L-114-01-65

Taiwan - Japan Simulation Technology for Urban Flooding and River Hydraulics Sediment Transport Technology Workshop & iRIC training session

臺日「都會區淹水與河川水理輸砂模擬技術」交流講席會

Simulation Technology for Urban Flooding and River Hydraulics Sediment Transport Workshop (STW)

Agenda

(Apr. 22nd 2025)

09:20~09:30	Registration
09:30~09:40	**Prof. Tsang-Jung Chang / Chairman Sheng-Bao Tseng** Taiwan-Japan Simulation Technology for Urban Flooding and River Hydraulics Sediment Transport Technology Workshop (STW) Open Ceremony
09:40~10:30	**Host : Prof. Tsang-Jung Chang / Speaker : Prof. Yasuyuki Shimizu** Towards Next-Generation Hydraulic Analysis – The Full Scope of iRIC Ver.4’ s Latest Solvers
10:30~10:50	Tea break
10:50~11:05	**Host : Prof. Jihn-Sung Lai / Speaker : Chung-Kai Wang, Graduate student** Modeling Braided River Evolution and Lateral Alluvial Fan Interactions Using iRIC
11:05~11:20	**Host : Prof. Jihn-Sung Lai / Speaker : Yi-Jia Huang, Graduate student** Riverside intake impact under hydrological uncertainty
11:20~11:35	**Host : Prof. Jihn-Sung Lai / Speaker : Cheng-Chi Liu, Ph.D. student** SRH-2D and machine learning application on fluvial hydraulic and bridge scour prediction
11:40~12:00	**Prof. Tsang-Jung Chang** Comprehensive discussion

iRIC training session

13:30~14:30	**Host : Prof. Jihn-Sung Lai / Speaker : Prof. Yasuyuki Shimizu** Open ceremony & General Overview of the iRIC Software
14:30~14:40	Tea break
14:40~15:40	**Dr. Takaaki Abe** Basic sediment transport analysis and its utilization using iRIC-Nays2DH : Training session (1)
15:40~15:50	Tea break
15:50~16:50	**Dr. Takaaki Abe** Basic flood Analysis and its utilization using iRIC-Nays2D Flood : Training session (2)

CONTENTS

阿部 孝章 Takaaki Abe

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Basic sediment transport analysis and its utilization using iRIC-Nays2DH : Training session (1)

In this session, a two-dimensional sediment transport solver, Nays2DH is briefly introduced.　The model is developed for simulating horizontal fluid flow with sediment transport, morphological changes of bed and banks in rivers. In the training session a simple example, namely, the basic operation of Nays2DH by calculating the flow and morphological change of the river bed in a meandering channel with simple bed geometry, and also understand the fundamental bed evolution phenomena in a meandering channel.

Basic flood Analysis and its utilization using iRIC-Nays2DFlood : Training session (2)

In this session a two-dimensional flood inundation model Nays2D Flood is introduced. The model handle with multiple inflows and outflows. The course will cover basic data input procedure, process of calculation grid generation, model execution, visualization of results, and verification. For this session geometry data of a real river is used and inundation is evaluated through the interface of iRIC software.

iRIC-Nays2DH
Introduction of Nays2DH model

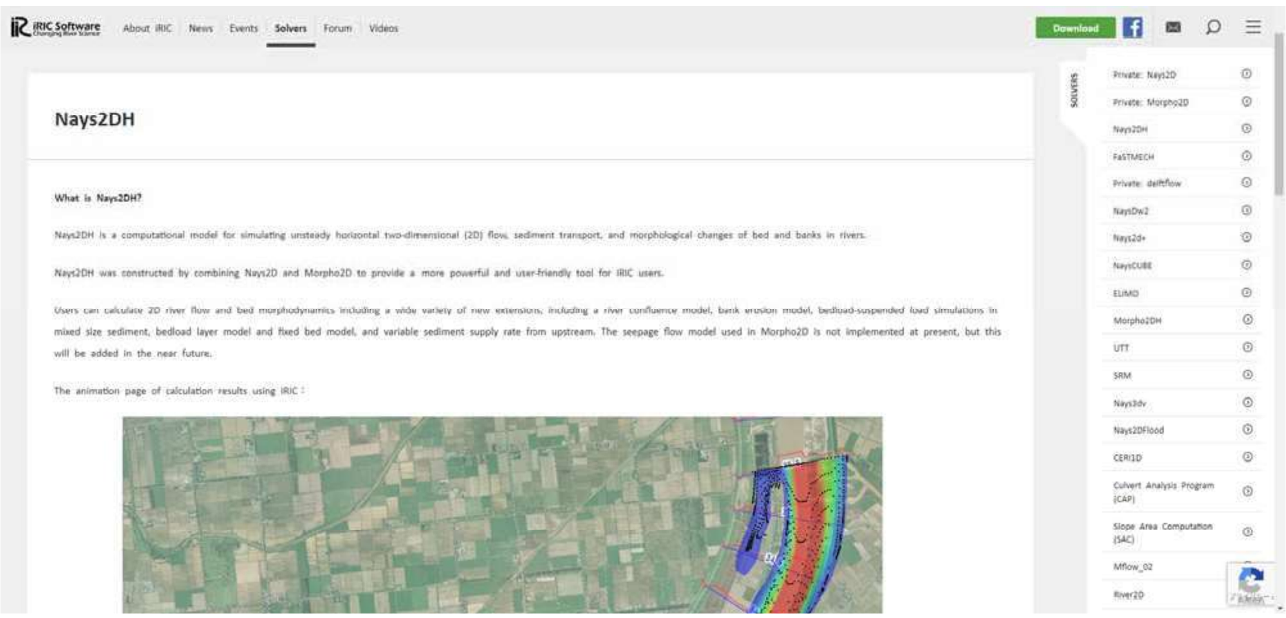
International River interface corporative, since 2010

Team Nays2DH

iRIC Software
Changing River Science

What you can do by using Nays2DH?

- Horizontal 2D flow, sediment transport and morphodynamics simulation for river system



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Model concept

- Unsteady shallow water flow model
- Moving boundary-fitted coordinate system
- Bedload and suspended load
- Graded sediment
- Bank erosion and channel migration
- River confluences
- Secondary flow model
- Sediment transport on fixed bed

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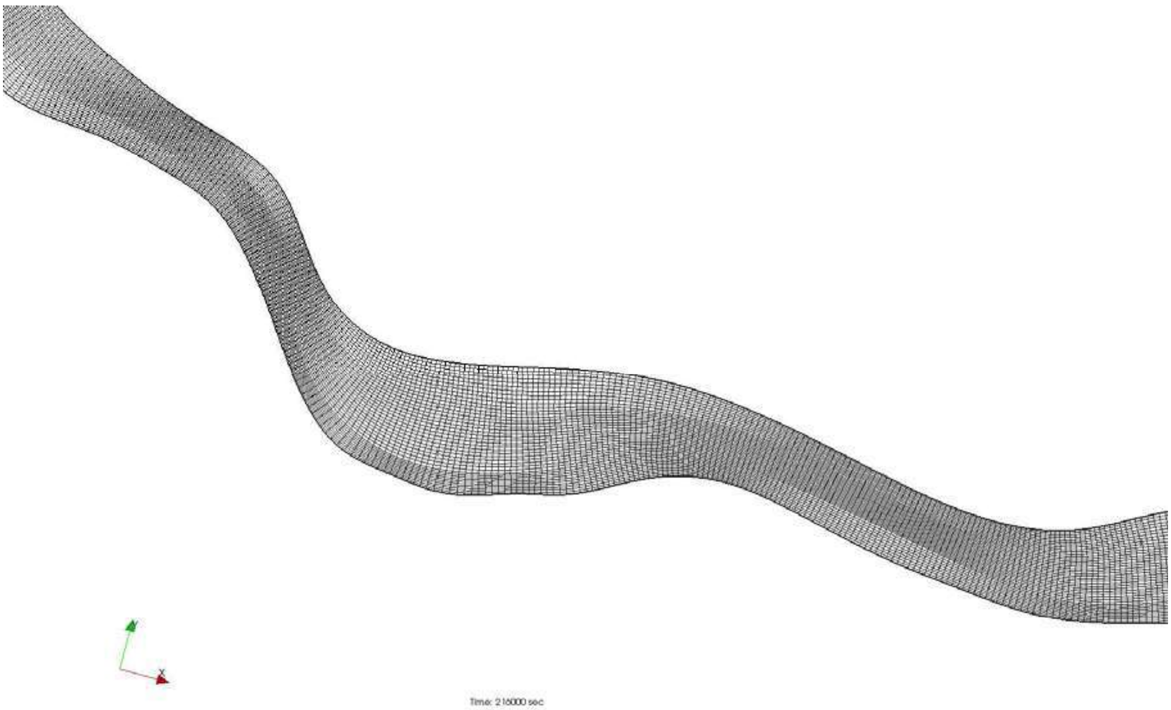
General coordinate system



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Hydrodynamic model

- Mass conservation of water

$$\frac{\partial}{\partial t}\left(\frac{h}{J}\right)+\frac{\partial}{\partial \xi}\left[\left(\xi_t+u^{\xi}\right)\frac{h}{J}\right]+\frac{\partial}{\partial \eta}\left[\left(\eta_t+u^{\eta}\right)\frac{h}{J}\right]=0$$

Resistance due to vegetation

Turbulent diffusion

- Momentum equations

$$\frac{\partial u^{\xi}}{\partial t}+\left(\xi_t+u^{\xi}\right)\frac{\partial u^{\xi}}{\partial \xi}+\left(\eta_t+u^{\eta}\right)\frac{\partial u^{\xi}}{\partial \eta}+\alpha_1 u^{\xi}u^{\xi}+\alpha_2 u^{\xi}u^{\eta}+\alpha_3 u^{\eta}u^{\eta}-D^{\xi}$$

$$=-g\left[\left({\xi_x}^2+{\xi_y}^2\right)\frac{\partial H}{\partial \xi}+\left(\xi_x\eta_x+\xi_y\eta_y\right)\frac{\partial H}{\partial \eta}\right]-\frac{C_f u^{\xi}}{hJ}\sqrt{\left(\eta_y u^{\xi}-\xi_y u^{\eta}\right)^2+\left(-\eta_x u^{\xi}+\xi_x u^{\eta}\right)^2}-\frac{F_{\xi}}{\rho h}$$

$$\frac{\partial u^{\eta}}{\partial t}+\left(\xi_t+u^{\xi}\right)\frac{\partial u^{\eta}}{\partial \xi}+\left(\eta_t+u^{\eta}\right)\frac{\partial u^{\eta}}{\partial \eta}+\alpha_4 u^{\xi}u^{\xi}+\alpha_5 u^{\xi}u^{\eta}+\alpha_6 u^{\eta}u^{\eta}-D^{\eta}$$

$$=-g\left[\left(\xi_x\eta_x+\xi_y\eta_y\right)\frac{\partial H}{\partial \xi}+\left(\eta_x^2+\eta_y^2\right)\frac{\partial H}{\partial \eta}\right]-\frac{C_f u^{\eta}}{hJ}\sqrt{\left(\eta_y u^{\xi}-\xi_y u^{\eta}\right)^2+\left(-\eta_x u^{\xi}+\xi_x u^{\eta}\right)^2}-\frac{F_{\eta}}{\rho h}$$

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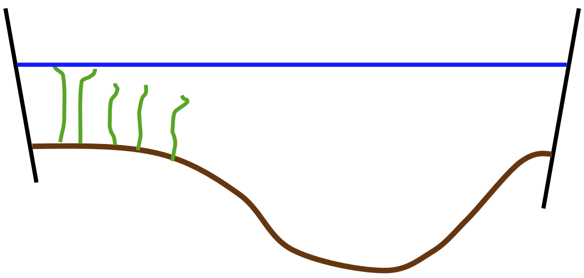

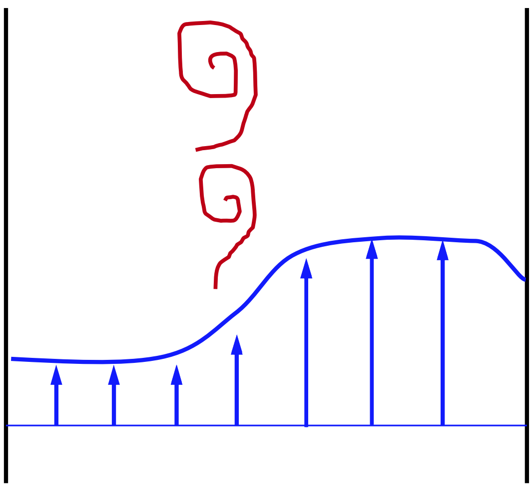

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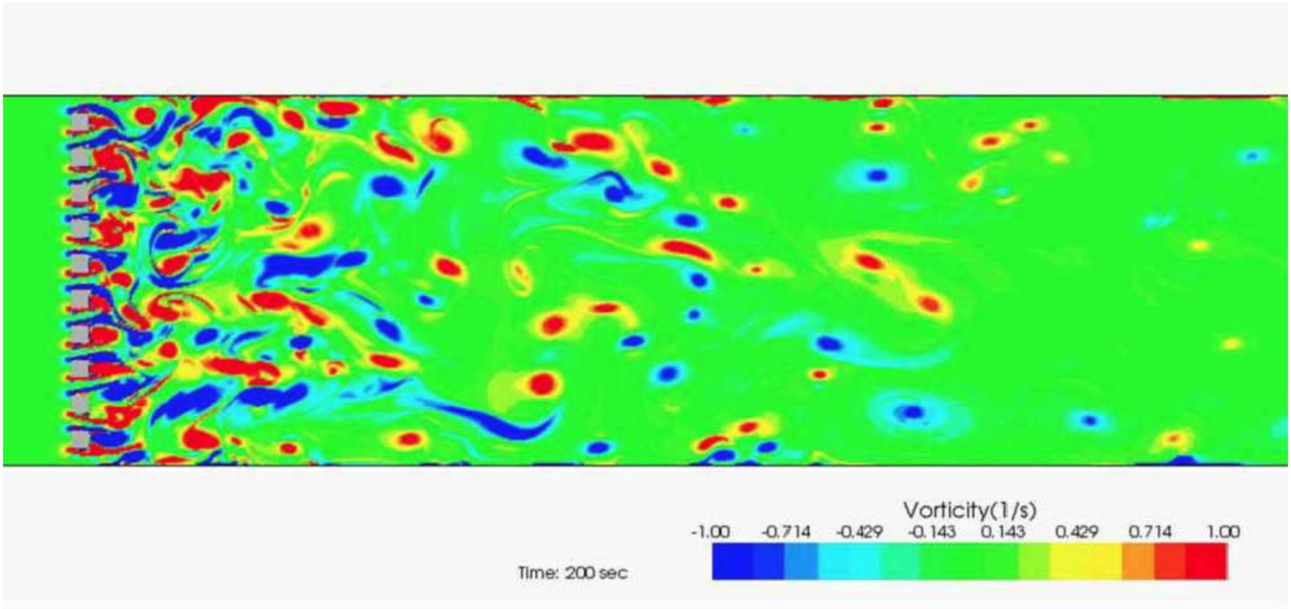
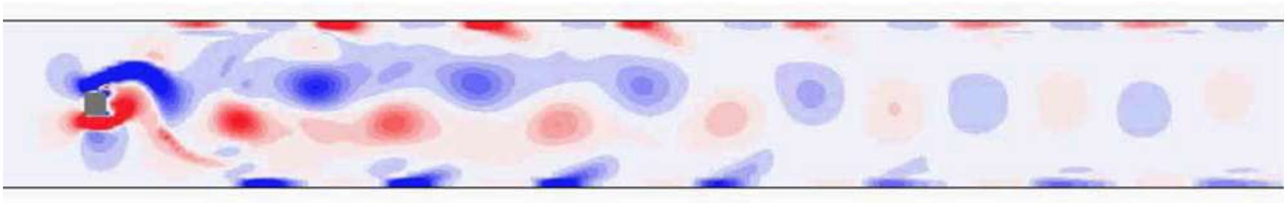
Unsteady flow structure in a shallow flow

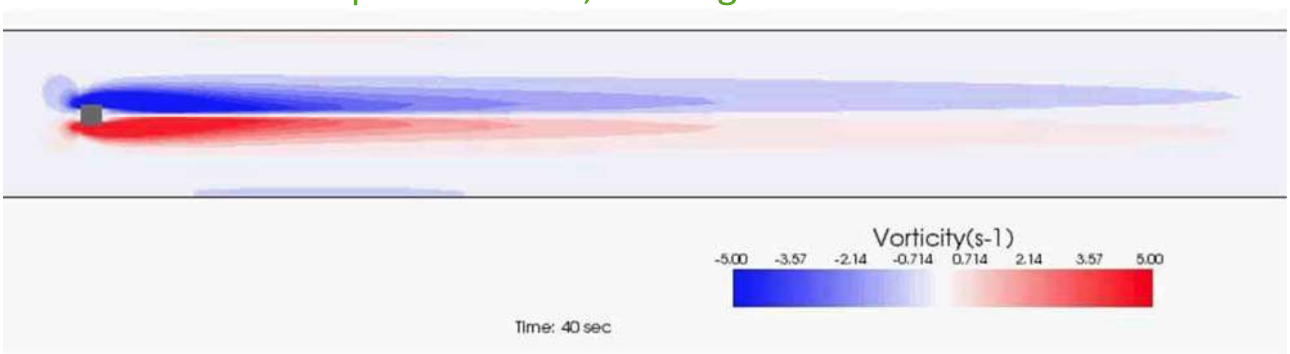


Karman vortex street

- Computational scheme for discretizing advection term
  - CIP method: high accuracy, sometimes unstable



  - 1st order upwind: stable, but large numerical diffusion



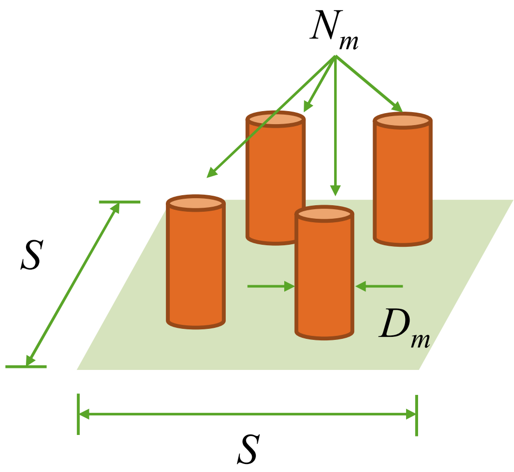
Flow resistance

- Bed friction

$$C_f = \frac{gn^2}{h^{1/3}}$$

Manning's roughness

- Resistance due to vegetation



$$a_s = \frac{N_m D_m}{S^2}$$

Spatial density of vegetation stem

$$F_\xi = \frac{1}{2}\rho C_D a_s h \frac{u^\xi}{J}\sqrt{(\eta_y u^\xi - \xi_y u^\eta)^2 + (-\eta_x u^\xi + \xi_x u^\eta)^2}$$

$$F_\eta = \frac{1}{2}\rho C_D a_s h \frac{u^\eta}{J}\sqrt{(\eta_y u^\xi - \xi_y u^\eta)^2 + (-\eta_x u^\xi + \xi_x u^\eta)^2}$$

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Vegetation cell

Satunai River, Japan

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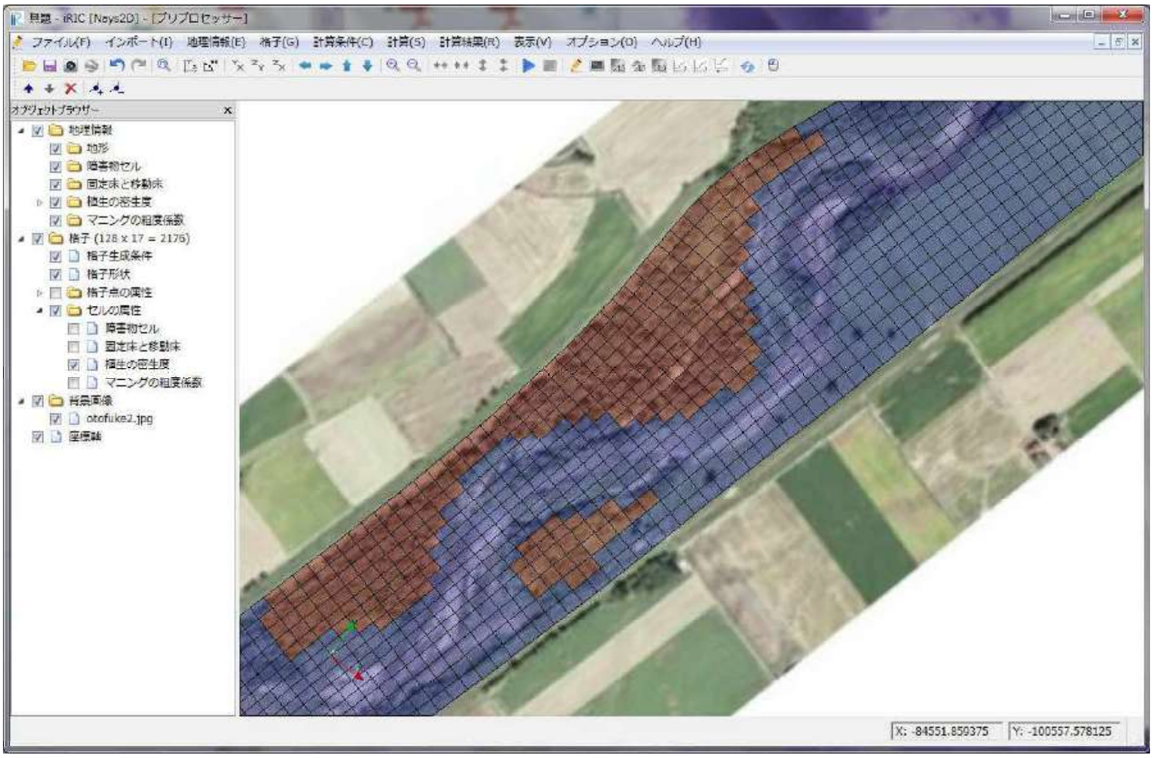
Vegetation cell



Sediment transport and Morphodynamics

- Morphological change of riverbed
- Bedload and suspended load

□ Mass conservation of uniform sediment

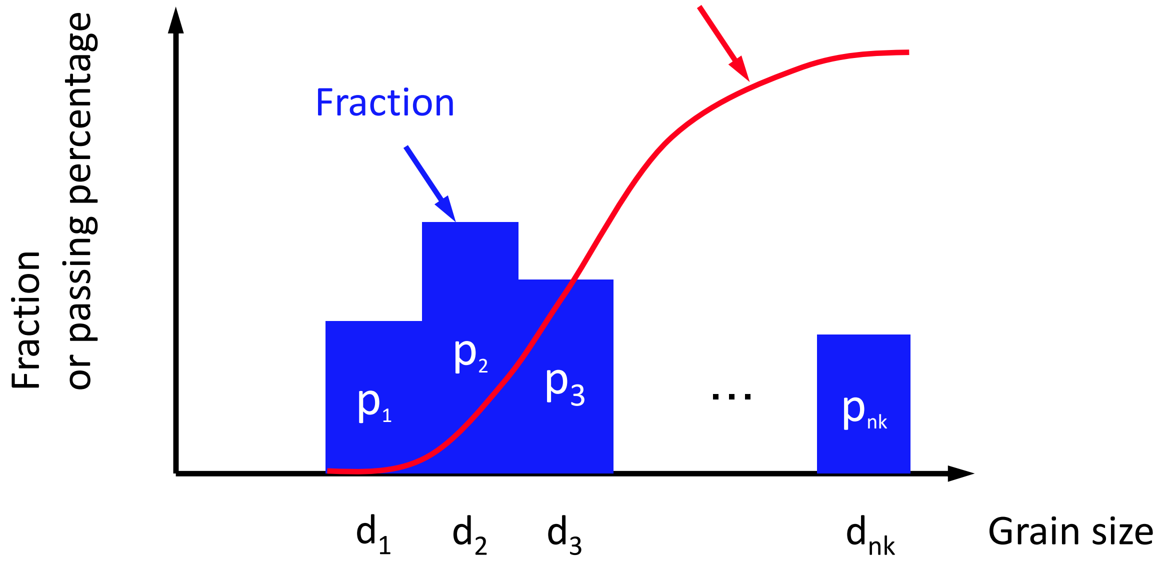
$$\frac{\partial}{\partial t}\left(\frac{z}{J}\right)+\frac{1}{1-\lambda}\left[\frac{\partial}{\partial \xi}\left(\frac{q_{b\xi}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{q_{b\eta}}{J}\right)+\frac{q_{su}-c_b w_f}{J}\right]=0$$

□ Mass conservation of graded sediment

$$\frac{\partial}{\partial t}\left(\frac{z}{J}\right)+\frac{1}{1-\lambda}\left[\frac{\partial}{\partial \xi}\left(\frac{\sum q_{bk}^{\xi}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{\sum q_{bk}^{\eta}}{J}\right)+\frac{1}{J}\sum\left(q_{suk}-c_{bk}w_{fk}\right)\right]=0$$

$$\frac{\partial}{\partial t}\left(\frac{p_{mk}}{J}\right)+\frac{1}{e_m(1-\lambda)}\left[\frac{\partial}{\partial \xi}\left(\frac{q_{bk}^{\xi}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{q_{bk}^{\eta}}{J}\right)+\frac{1}{J}\left(q_{suk}-c_{bk}w_{fk}\right)\right]=0$$

Graded sediment



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Sediment transport model

- Total bedload

$$\frac{q_{bs}}{\sqrt{sgd^3}} = 8(\tau_* - \tau_{*c})^{3/2}$$

Meyer, Peter and Muller, 1948

$$\frac{q_{bs}}{\sqrt{sgd^3}} = 17\tau_*^{3/2}\left(1-\frac{\tau_{*c}}{\tau_*}\right)\left(1-\frac{u_{*c}}{u_*}\right)$$

Ashida and Michiue, 1972

Uniform sediment

$$\frac{q_{bsk}}{\sqrt{sgd_k^3}} = 17\tau_*^{3/2}\left(1-\frac{\tau_{*ck}}{\tau_{*k}}\right)\left(1-\sqrt{\frac{\tau_{*ck}}{\tau_{*k}}}\right)$$

Ashida and Michiue, 1972

Graded sediment

- Bedload transport direction: Watanabe et al., 2001

$$\tilde{q}_{b\xi} = q_{bs}\left[\frac{\tilde{u}_\xi^b}{V^b} - \gamma\left(\frac{\partial z}{\partial \tilde{\xi}} + \cos\theta \frac{\partial z}{\partial \tilde{\eta}}\right)\right]$$

$$\tilde{q}_{b\eta} = q_{bs}\left[\frac{\tilde{u}_\eta^b}{V^b} - \gamma\left(\frac{\partial z}{\partial \tilde{\eta}} + \cos\theta \frac{\partial z}{\partial \tilde{\xi}}\right)\right]$$

$$\gamma = \begin{cases} \sqrt{\dfrac{\tau_{*c}}{\mu_s \mu_k \tau_*}} & \text{Uniform sediment} \\ \sqrt{\dfrac{\tau_{*ck}}{\mu_s \mu_k \tau_{*k}}} & \text{Graded sediment} \end{cases}$$

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Alluvial river morphology: Sand bars

Alternate bars (mode = 1)

Tokachi River, Japan

Multiple bars (mode > 1)

Hii River, Japan

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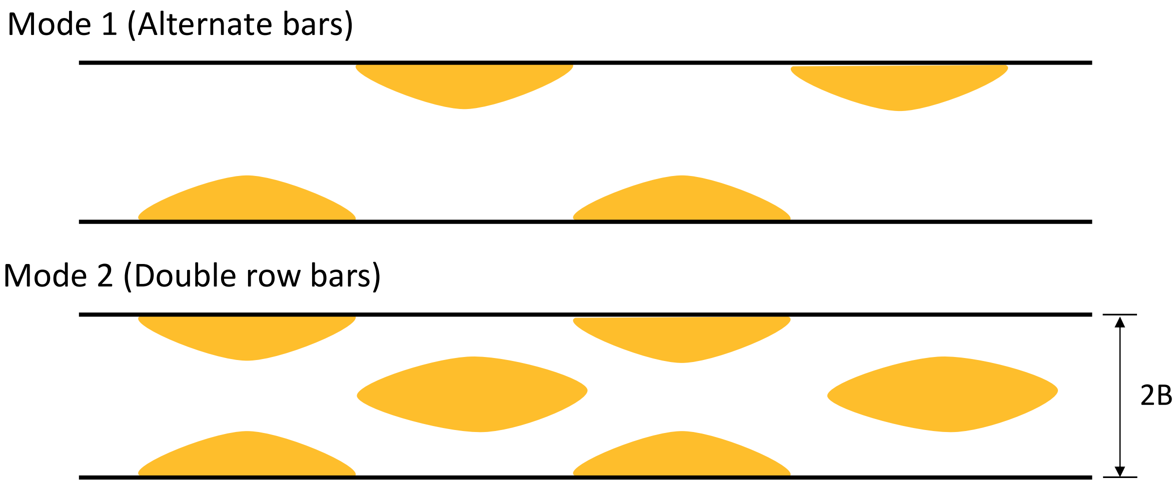
Free bars in rivers



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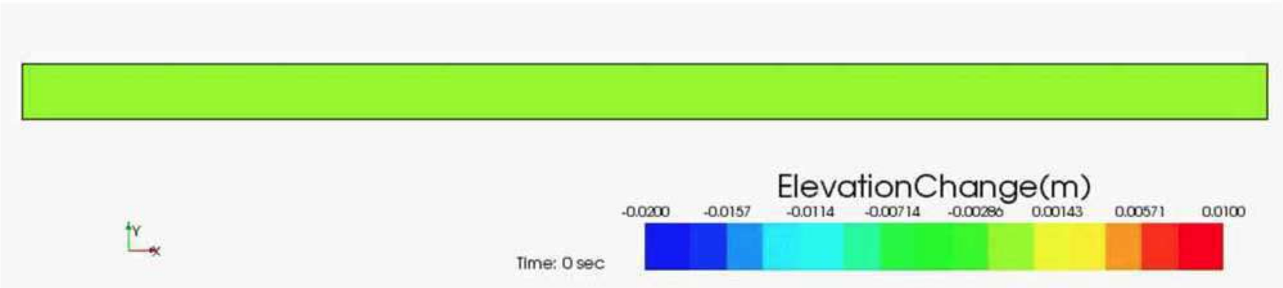
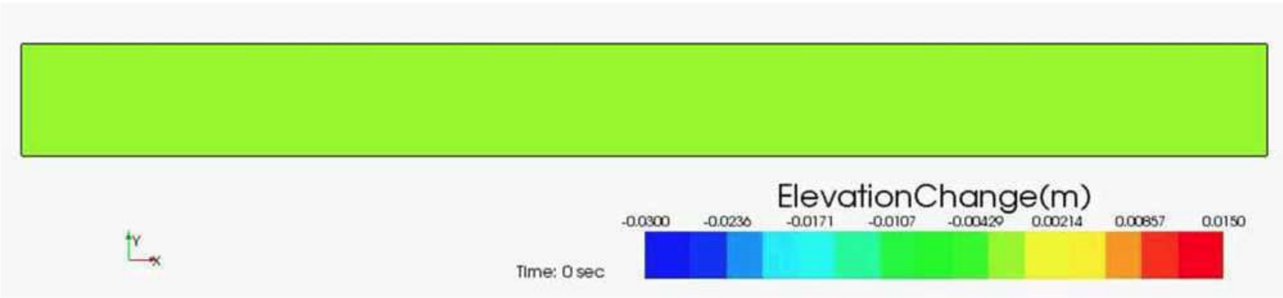
Morphodynamics of free bars in rivers

- Alternate and double row bars





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Suspended sediment transport

- Advection-diffusion equation

$$\frac{\partial}{\partial t}\left(\frac{ch}{J}\right)+\frac{\partial}{\partial \xi}\left(\frac{u^{\xi}ch}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{u^{\eta}ch}{J}\right)=\frac{q_{su}-w_f c_b}{J}+D_c^{\xi}+D_c^{\eta}$$

- Sediment entrainment flux from river bed (Itakura and Kishi)

$$q_{su}=p_k^* K\left[a_* \frac{\rho_s-\rho}{\rho_s}\frac{gd}{u_*}\Omega - w_f\right]$$

- Near-bed suspended sediment concentration

$$c_b=\frac{\beta c}{1-\exp(-\beta)}, \quad \beta=\frac{w_f h}{\varepsilon}$$

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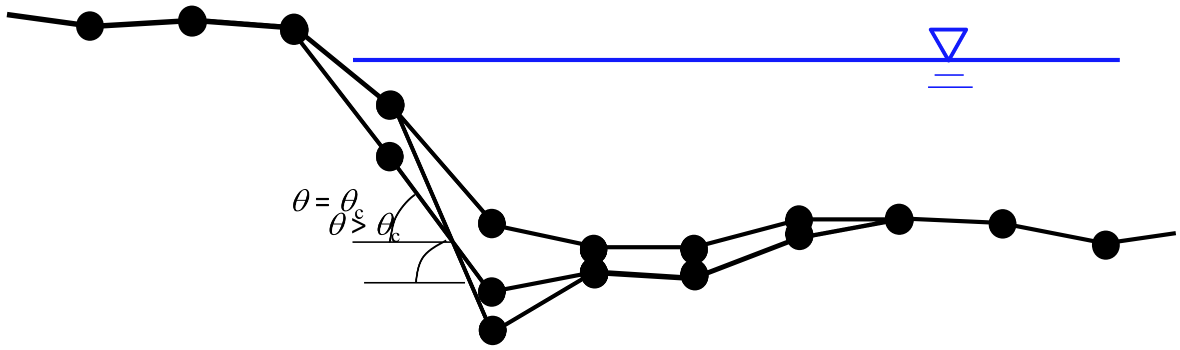
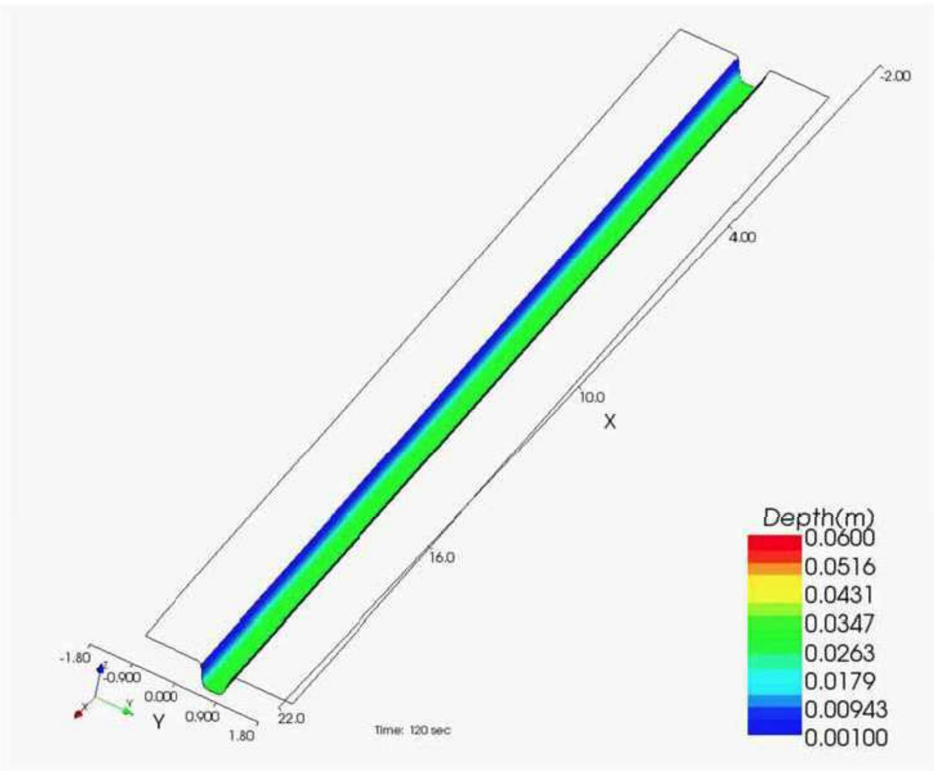
Bank erosion model 1

- River bank failure model based on a critical angle

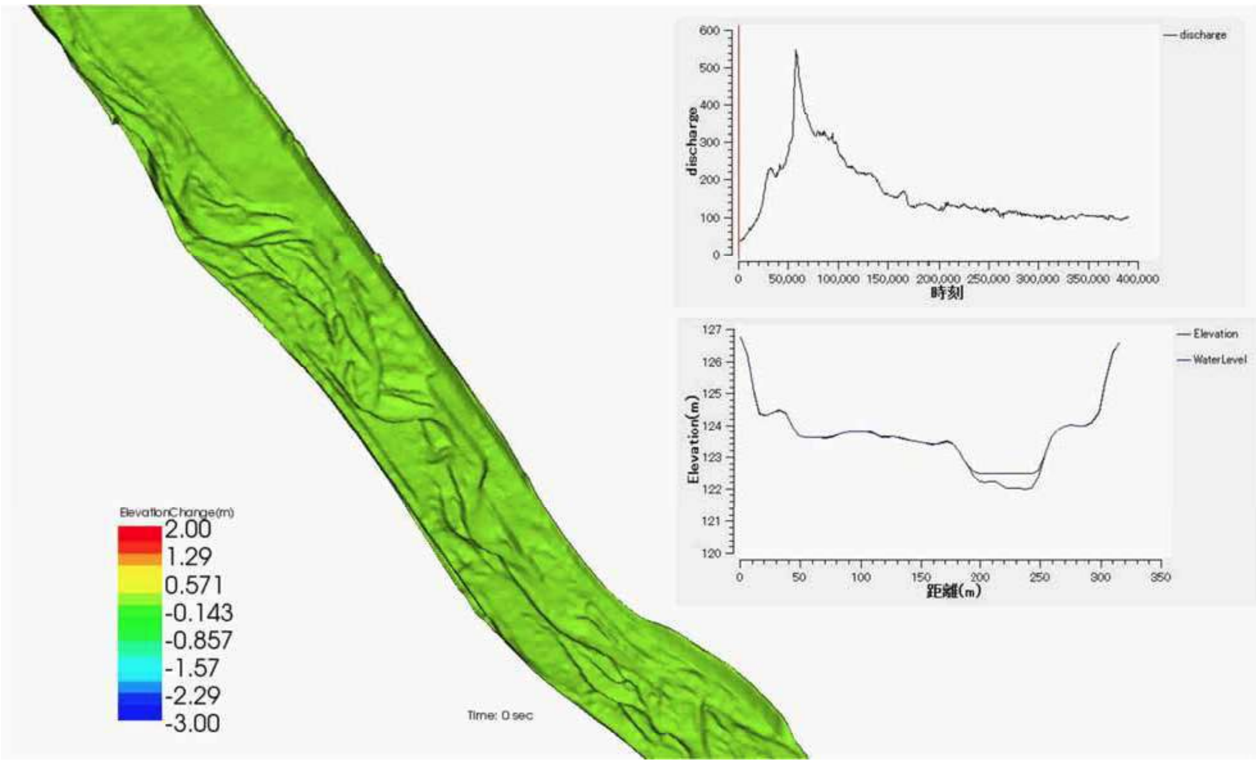


θ_c : Critical angle for river bank failure

Co-evolution of sand bar and meandering



Application for a real scale river



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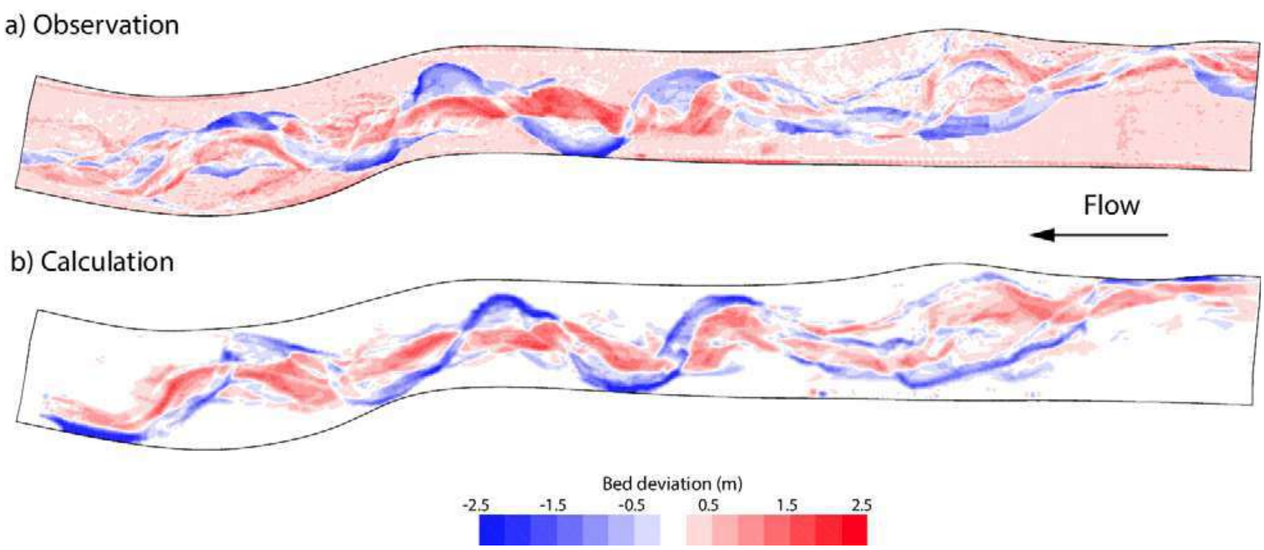

Iwasaki et al., 2016,
Advances in Water Resources

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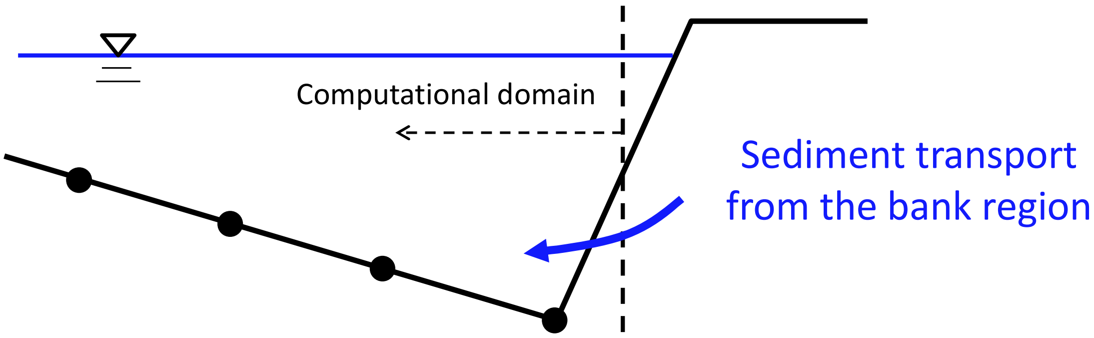
Channel migration model



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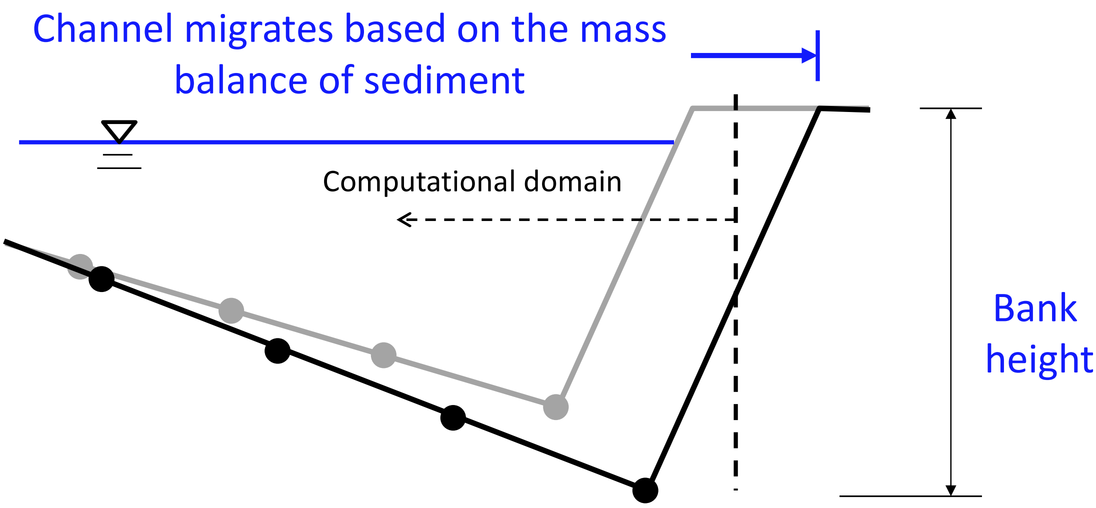
Channel migration model



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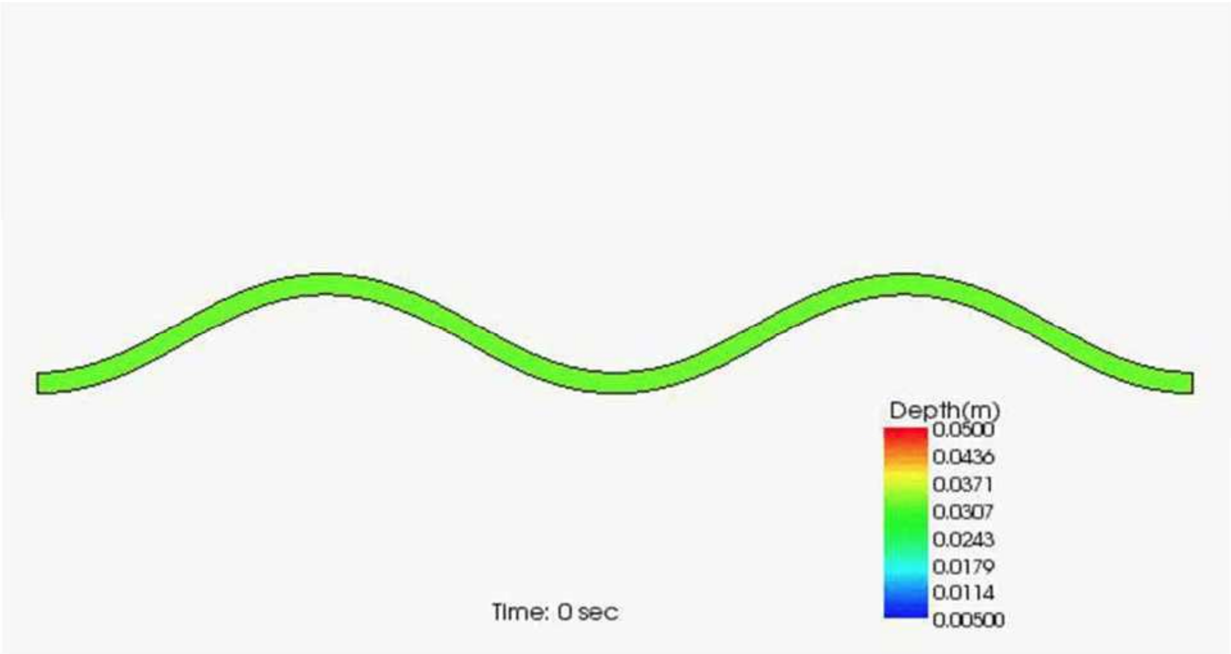
Bed evolution and channel migration

- A free meandering process



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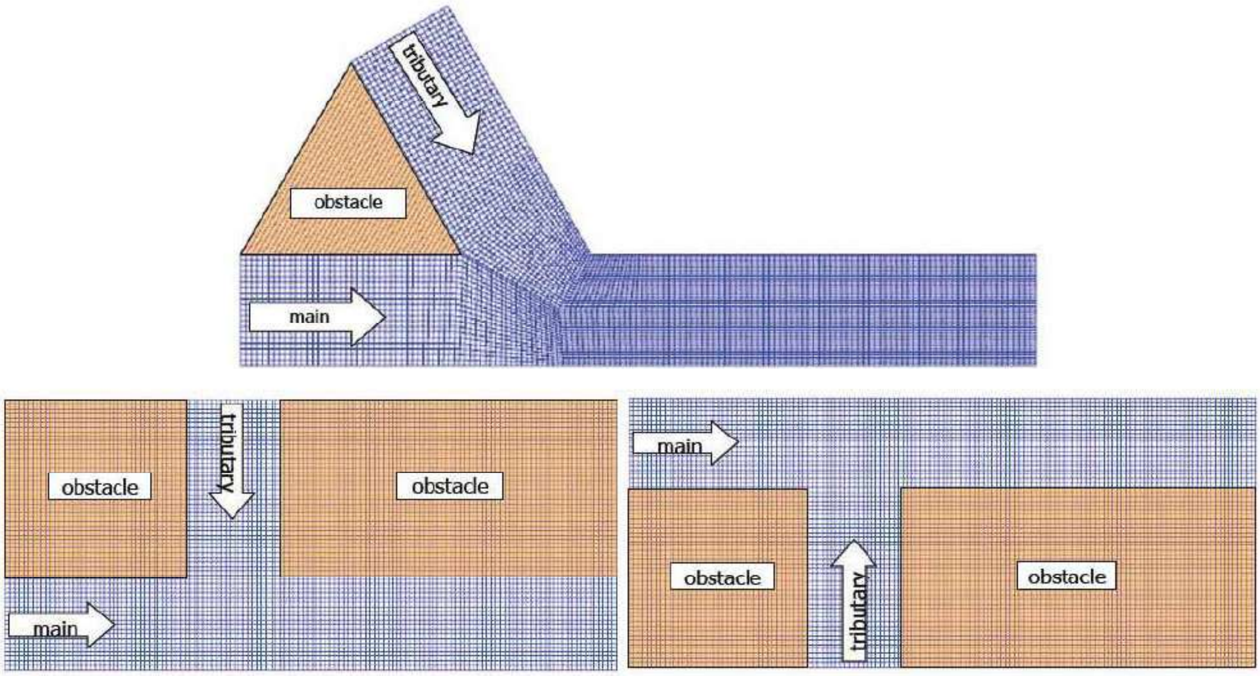
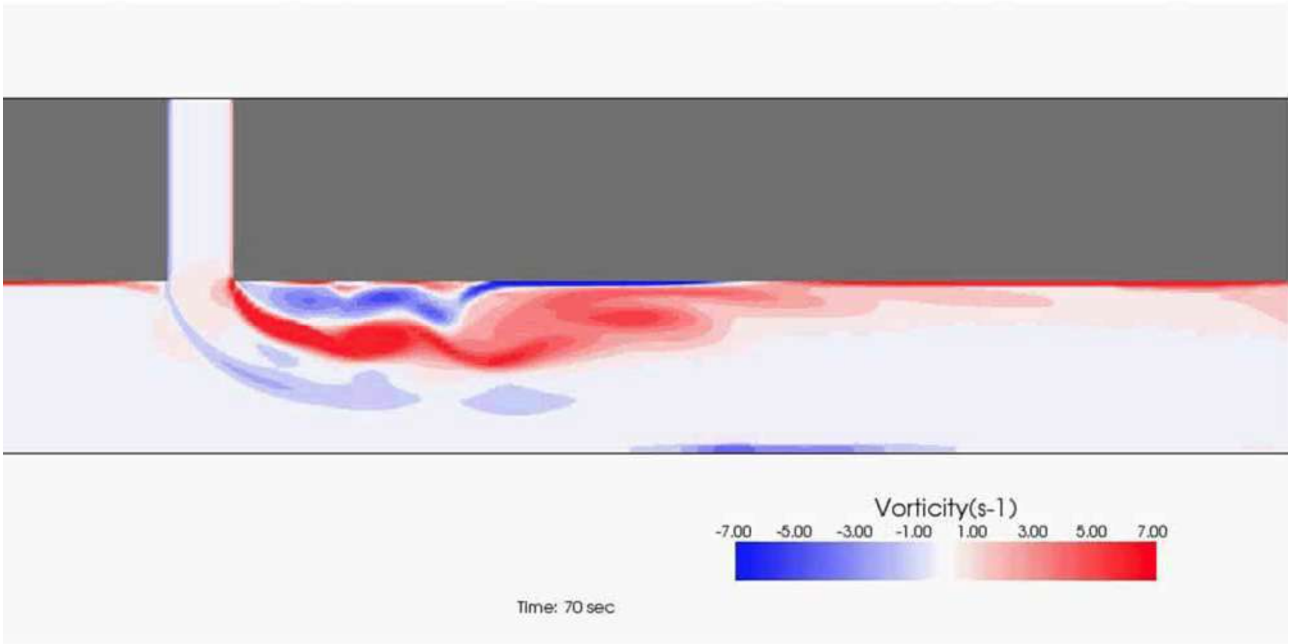
Confluence model

- Several types of boundary conditions are available for simulations at river confluences



A flow structure at a river confluence



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Cell attributes

- You can set following conditions on computational cells
  - Obstacles
  - Fixed/Movable bed
  - Density of vegetation stem
  - Bed friction coefficient (Manning's roughness)

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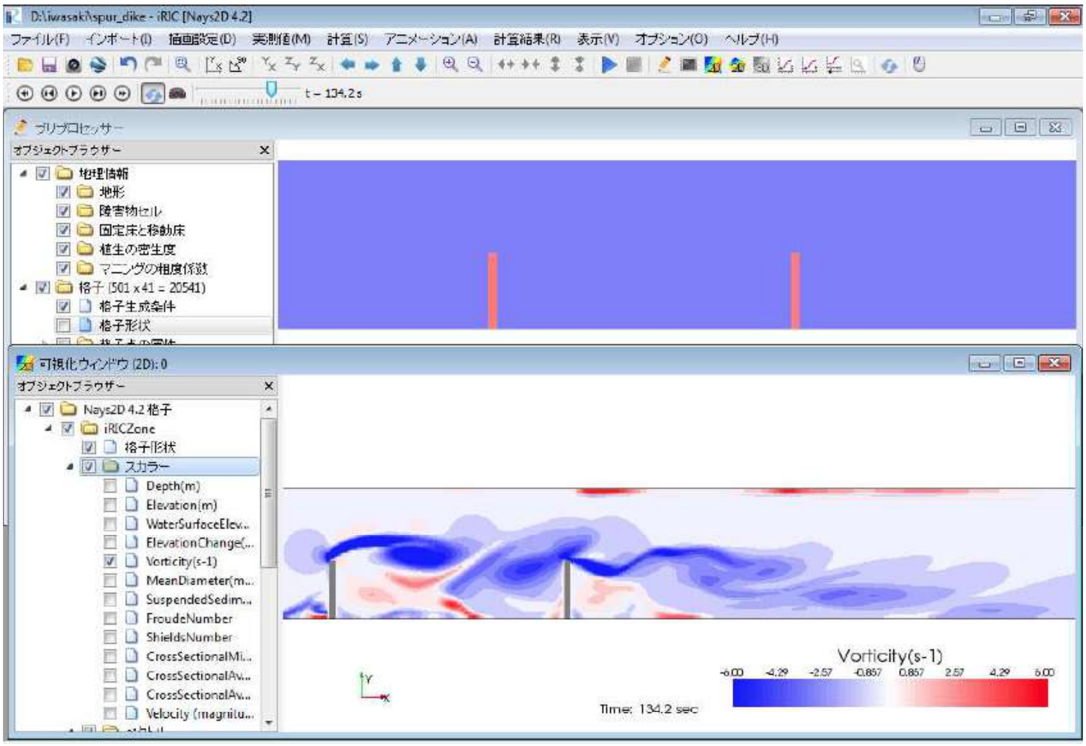
Obstacles

- Can be used to express spur dikes, bridge piers etc…



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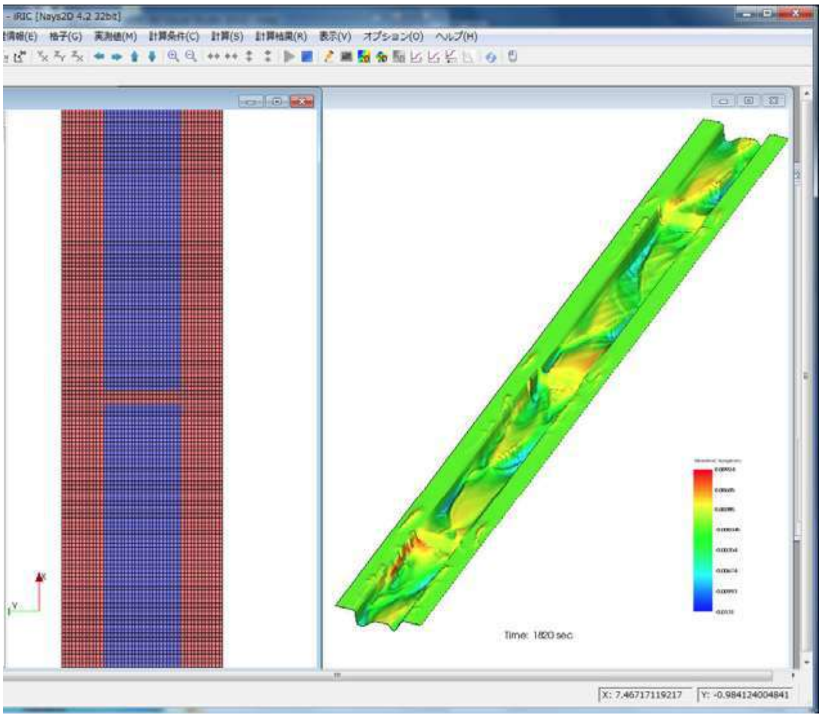
Fixed/Movable bed

- Non-erodible bed (concrete, bedrock etc..)



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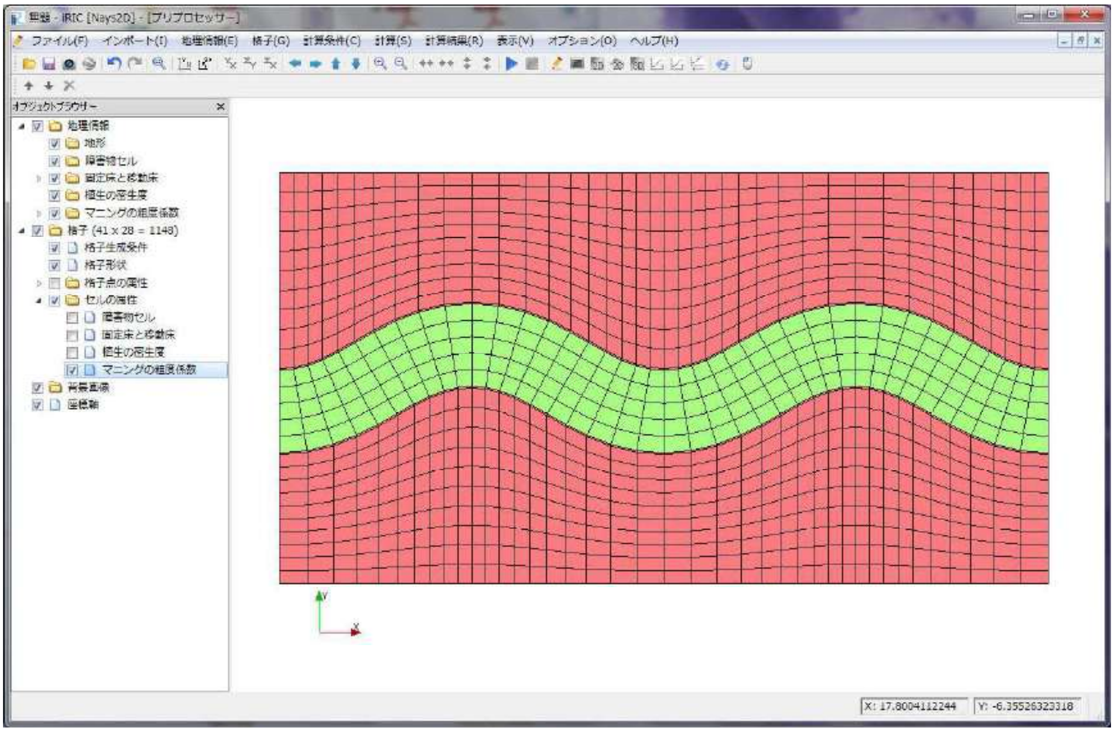
Bed friction

- Spatially-varying roughness coefficient



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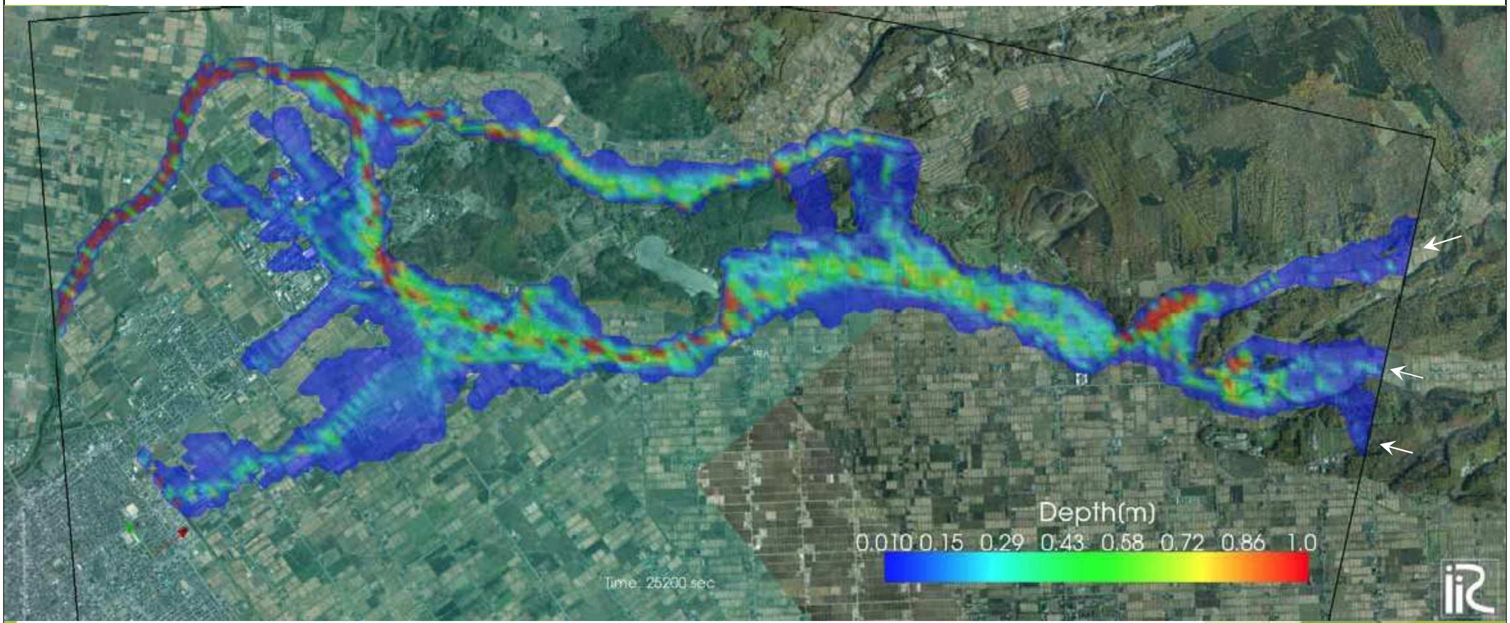


Basic flood Analysis and its utilization using iRIC-Nays2DFlood

Taka-aki Abe, Civil Engineering Research Institute for Cold Region, PWRI

Training session

April 22, 2025, National Taiwan University

Basic concept of Nays2D Flood

Nays2D

Nays2D Flood

Unsteady 2-D plane flow

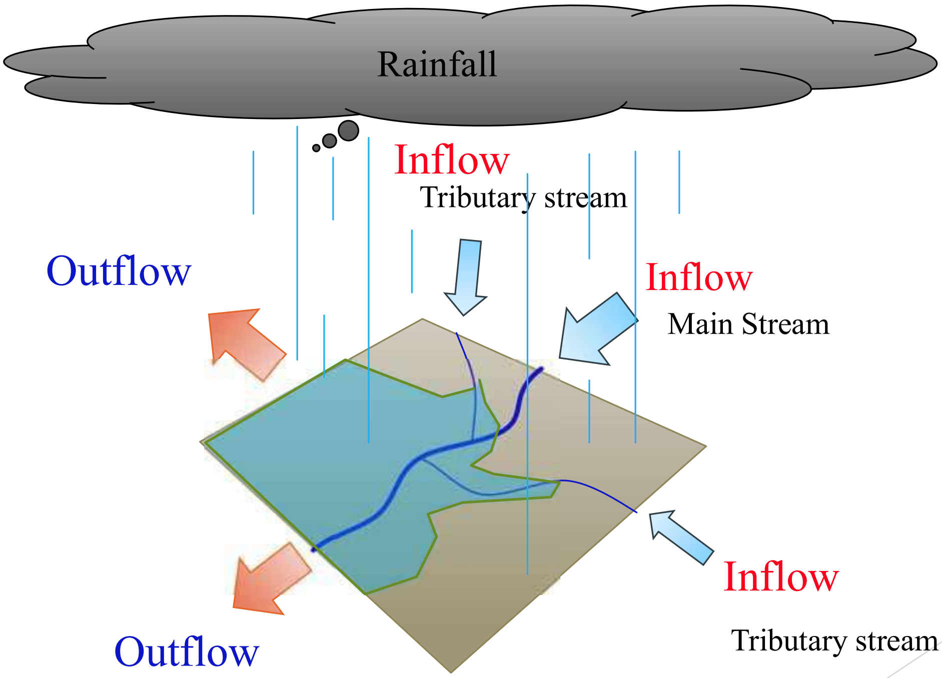
- River flow
- Bed erosion
- Bank erosion
- Mixed grain-size
- Confluences

Flood flow on Floodplains

- Simple operation
- Specialized in flood analysis
- Multiple inflow rivers

Specialized in flood analysis

Multiple inflow, outflow and rainfall



Basic equations

Nays2D Flood is a flood flow analysis solver that relies on unsteady 2-D plane flow simulation.

Equation of continuity

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=q+r$$

Inflow/outflow per unit area (q)

Rainfall (r)

Equations of motion

$$\frac{\partial (uh)}{\partial t}+\frac{\partial (hu^2)}{\partial x}+\frac{\partial (huv)}{\partial y}=-hg\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho}+D^x$$

$$\frac{\partial (vh)}{\partial t}+\frac{\partial (huv)}{\partial x}+\frac{\partial (hv^2)}{\partial y}=-hg\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho}+D^y$$

where, h is water depth, t is time, u is flow velocity in the x direction, v is flow velocity in the y direction, g is gravitational acceleration, H is water surface elevation, τ_x and τ_y are bed shear stress, ρ is the density of water, D^x and D^y are Reynolds stresses, q is inflow through a box culvert, a sluice pipe or a pump per unit area and r is rainfall.

Bottom friction

Nays2D Flood sets the bottom friction by using the Manning's roughness coefficient.

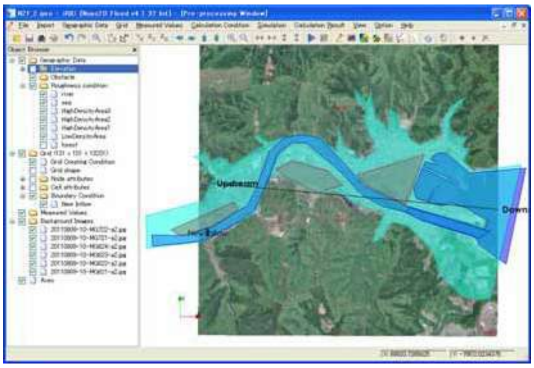
Bed friction coefficient (C_f)

$$\frac{\tau_x}{\rho}=C_f u\sqrt{u^2+v^2}$$

$$\frac{\tau_y}{\rho}=C_f v\sqrt{u^2+v^2}$$

Manning's roughness coefficient (n_m)

$$C_f=\frac{g{n_m}^2}{h^{1/3}}$$



- Manning's roughness coefficient n_m can be given to each grid cell.
- This makes it possible to adjust the coefficient by taking into account the variations in the bottom friction according to the land use of the floodplain.

Turbulent flow

Nays2D Flood employs a zero-equation model for turbulent flow field simulation.

Eddy viscosity coefficient

$$D^x = \frac{\partial}{\partial x}\left[\nu_t \frac{\partial (uh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[\nu_t \frac{\partial (uh)}{\partial y}\right]$$

$$D^y = \frac{\partial}{\partial x}\left[\nu_t \frac{\partial (vh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[\nu_t \frac{\partial (vh)}{\partial y}\right]$$

Assumption ---> eddy viscosity coefficients in the vertical and the horizontal directions have the same order and that bed shear velocity and water depth are the dominant factors in momentum transfer.

$$\nu_t \propto u_* h$$

Fisher(1973)

Webel and Schatzmann (1984)

$$\nu_t = A\frac{\kappa}{6} u_* h + B$$

κ : von Karman constant (0.4)
u* : bed shear velocity
h : water depth
A, B : parameters that can be adjusted by users
Initial value *A=1, B=0*

Numerical method

Momentum equation in the X direction

$$\frac{\partial (uh)}{\partial t} + \frac{\partial (hu^2)}{\partial x} + \frac{\partial (huv)}{\partial y} = -hg\frac{\partial H}{\partial x} - \frac{\tau_x}{\rho} + D^x$$

Splitting method

Continuity equation

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = q + r$$

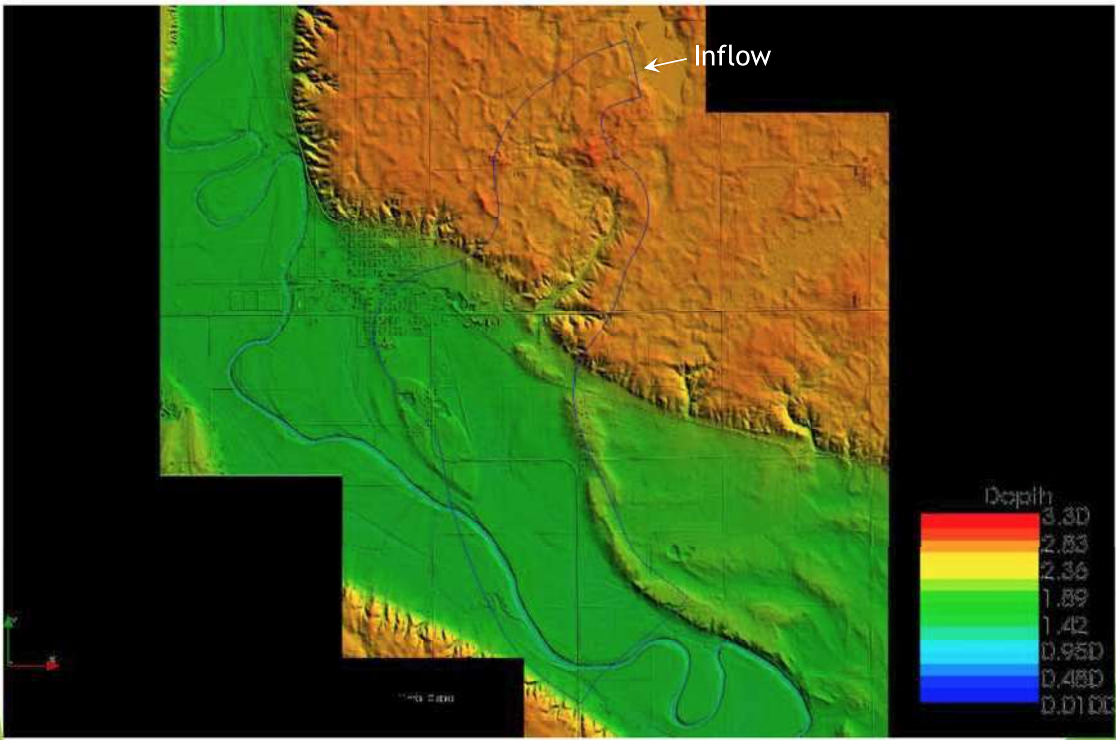
$h_t \rightarrow h_{t+\Delta t}$

(1) $$\frac{\partial u}{\partial t} = -g\frac{\partial h}{\partial x} - g\frac{\partial \eta}{\partial x} - \frac{g n_m{}^2 u\sqrt{u^2+v^2}}{h^{4/3}}$$ $u_t \rightarrow u'$

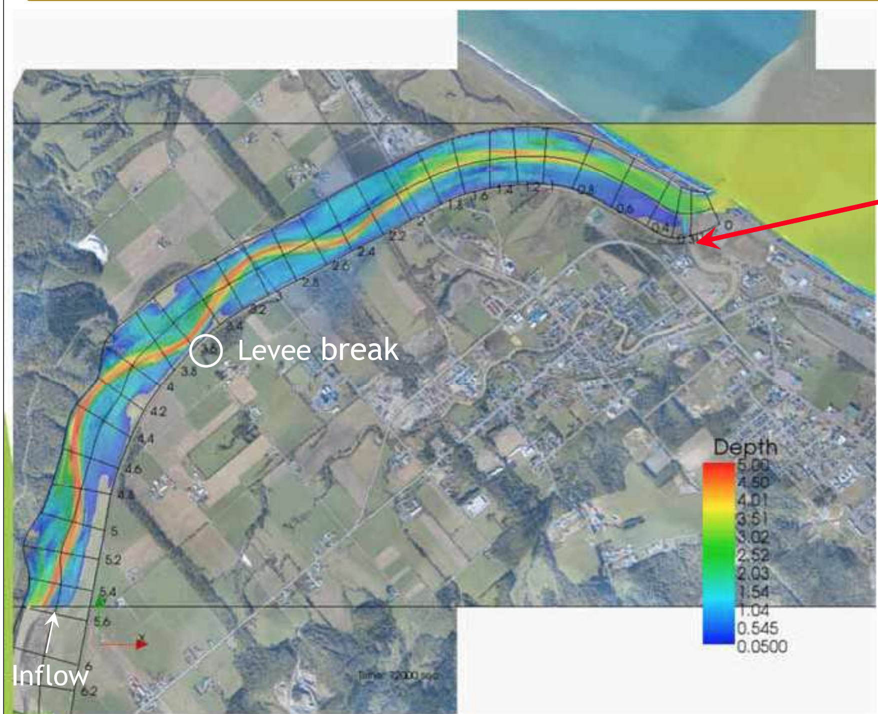
(2) $$\frac{\partial u}{\partial t} = \nu_t\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right]$$ $u' \rightarrow u''$

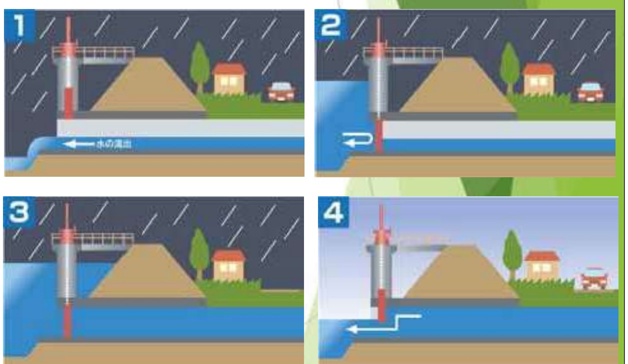
(3) $$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = 0$$ CIP scheme or upwind scheme $u'' \rightarrow u_{t+\Delta t}$

Example 1. Simple flood analysis

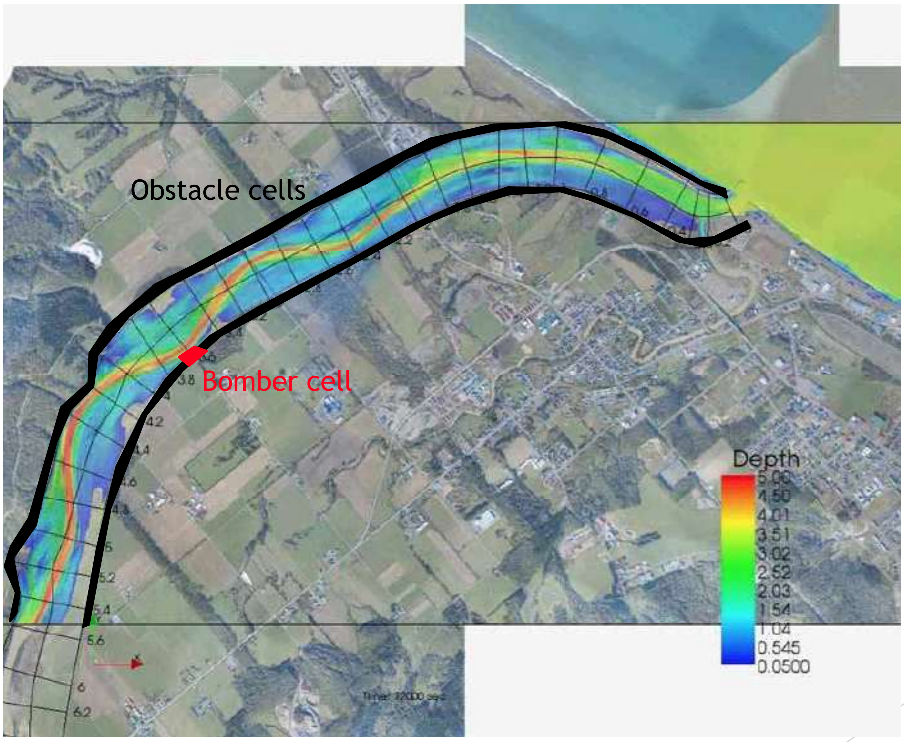


Example 2. Analysis of the drainage plan

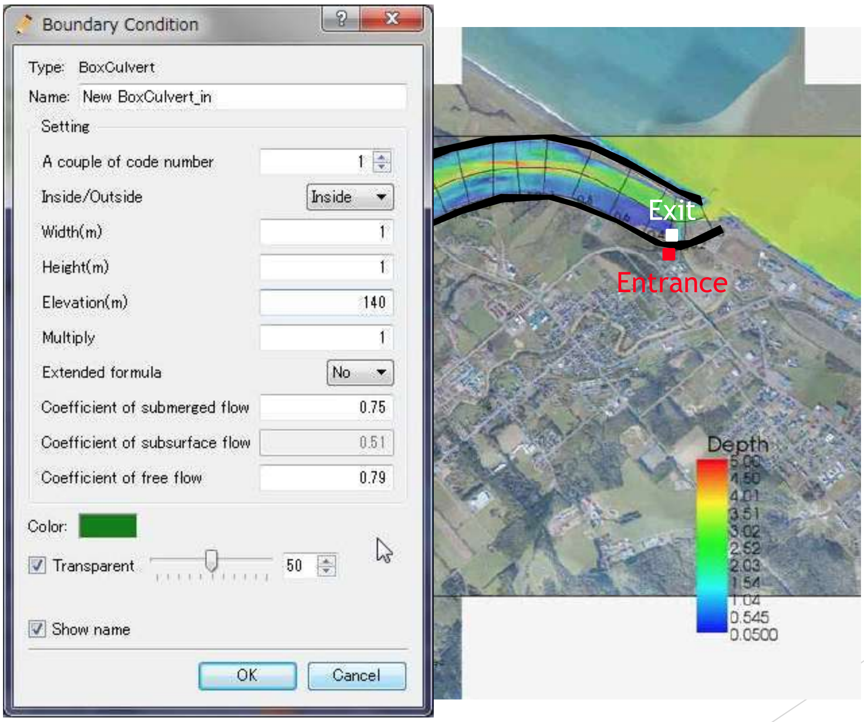




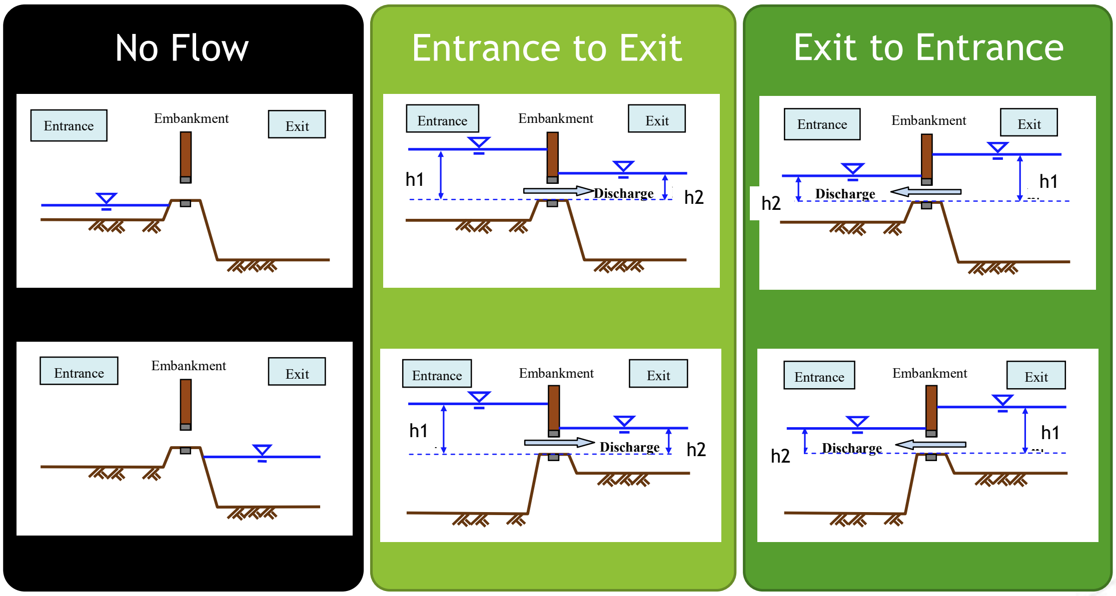
How to set up levee break



How to include culverts and gates



How to calculate the drainage flow rate



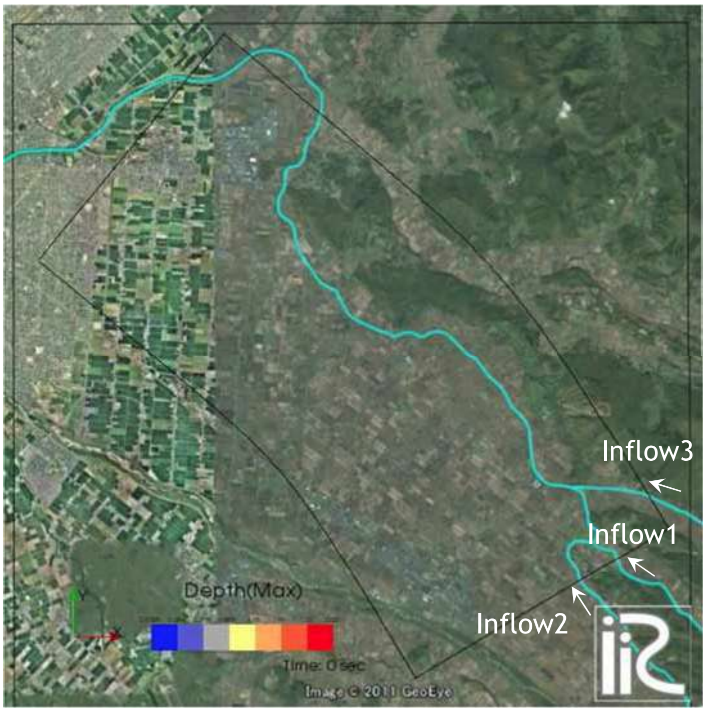
if $h_2 \geq H$, $Q = nC_1 BH\sqrt{2g(h_1 - h_2)}$ submerged flow

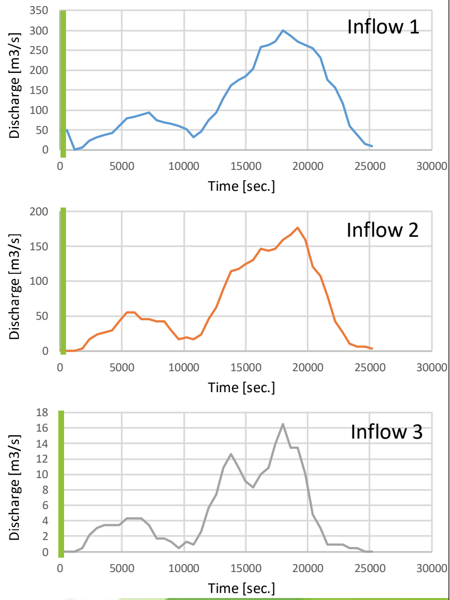
if $h_2 < H$, $Q = nC_3 Bh_2\sqrt{2g(h_1 - h_2)}$ free outflow

Example 3. Flood analysis for hazard map (Tutorial Chapter 3)

Movie by Dr. Shimizu, url: https://www.youtube.com/watch?v=nlJ8W9uX3ik

Example 3. Flood analysis for hazard map (Tutorial Chapter 3)



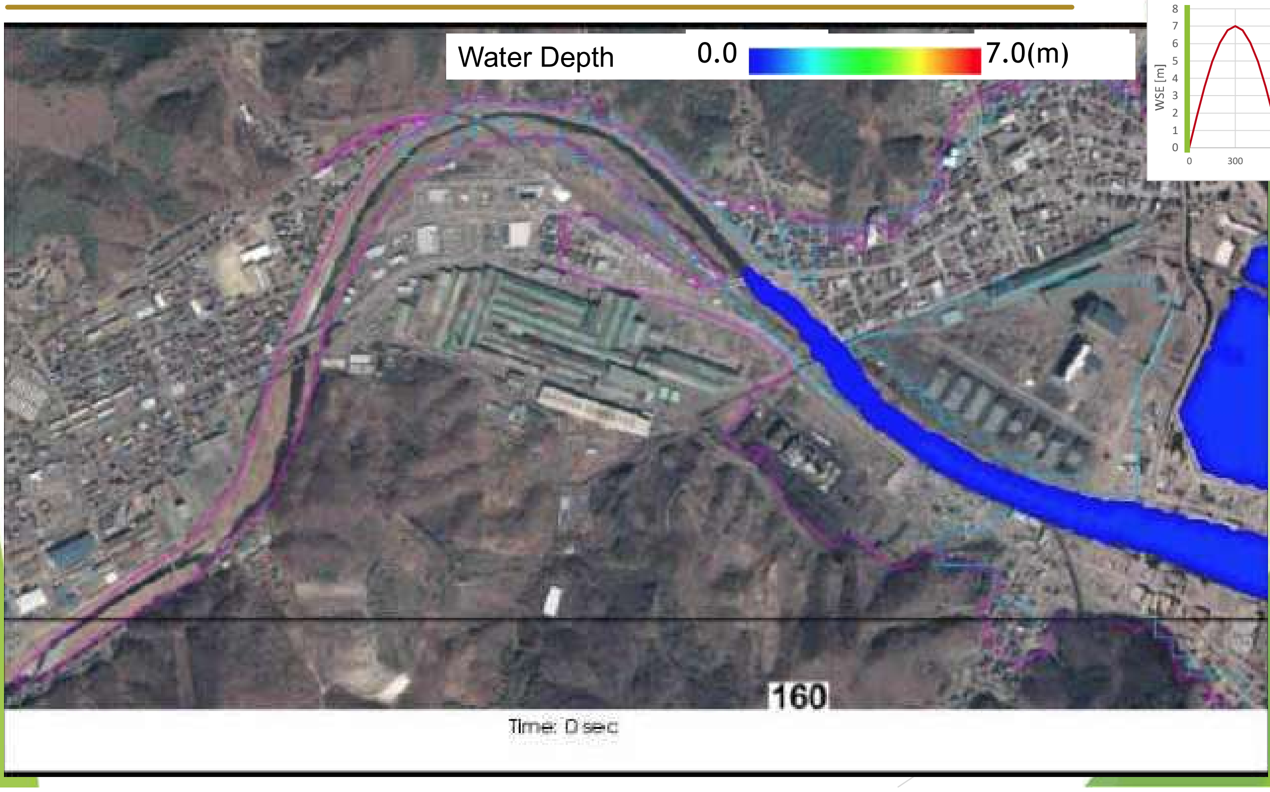


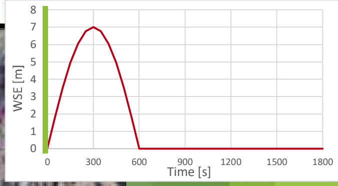
Example 4. A simulation of flooding caused by Tsunami run-up (Tutorial Chapter 4)

- The tsunami flood in Japan2011

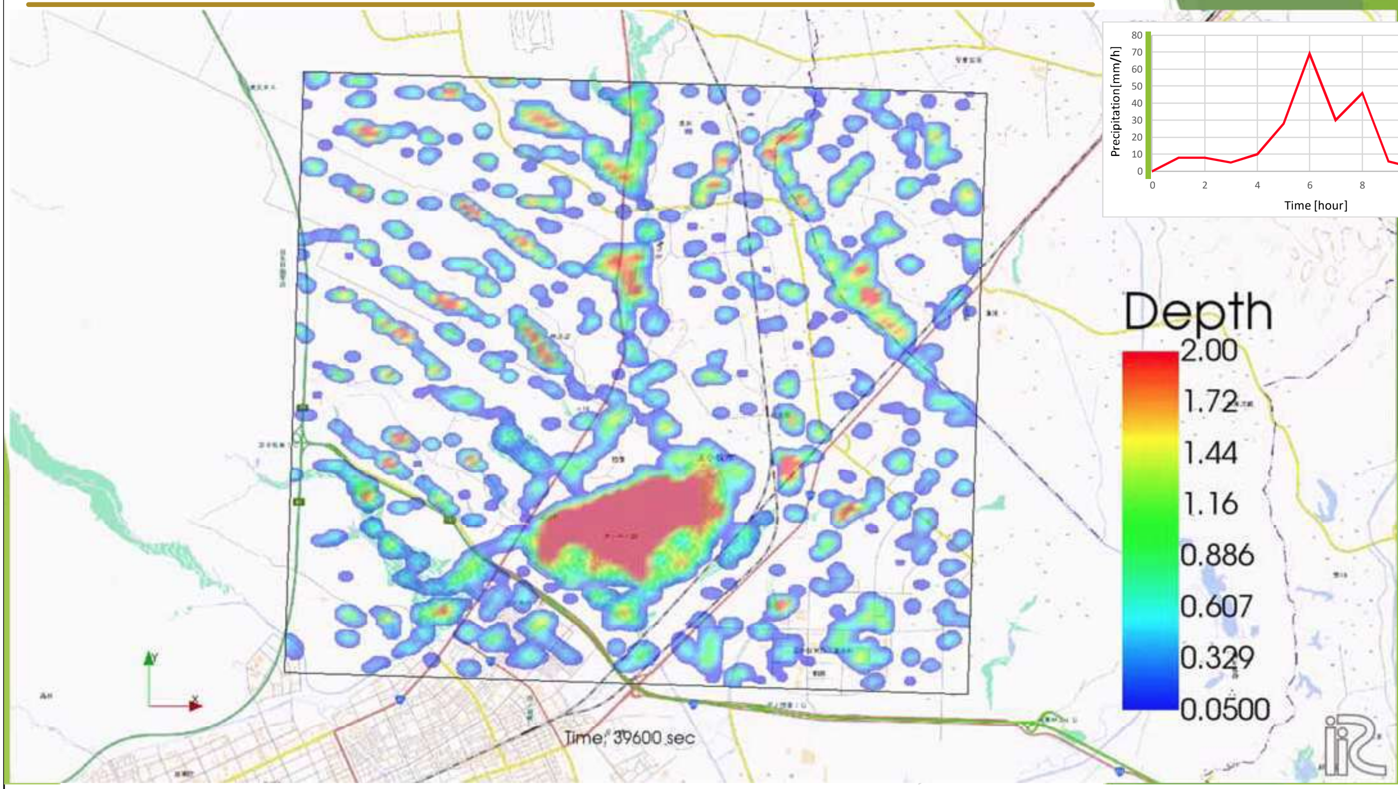
The tsunami washed away almost all the houses in its path

Example 4. A simulation of flooding caused by Tsunami run-up (Tutorial Chapter 4)

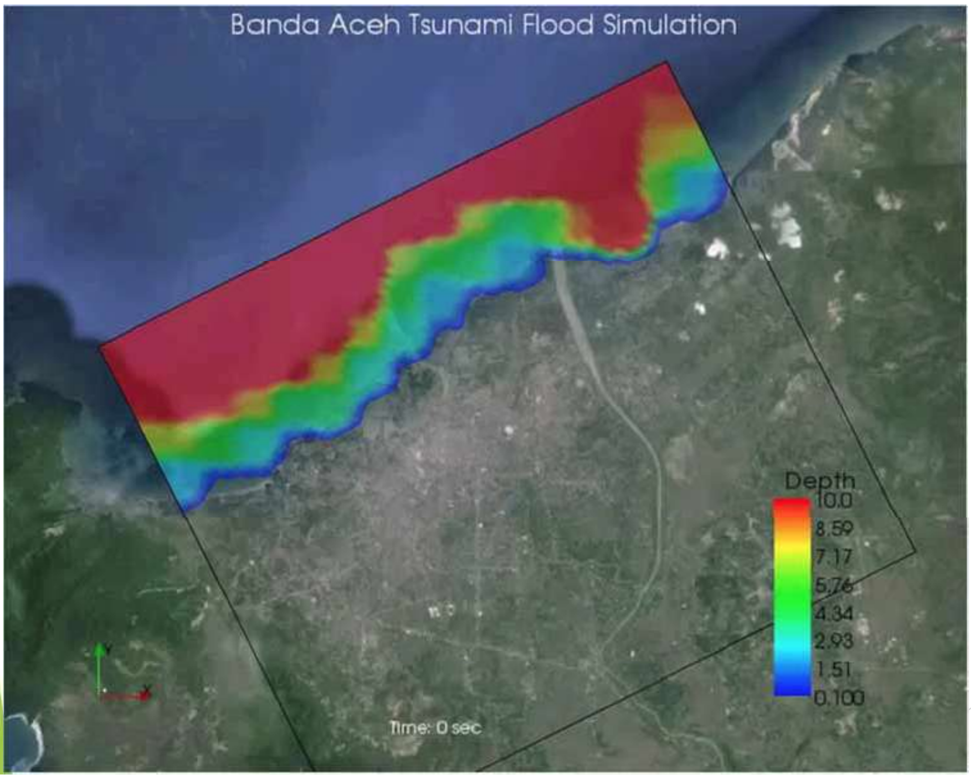


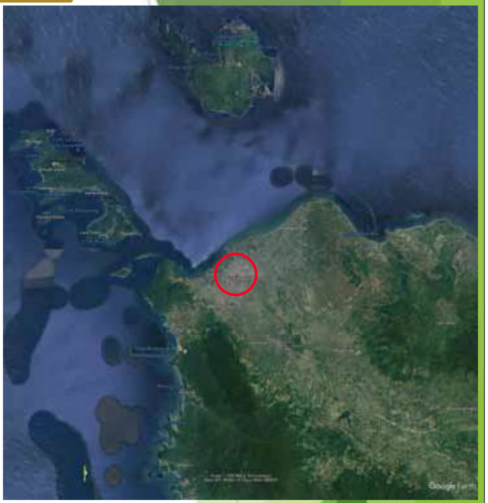


Example 5. A simulation of flooding with rainfall data (Tutorial Chapter 5)



Example 6. Simulation of flooding caused by Tsunami run-up (Banda Aceh)





End.

Taiwan - Japan
Simulation Technology for Urban Flooding and River Hydraulics Sediment Transport Technology Workshop & iRIC training session

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