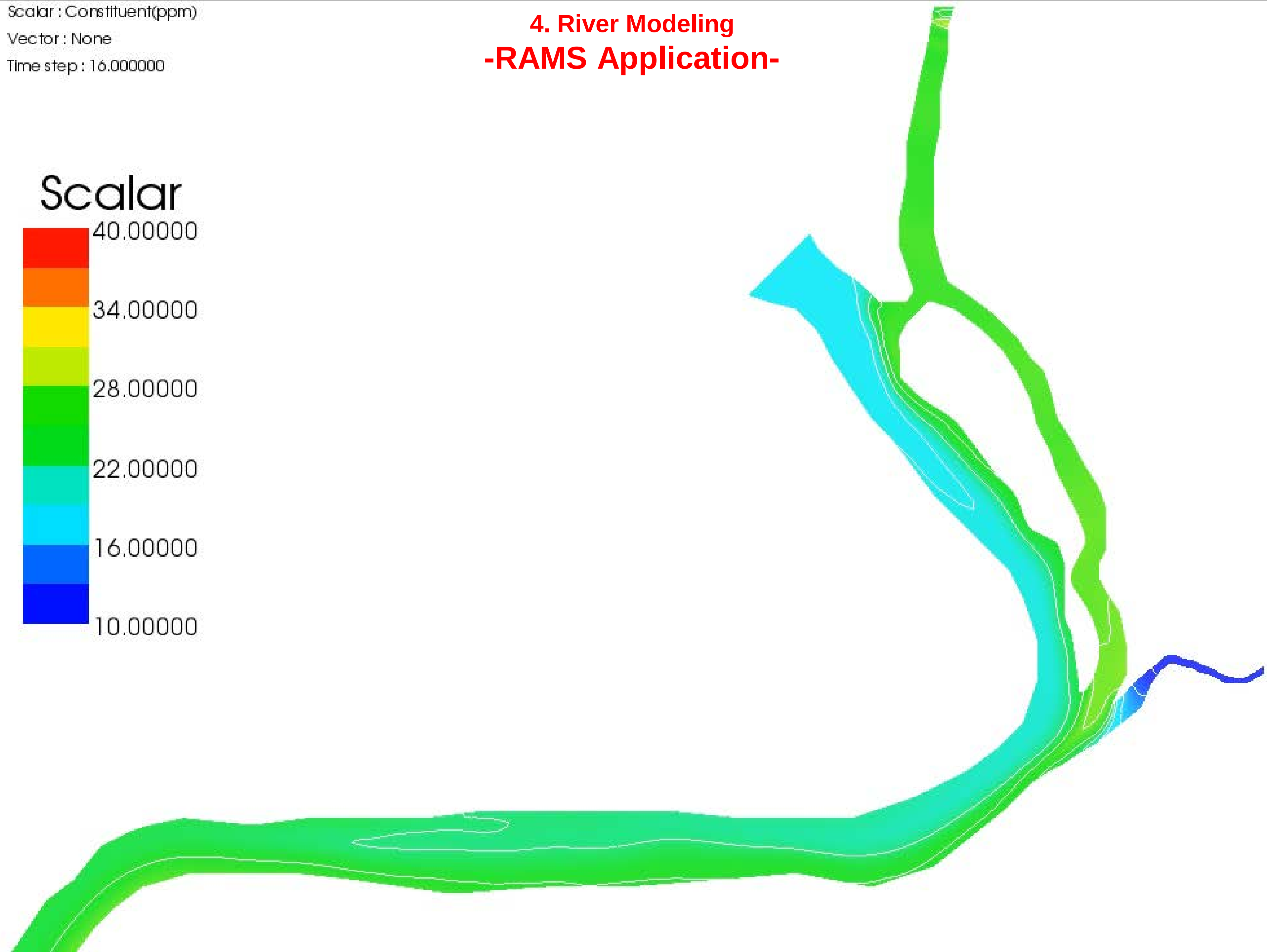


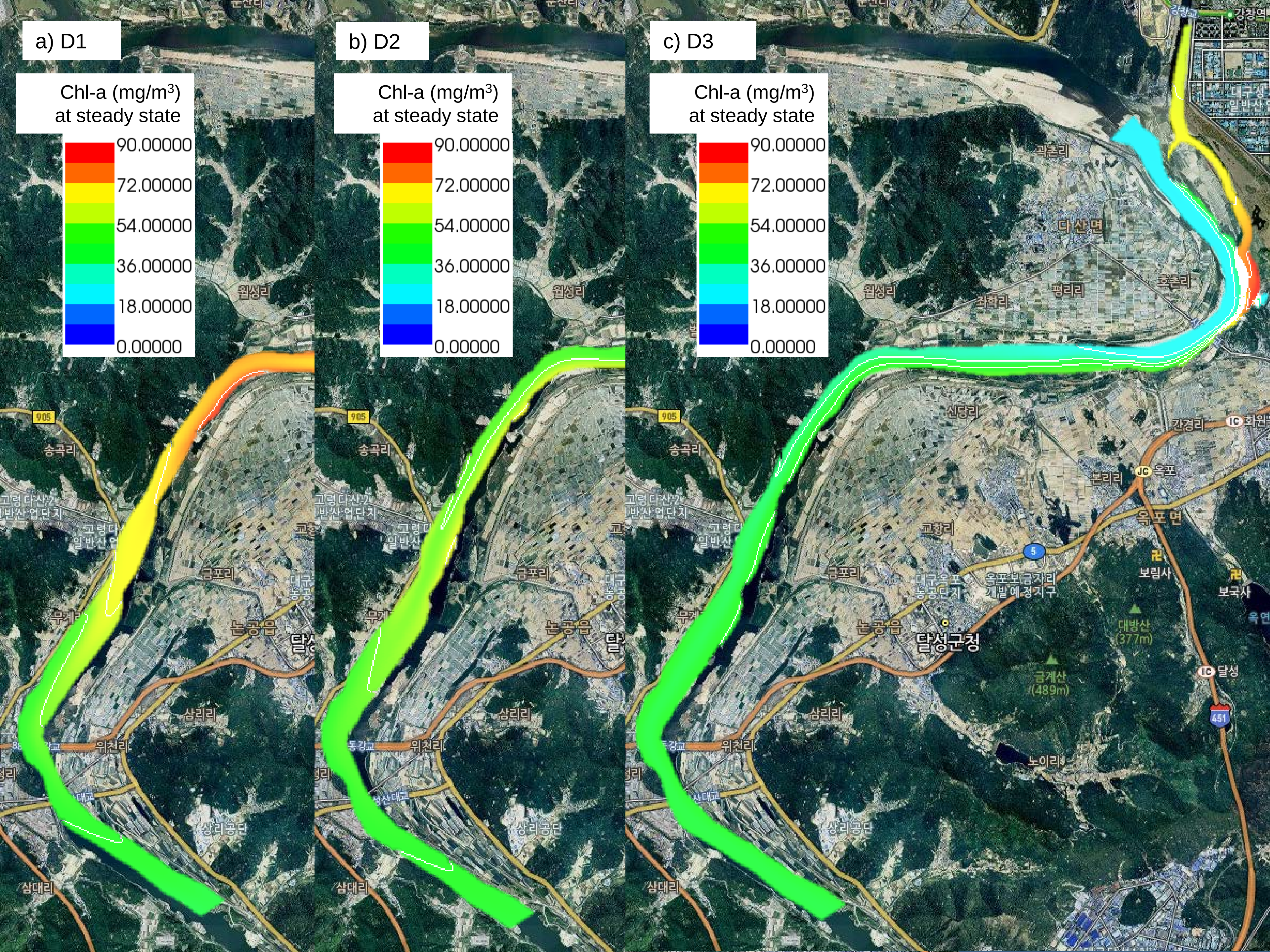




4. River Modeling

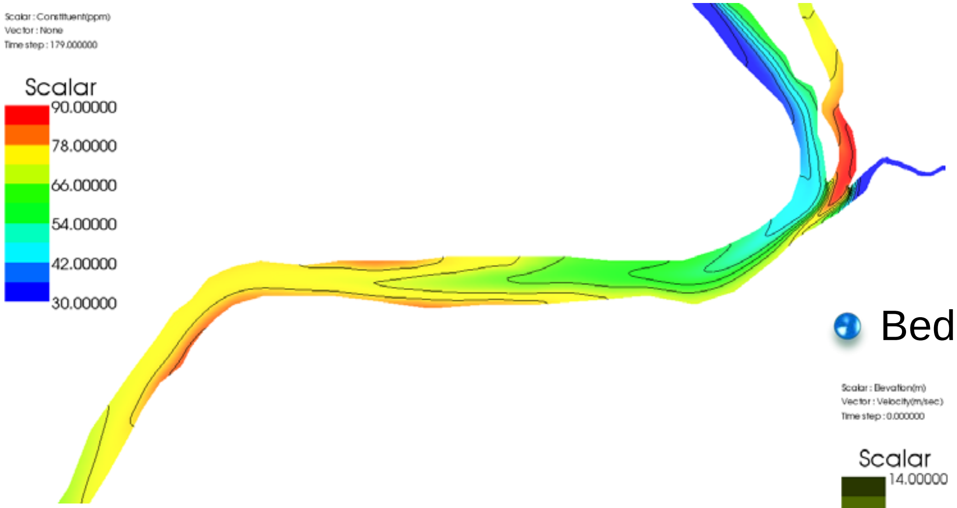
-RAMS Application-




a) D1
b) D2
c) D3
Chl-a (mg/m³) at steady state
90.00000
72.00000
54.00000
36.00000
18.00000
0.00000
905
송곡리
원성리
구포리
논공읍
달성군청
삼리리
위천리
삼대리
상리공단
다산면
평리리
곽촌리
호촌리
신당리
고정리
본리리
간경리
옥포
옥포면
옥포보금자리 개발예정지구
보림사
보국사
대방산 (377m)
금계산 (489m)
노이리
달성
451
5

Diatom Prediction

- Spatial distribution of diatom bloom at steady state
  - Diatom blooming area (D1):



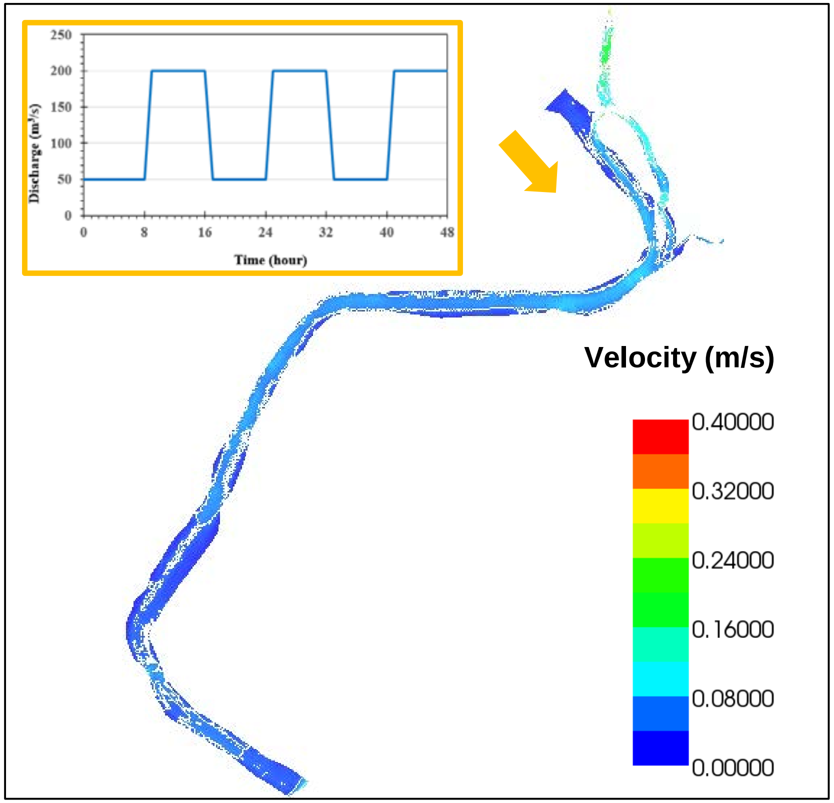
High concentration of diatom simulated at shallow water zones with sufficient light intensity for photosynthesis

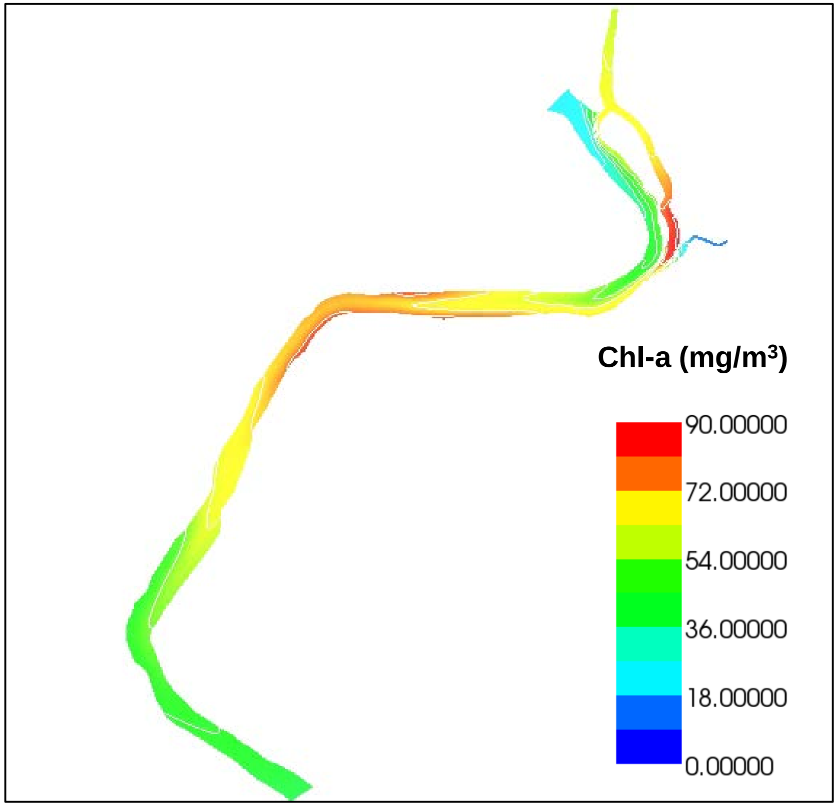
Shallow water zone with low velocity developed along bank of the river

- Bed elevation

Diatom Prediction

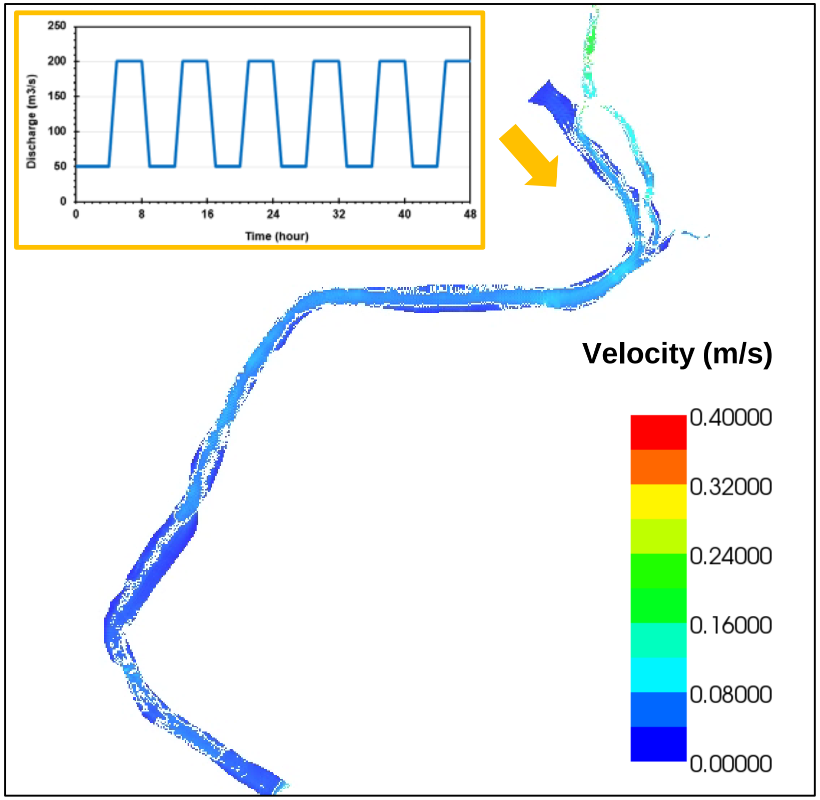
- **Unsteady simulation with pulse discharge: scenario PD1**
  - Discharge 200 m³/s from Ganjeong weir 3 times (each for 8 hours) during 2 days

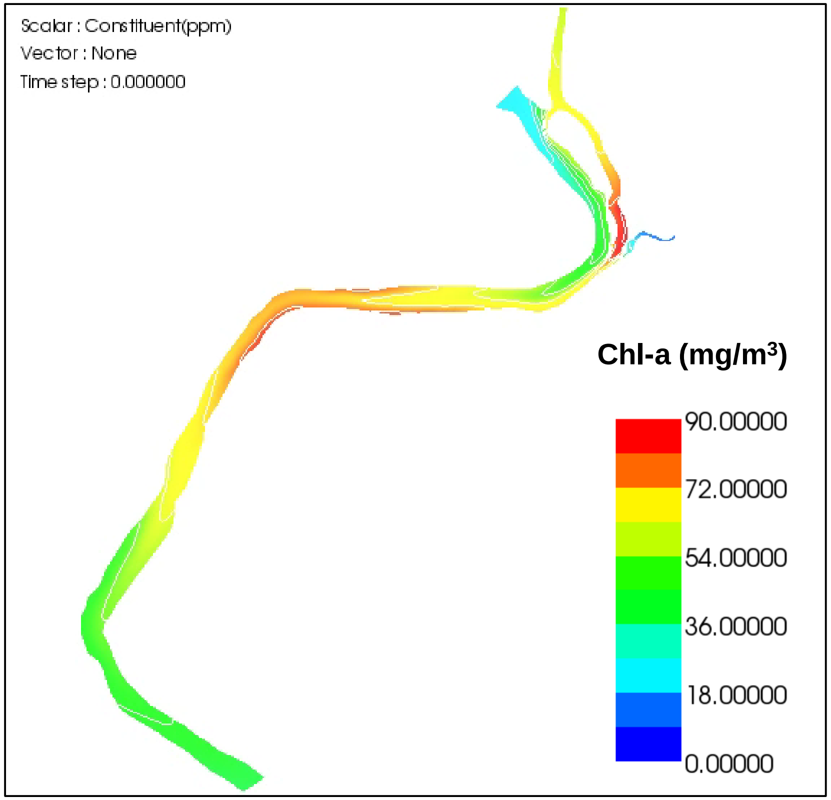




Diatom Prediction

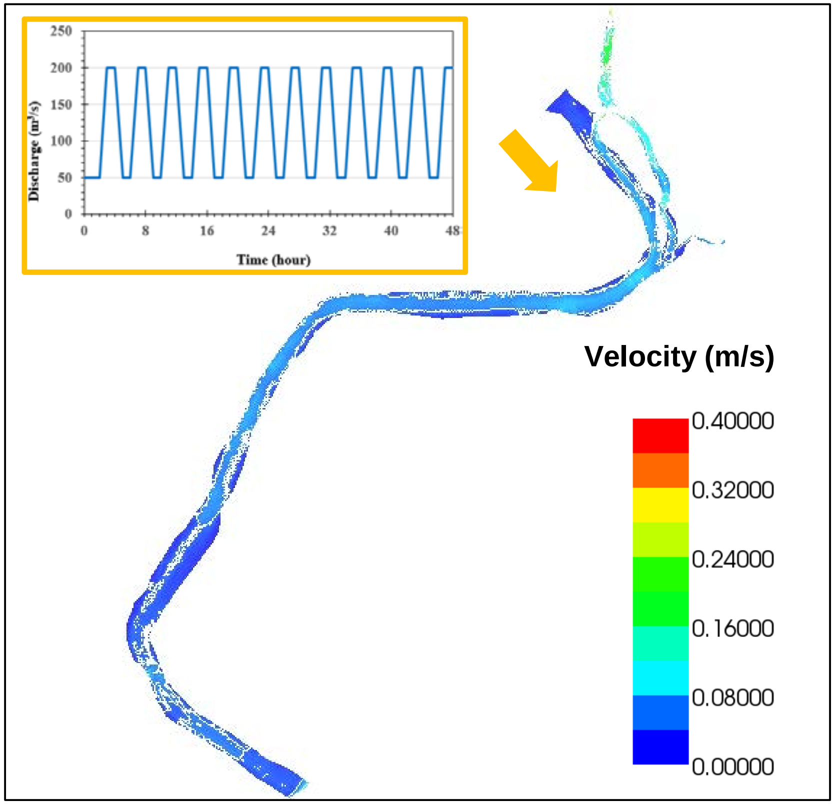
- **Unsteady simulation with pulse discharge: scenario PD2**
  - Discharge 200 m³/s from Ganjeong weir 6 times (each for 4 hours) during 2 days

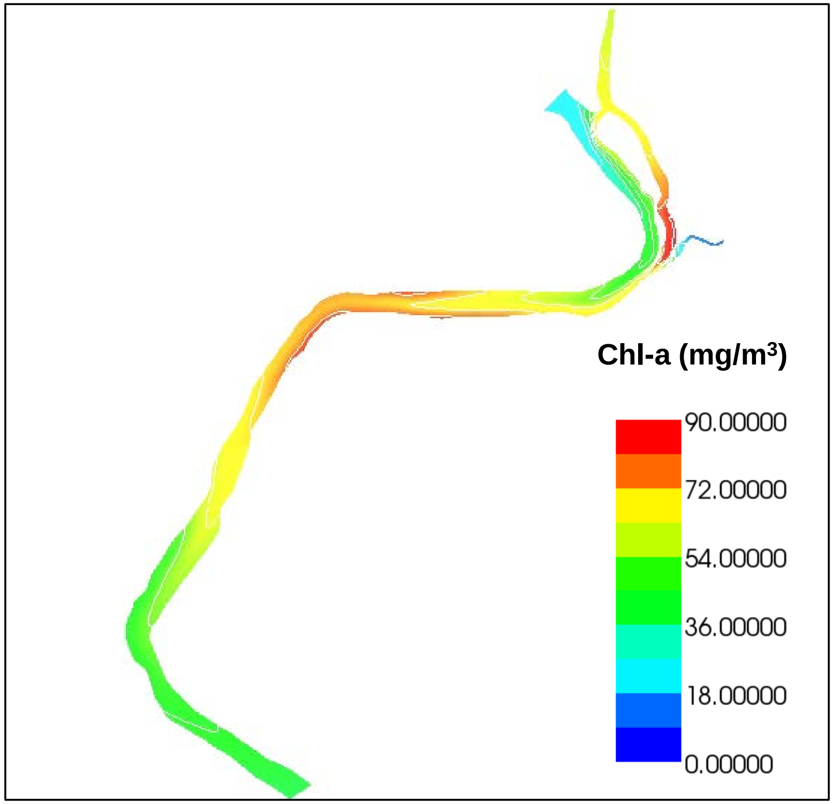




Diatom Prediction

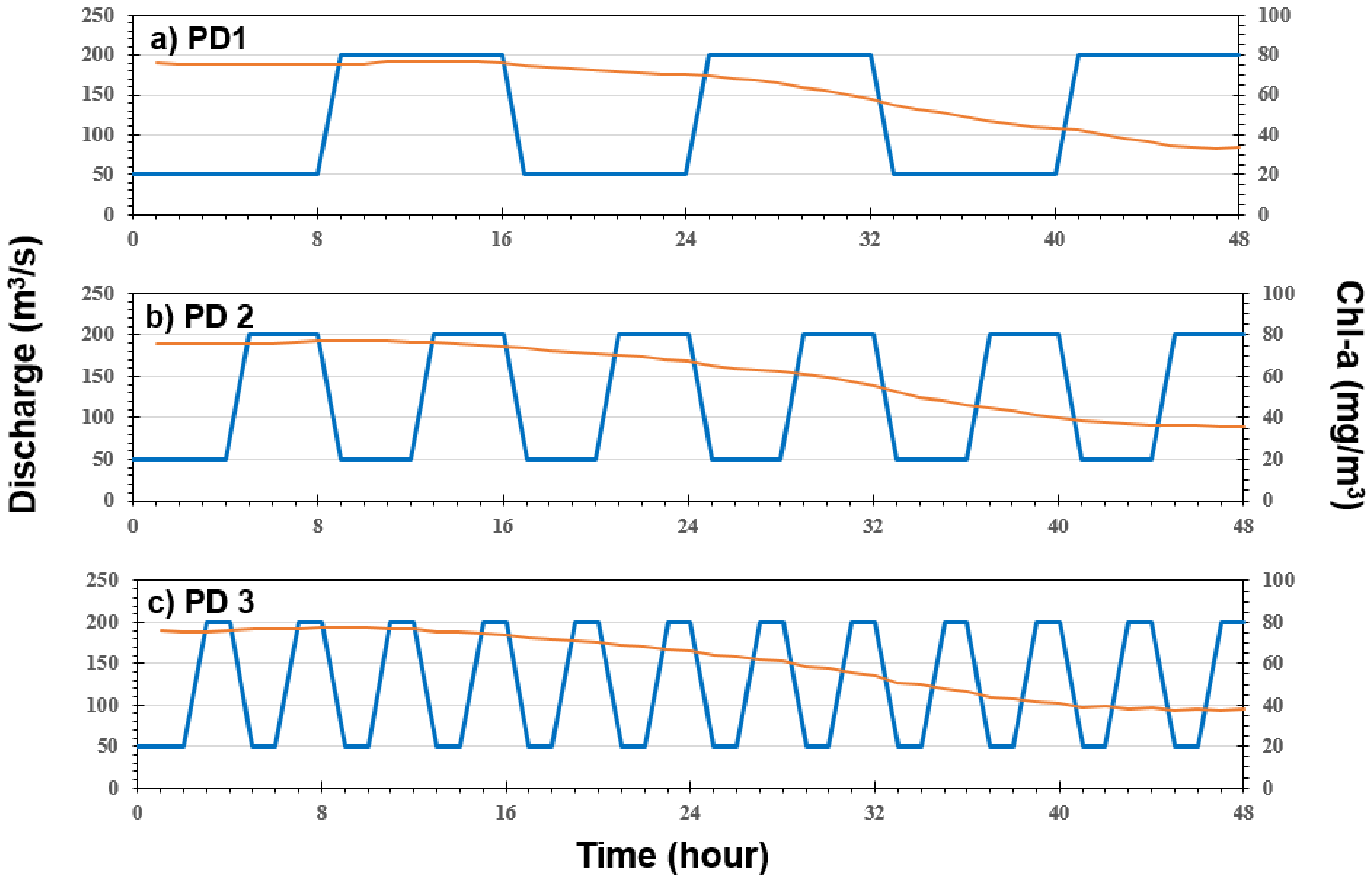
- **Unsteady simulation with pulse discharge: scenario PD3**
  - Discharge 200 m³/s from Ganjeong weir 12 times (each for 2 hours) during 2 days





Diatom Prediction

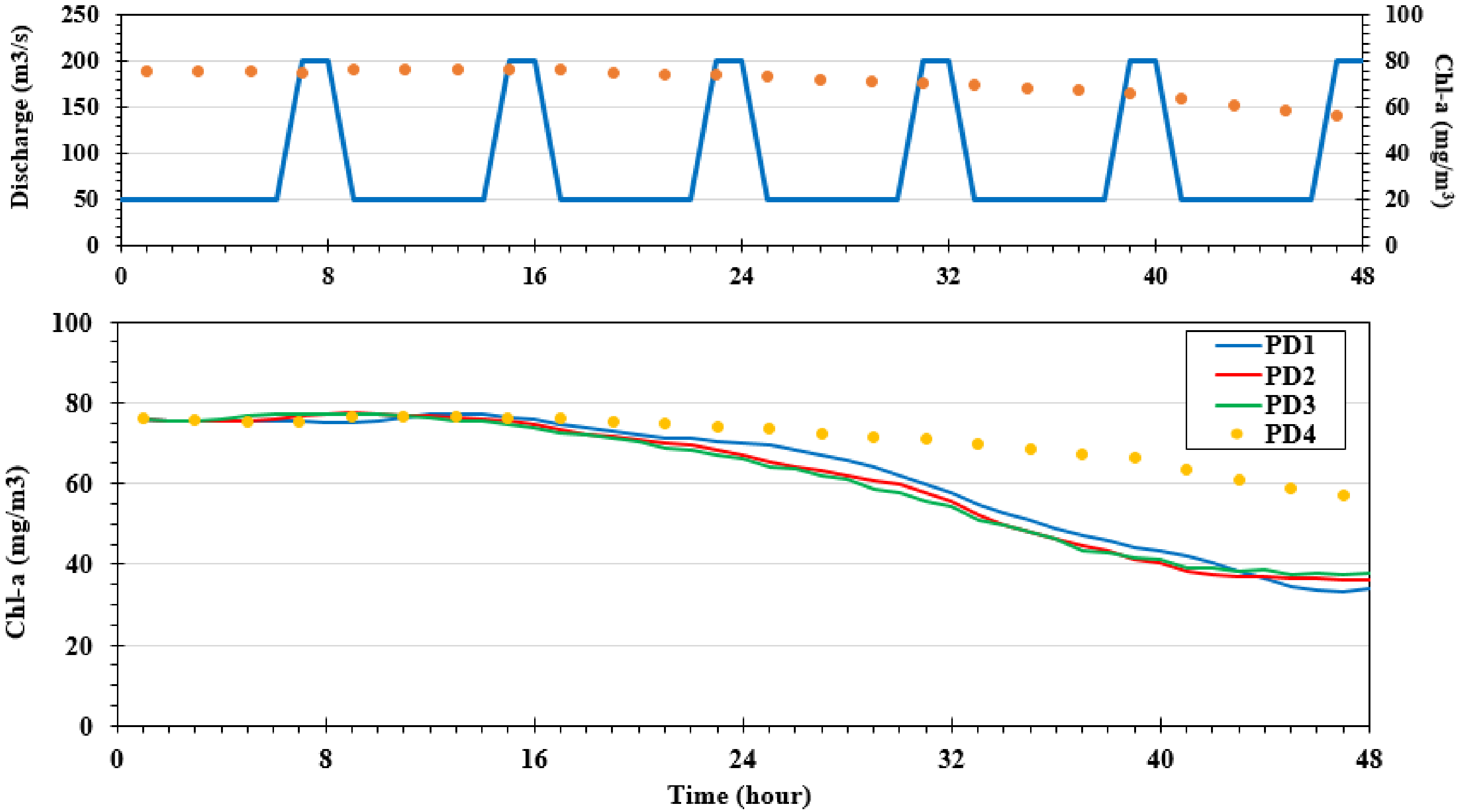
- **Simulation results at WQ-2 station**



Diatom Prediction

Unsteady simulation with pulse discharge: scenario PD4

- Discharge 200 m³/s from Ganjeong weir 6 times (each for 2 hours) during 2 days



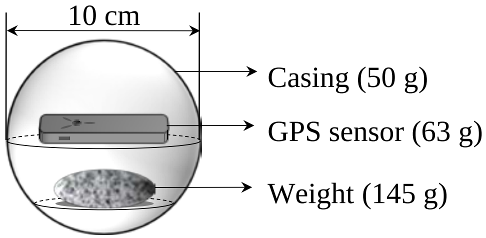
Nakdong River Buoyant Contaminant Mixing Modeling

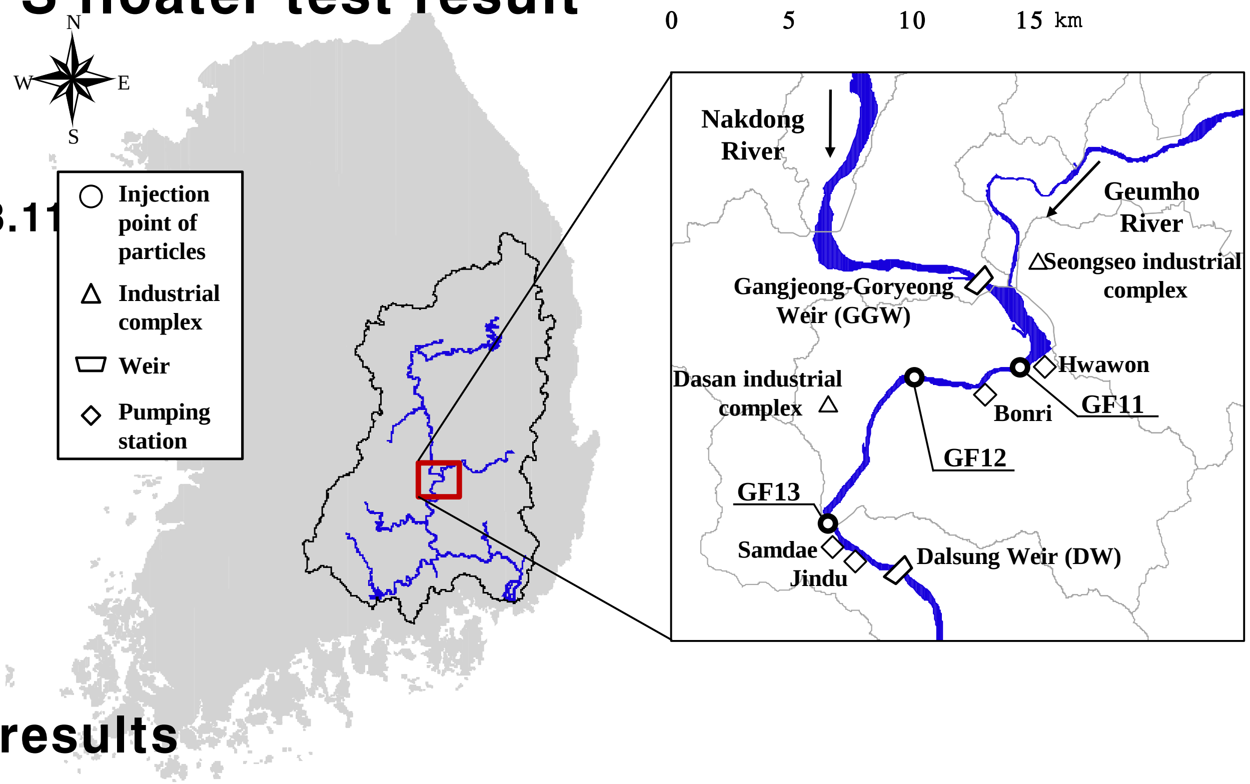
Nakdong River GPS floater test result

Outline

Field test: 2012.05 ~ 2013.11

GPS floater



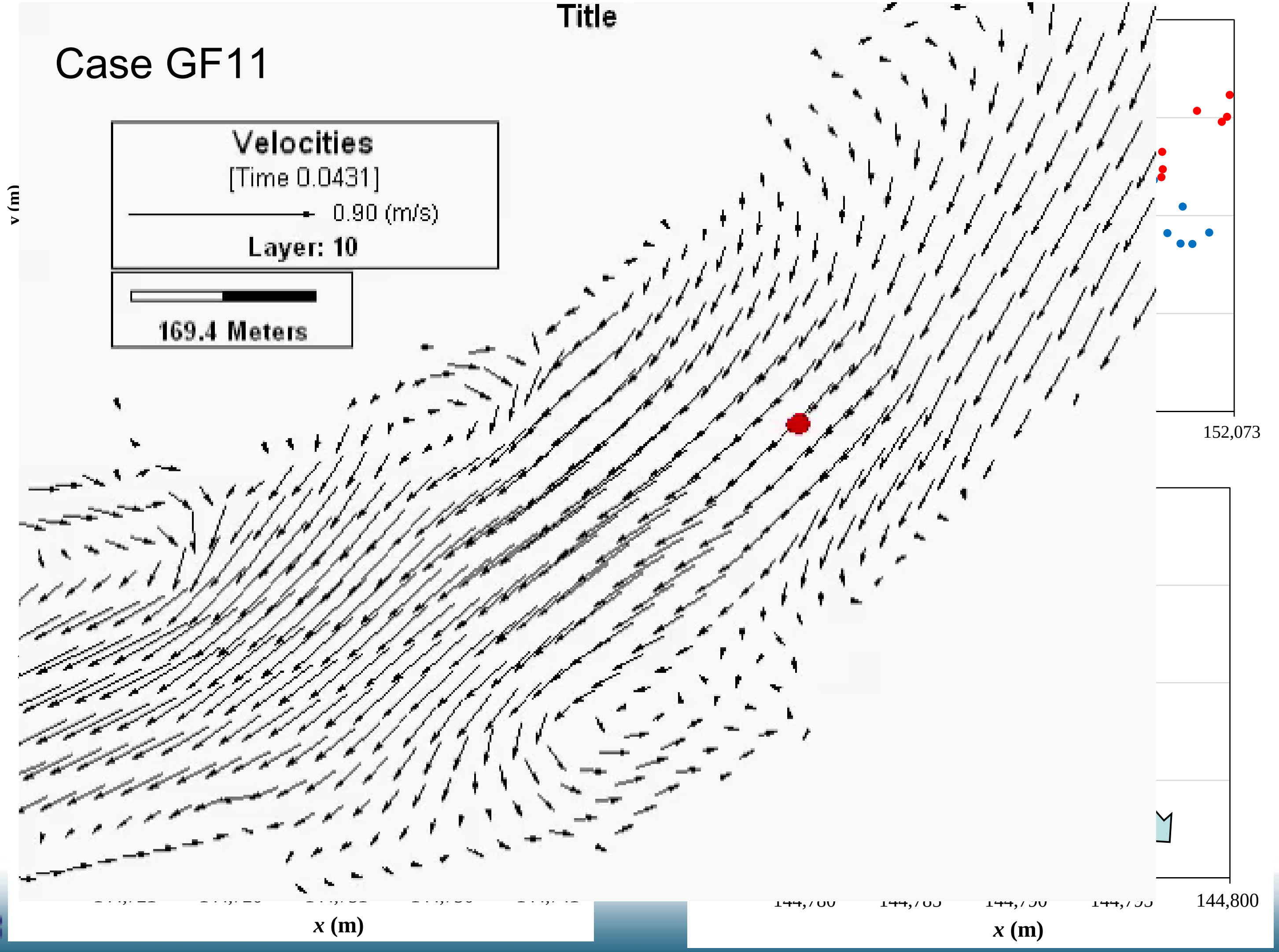


EFDC simulation results

Case	Q (m^3/s)	h (m)	K_H (m^2/s)	Wind (m/s)	No. of layer	No. of particles
GF11	547	6.0	0.027	0.15	10	35
GF12	681	7.1	0.007	0.50	10	24
GF13	697	8.5	0.002	0.50	10	30

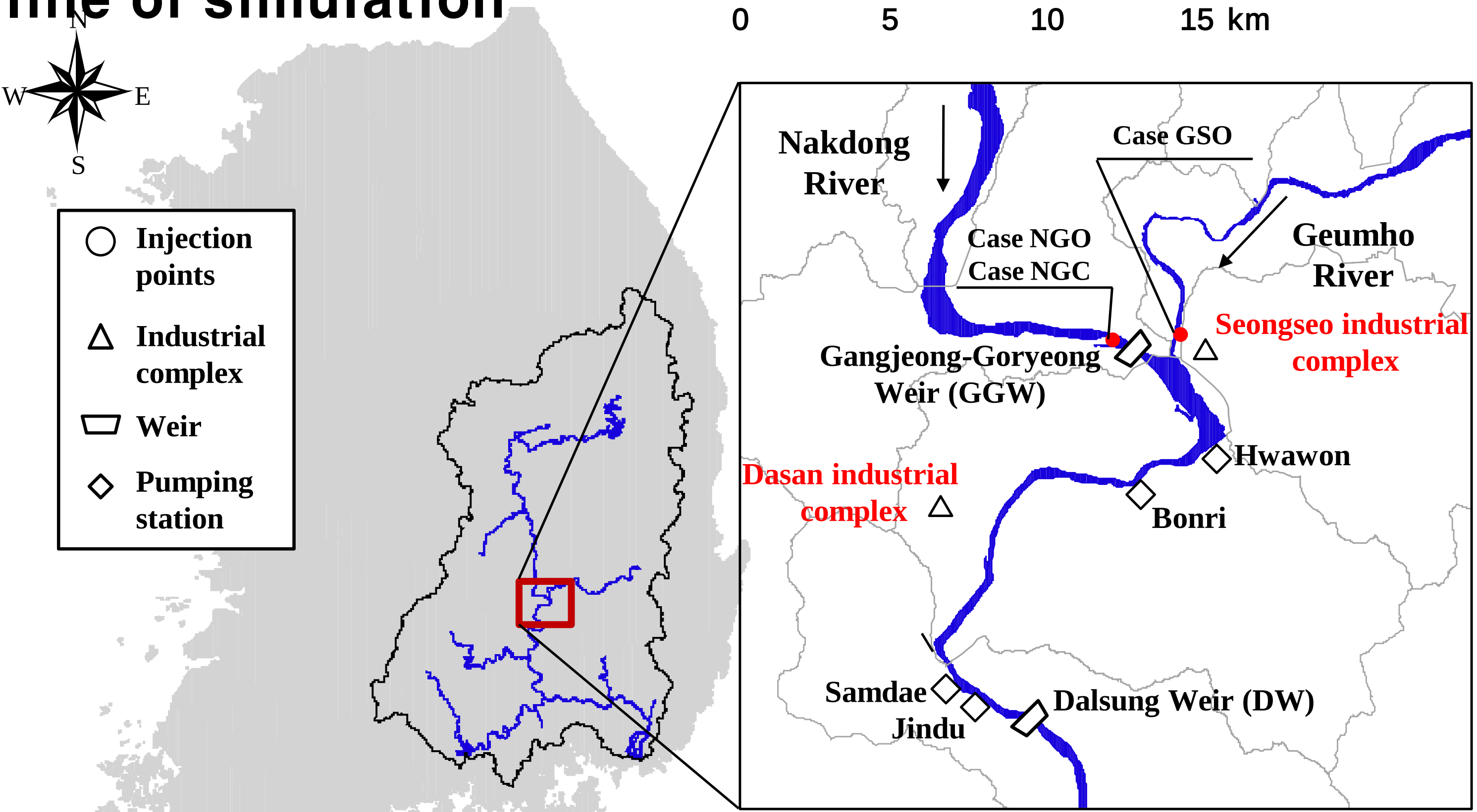
Nakdong River Buoyant Contaminant Mixing Modeling

- **Comparison of particle dispersion**



Water pollution accidents in the Nakdong River

Outline of simulation



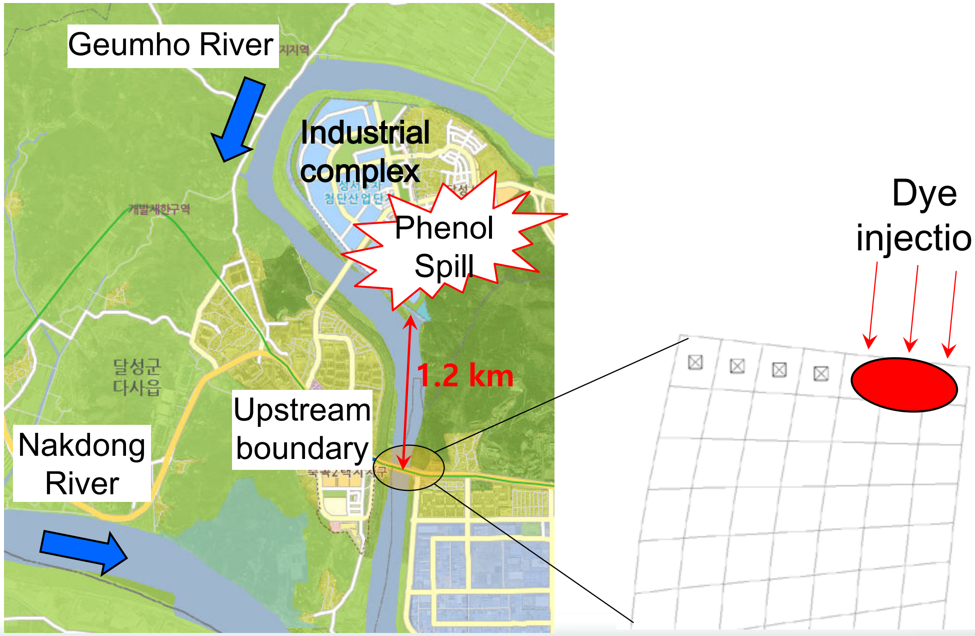
Case	Injection point	Accident	Weir operation	Model
GSO	Geumho River	Phenol spill from the Seongseo industrial complex	Open	Dye
NGO	Nakdong River	Oil spill from the Gangjeong-Goryeong Weir	Open	LPT
NGC			Close	

Water pollution accidents in the Nakdong River

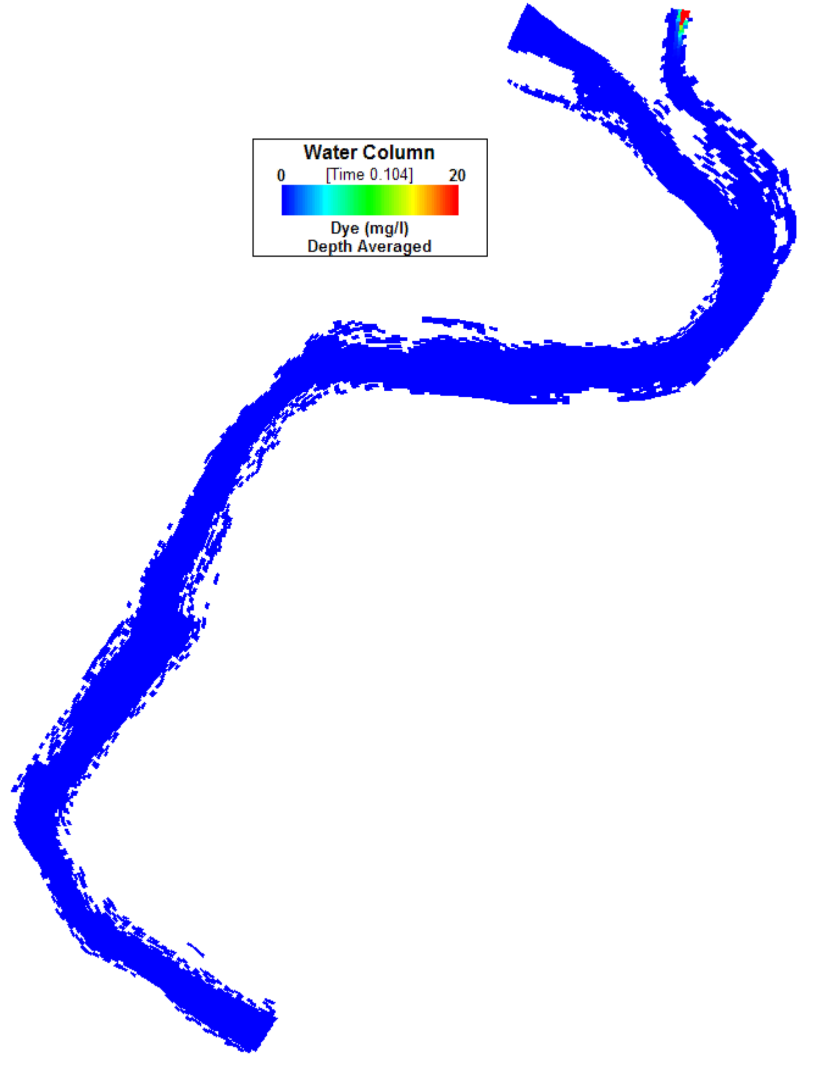
Case GSO

- Distance for transverse mixing completion

$$L = 0.4U\frac{W^2}{\varepsilon_t} = 0.4\times 0.02\times\frac{200^2}{0.1} = 3.2\ \text{km}$$



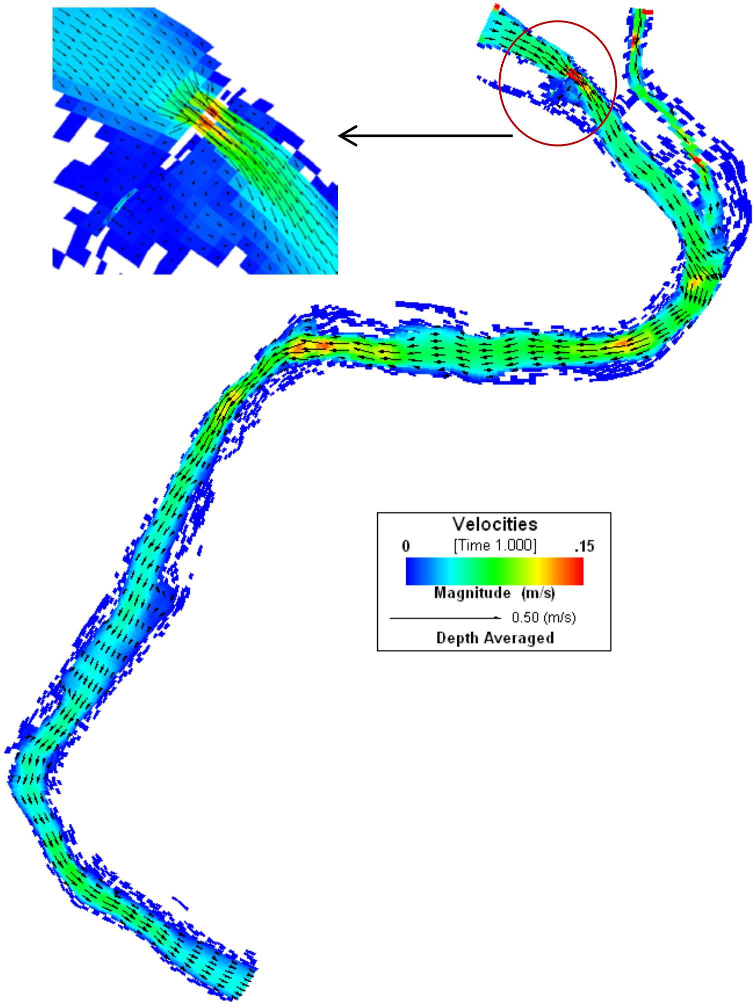
Simulation results



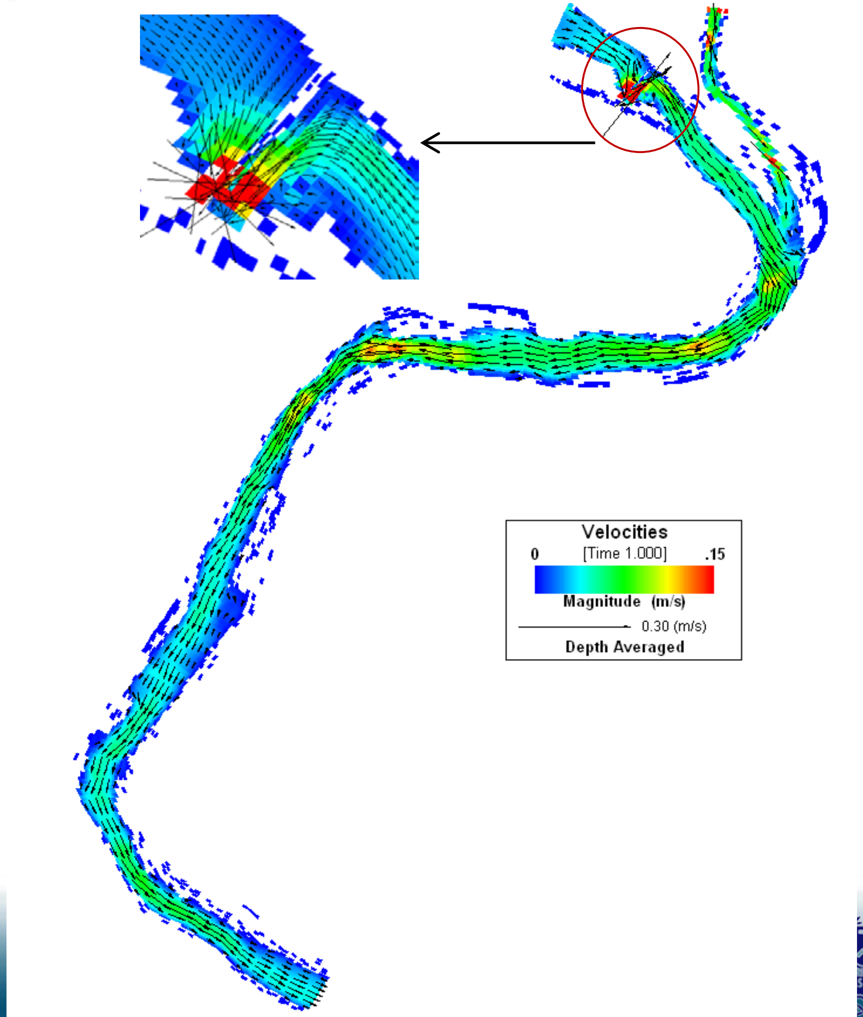
Water pollution accidents in the Nakdong River

Simulation results according to weir operation

- Case NGO

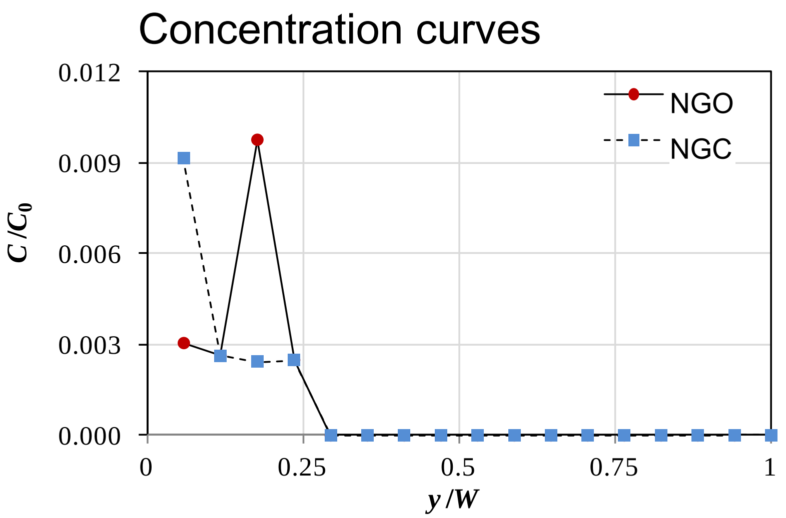


- Case NGC



Water pollution accidents in the Nakdong River

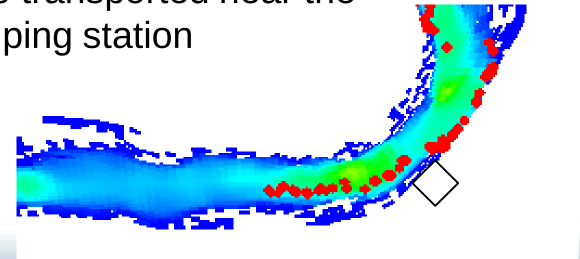
Particle distributions

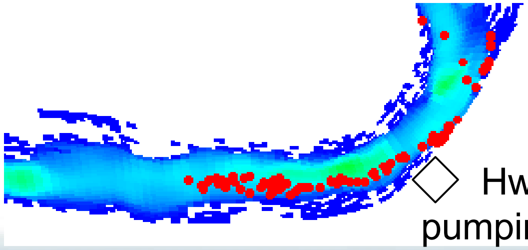

Concentration curves

- C_p of Case NGC is higher than Case NGO at the left bank
- More particles were accumulated near the pumping station when the gate was closed

- *t* = 32 hr

Particles were transported near the Hwawon pumping station



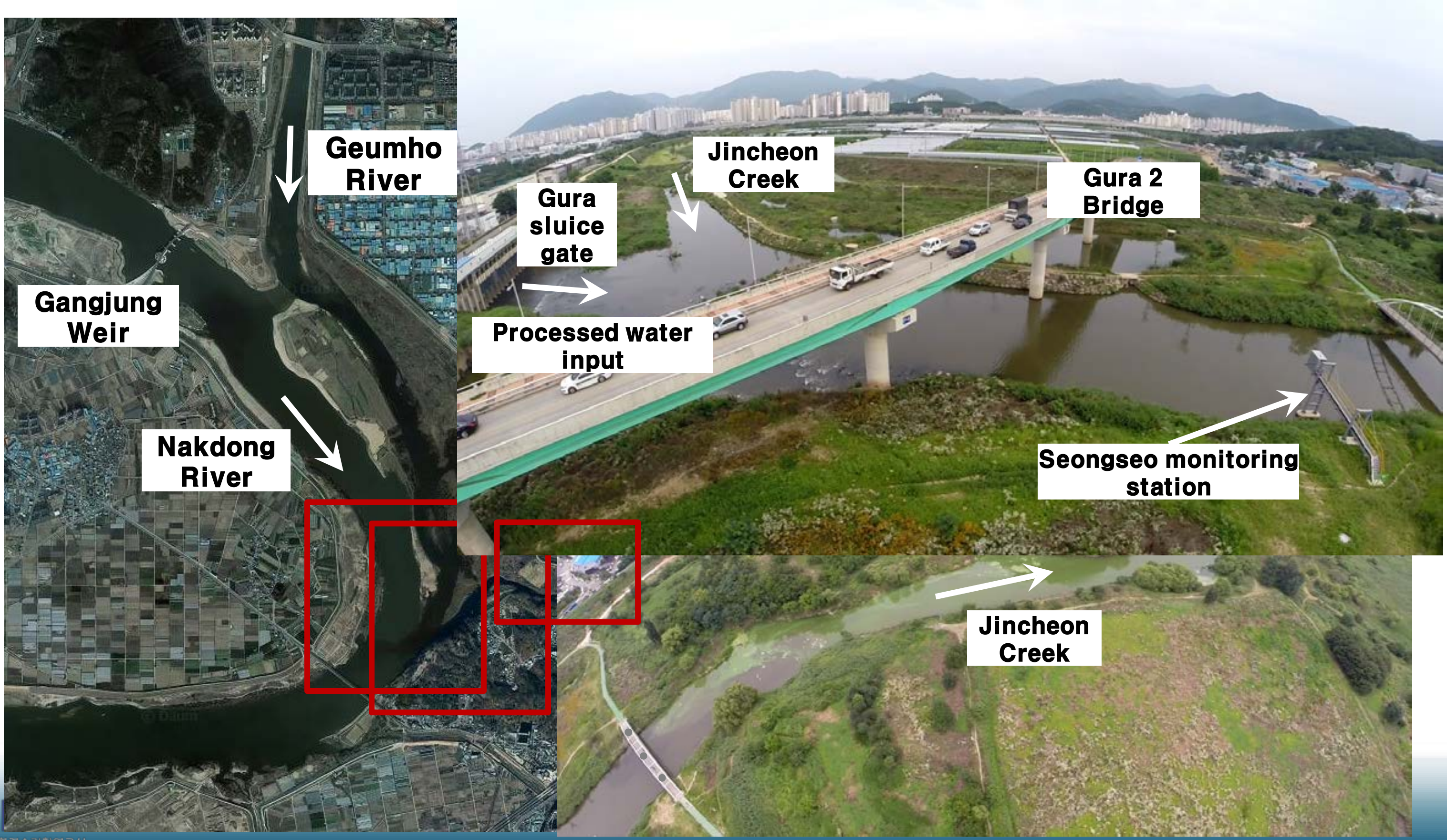


Hwawon pumping station

Nakdong River EC Mixing Modeling

- **Nakdong EC tracer test result comparison**
  - **Outline**

Field experiment date: 2014.05 ~ 2014.11

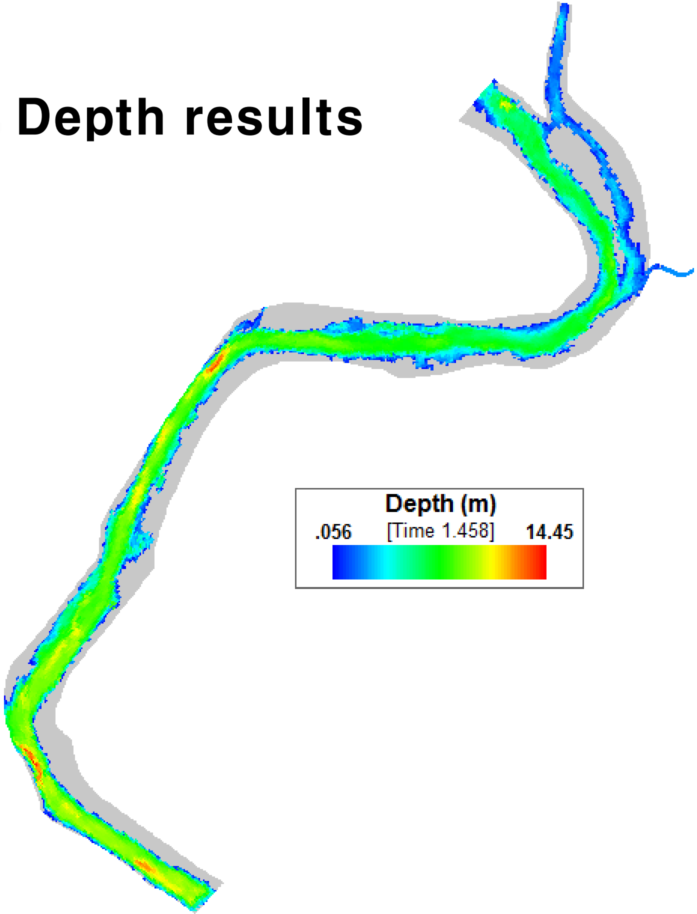


Nakdong River EC Mixing Modeling

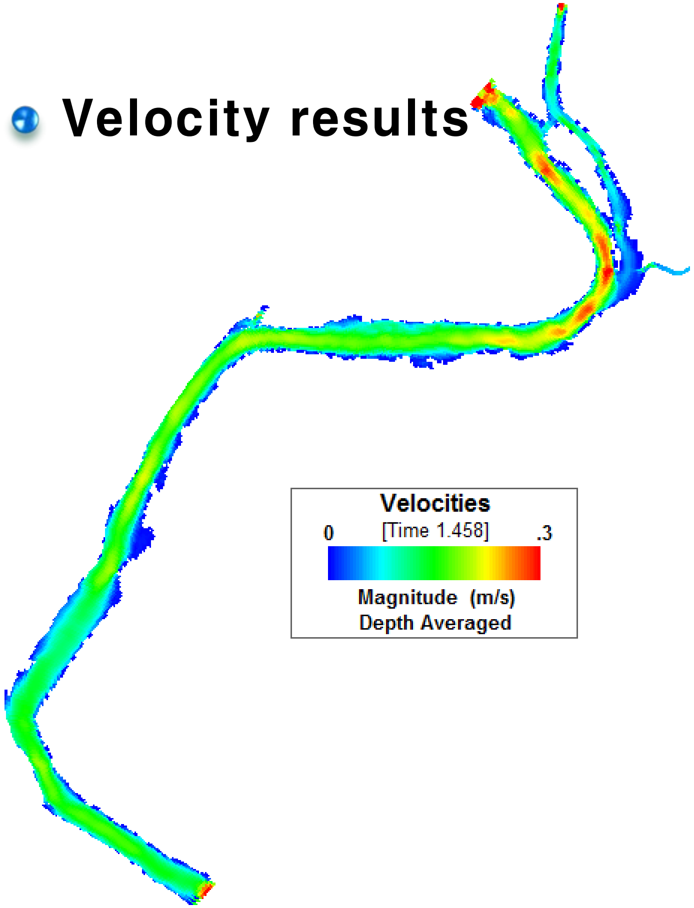
Numerical boundary conditions

Q_N (m^3/s)	Q_G (m^3/s)	Q_J (m^3/s)	EC_N (uS/cm)	EC_G (uS/cm)	EC_J (uS/cm)	A_H (m^2/s)	C_s	No. of Layers
410.1	64.4	6.9	228	391	660	0.1	0.1	10

Depth results

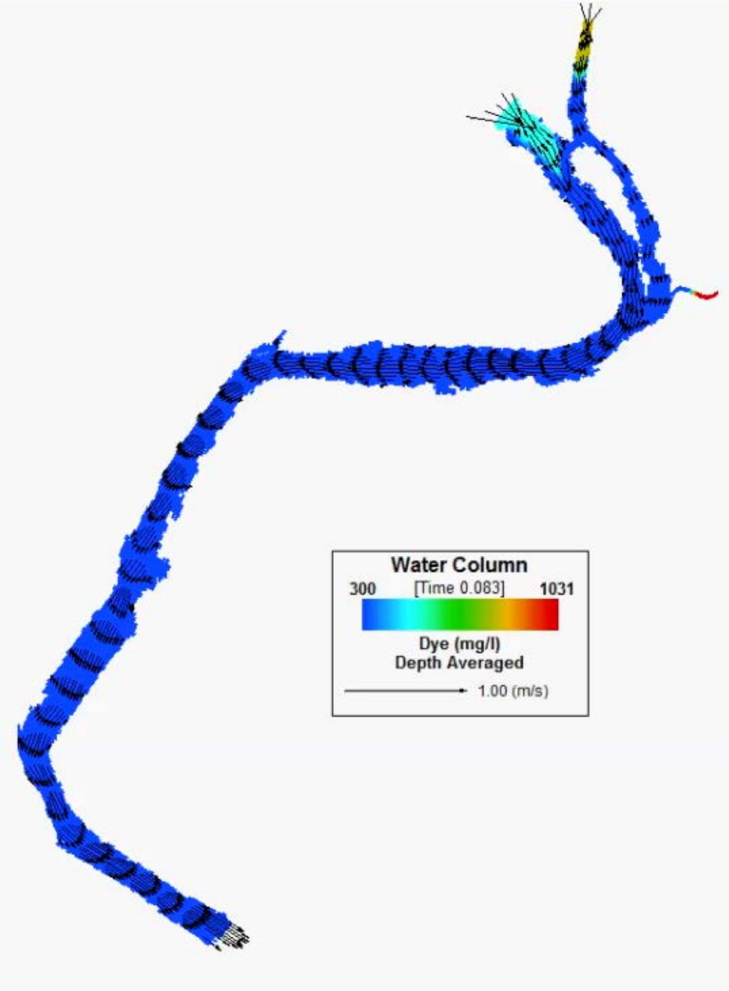


Velocity results

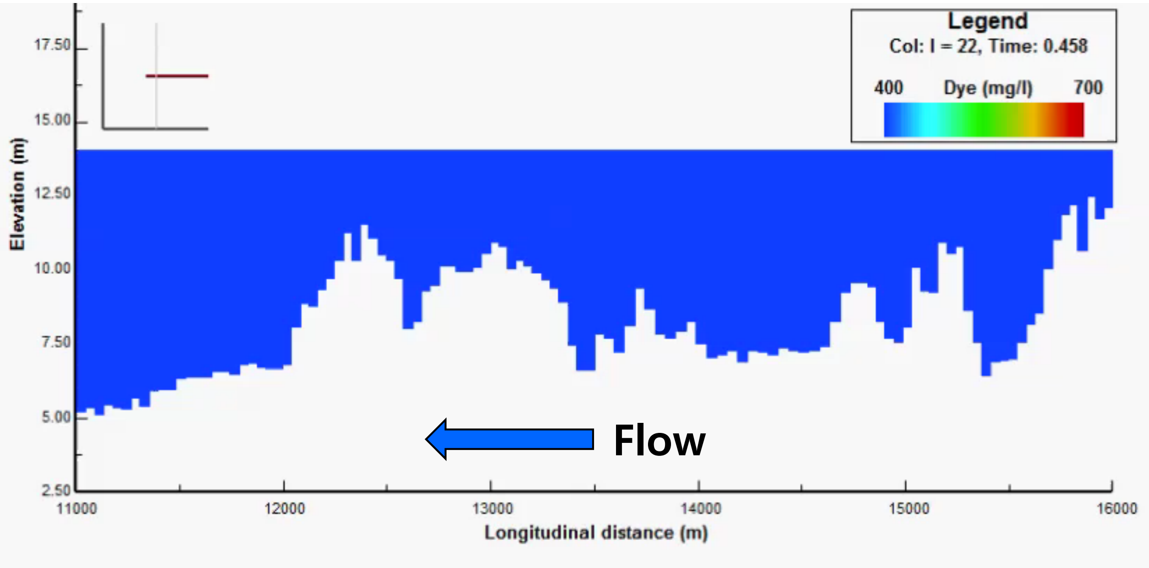


Nakdong River EC Mixing Modeling

- **Continuous input results**

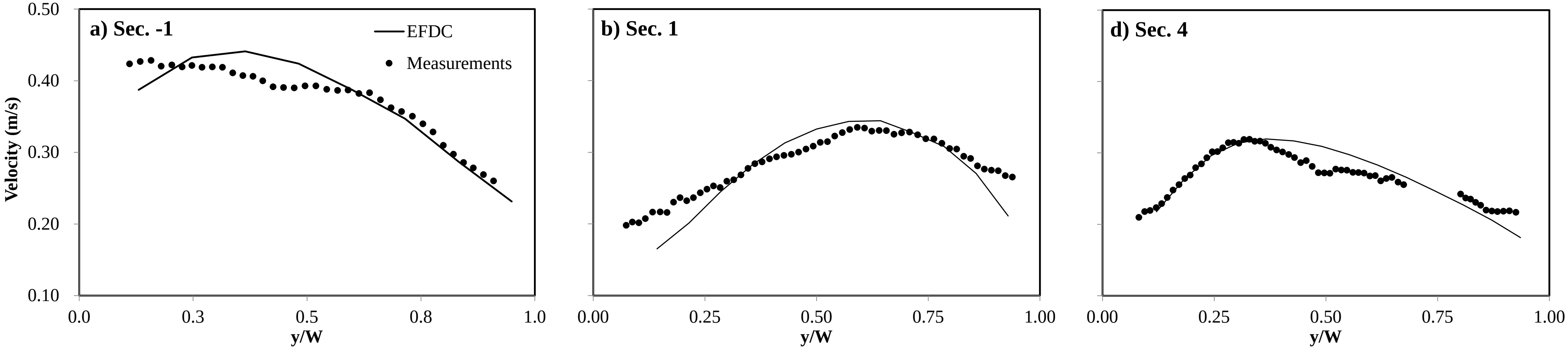


- **(y/W=0.1) vertical mixing concentration simulation results**



Nakdong River EC Mixing Modeling

Flow velocity modeling comparison



EC lateral mixing comparison