

# 河川流・氾濫流一体解析による 令和2年球磨川水害における建物流失率の検討

○柏田仁<sup>1</sup>, 窪田利久<sup>1</sup>, 平本達典<sup>1</sup>, 山田真史<sup>2</sup>,  
佐山敬洋<sup>2</sup>, 二瓶泰雄<sup>1</sup>

1 東京理科大学 2 京都大学防災研究所

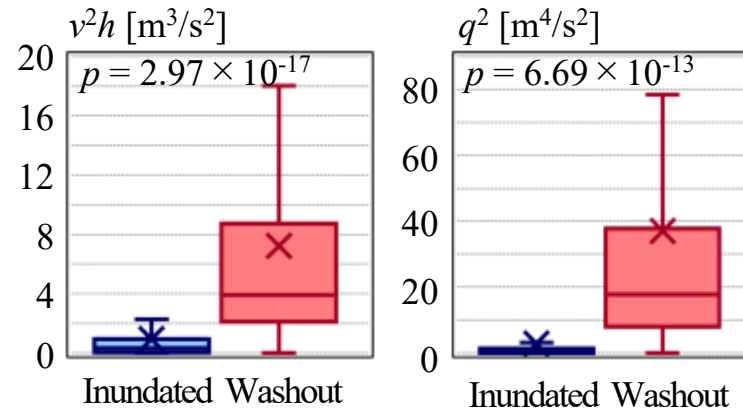
令和2年球磨川水害の被害実績を基に、建物流失を引き起こす水理条件を明らかにする

令和2年7月球磨川水害を  
河川流・氾濫流一体解析

痕跡水位や浸水範囲を  
概ね精度良く再現

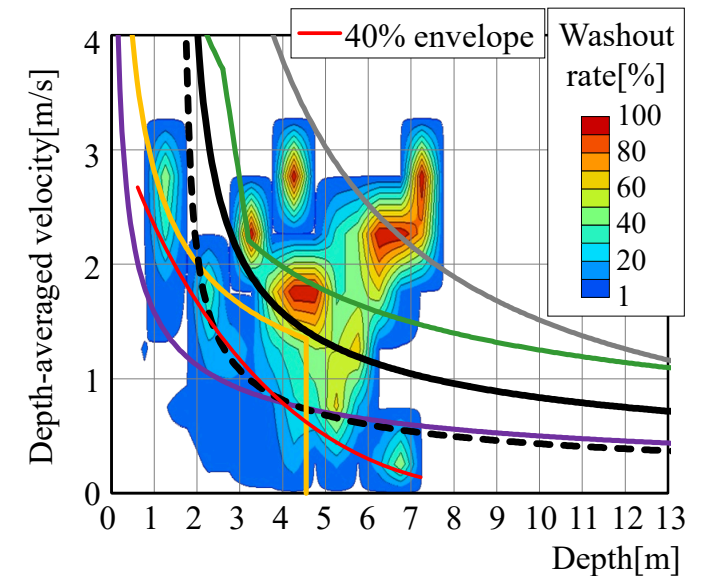
建物位置の水理量を抽出

建物の流失・浸水地点の  
水理量には  
統計的に有意な差



流速や水深, 流体力, モーメント指標から  
建物流失リスクを判定可能

水理量と流失率の関係  
一義的な閾値設定は困難  
流失率の評価が適当



# 河川流・氾濫流一体解析による 令和2年球磨川水害における建物流失率の検討



○柏田仁<sup>1</sup>, 窪田利久<sup>1</sup>, 平本達典<sup>1</sup>,  
山田真史<sup>2</sup>, 佐山敬洋<sup>2</sup>, 二瓶泰雄<sup>1</sup>  
1 東京理科大学 2 京都大学防災研究所





ピーク付近

引用：NHKオンデマンド



2020/7/4 17:15

引用：朝日新聞デジタル

令和2年球磨川水害では全川で水位が堤防高を数m超過



**河川流と氾濫流が一体**となって流下 **3次元性の強い複断面蛇行流れ**の形態





茶屋集落における建物流失



現地調査による建物・橋梁被災の平面分布

数～数十棟の流失・全壊  
@建物被災の先行研究

に対し

全壊1,234棟, 半壊1,526棟  
@人吉市・球磨村(県調べ)

令和2年球磨川水害の被害実績を基に、建物流失を引き起こす水理条件を明らかにする



令和2年球磨川水害の被害実績を基に、建物流失を引き起こす水理条件を明らかにする

### *Calculation*

流下型氾濫の形態を呈した  
令和2年球磨川水害時の流れを  
河川流・氾濫流一体解析  
by 2D-3D hybrid model

×

### *Observation*

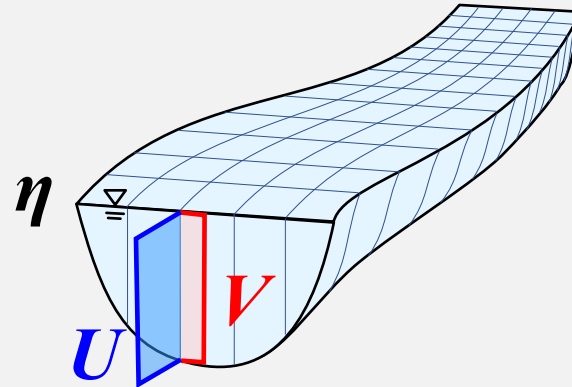
流失建物  
浸水建物  
の実績分布

建物流失リスクの指標（流速？水深？流体力？）を分析

広域の河川流+氾濫流を三次元性を考慮しながら効率的に解析するために

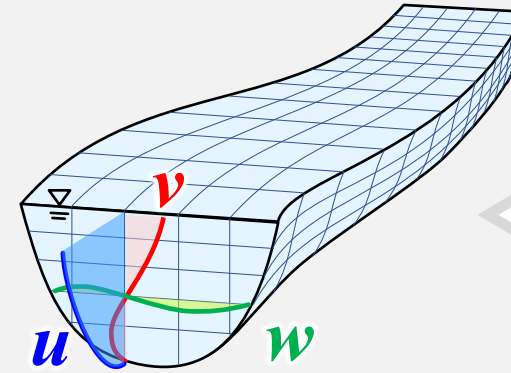
## 2D-3D hybridモデル を適用

$U$  : 主流方向水深平均流速  
 $V$  : 横断方向水深平均流速  
 $\eta$  : 水位



2D計算+補正項

全てのtime stepで実行



$u$  : 主流方向流速  
 $v$  : 横断方向流速  
 $w$  : 鉛直方向流速

3D計算

たまに実行

三次元流動の影響を  
補正項として2D計算に反映



## 3D calc. (Internal mode)

$$\frac{1}{1+N} \frac{\partial}{\partial s} (Du_s) + \frac{\partial}{\partial n} (Du_n) + \frac{Du_n}{(1+N)R} + \frac{\partial w^*}{\partial \sigma} + \frac{\partial D}{\partial t} = 0$$

$$\frac{\partial u_s}{\partial t} + \frac{u_s}{1+N} \frac{\partial u_s}{\partial s} + u_n \frac{\partial u_s}{\partial n} + \frac{w^*}{D} \frac{\partial u_s}{\partial \sigma} + \frac{u_s u_n}{(1+N)R} = -\frac{g}{1+N} \frac{\partial (D+z_b)}{\partial s} + \frac{1}{1+N} \frac{\partial}{\partial s} \left( \frac{2A_H}{1+N} \frac{\partial u_s}{\partial s} \right) + \frac{\partial}{\partial n} \left\{ A_H \left( \frac{\partial u_s}{\partial n} + \frac{1}{1+N} \frac{\partial u_n}{\partial s} \right) \right\} + \frac{1}{D} \frac{\partial}{\partial \sigma} \left( \frac{A_V}{D} \frac{\partial u_s}{\partial \sigma} \right)$$

$$\frac{\partial u_n}{\partial t} + \frac{u_s}{1+N} \frac{\partial u_n}{\partial s} + u_n \frac{\partial u_n}{\partial n} + \frac{w^*}{D} \frac{\partial u_n}{\partial \sigma} - \frac{u_s^2}{(1+N)R} = -g \frac{\partial (D+z_b)}{\partial n} + \frac{1}{1+N} \frac{\partial}{\partial s} \left\{ A_H \left( \frac{\partial u_s}{\partial n} + \frac{1}{1+N} \frac{\partial u_n}{\partial s} \right) \right\} + \frac{\partial}{\partial n} \left( 2A_H \frac{\partial u_n}{\partial n} \right) + \frac{1}{D} \frac{\partial}{\partial \sigma} \left( \frac{A_V}{D} \frac{\partial u_n}{\partial \sigma} \right)$$

## 2D calc. (External mode)

$$\frac{\partial \eta}{\partial t} + \frac{1}{1+N} \frac{\partial}{\partial s} (DU_s) + \frac{\partial}{\partial n} (DU_n) + \frac{DU_n}{(1+N)R} = 0$$

***Correction term***

$$\frac{\partial U_s}{\partial t} + \frac{U_s}{1+N} \frac{\partial U_s}{\partial s} + U_n \frac{\partial U_s}{\partial n} + \frac{U_s U_n}{(1+N)R} = -\frac{g}{1+N} \frac{\partial (D+z_b)}{\partial s} + \frac{1}{1+N} \frac{\partial}{\partial s} \left( \frac{2A_{H2D}}{1+N} \frac{\partial U_s}{\partial s} \right) + \frac{\partial}{\partial n} \left\{ A_{H2D} \left( \frac{\partial U_s}{\partial n} + \frac{1}{1+N} \frac{\partial U_n}{\partial s} \right) \right\} - \frac{C_{fb}}{D} U_s \sqrt{U_s^2 + U_n^2} - G_s$$

$$\frac{\partial U_n}{\partial t} + \frac{U_s}{1+N} \frac{\partial U_n}{\partial s} + U_n \frac{\partial U_n}{\partial n} - \frac{U_s^2}{(1+N)R} = -g \frac{\partial (D+z_b)}{\partial n} + \frac{1}{1+N} \frac{\partial}{\partial s} \left\{ A_{H2D} \left( \frac{\partial U_s}{\partial n} + \frac{1}{1+N} \frac{\partial U_n}{\partial s} \right) \right\} + \frac{\partial}{\partial n} \left( 2A_{H2D} \frac{\partial U_n}{\partial n} \right) - \frac{C_{fb}}{D} U_n \sqrt{U_s^2 + U_n^2} - G_n$$

*Depth-averaged 3D advection term**2D advection term*

$$G_s = \int_{-1}^0 \left( \frac{u_s}{1+N} \frac{\partial u_s}{\partial s} + u_n \frac{\partial u_s}{\partial n} + \frac{w^*}{D} \frac{\partial u_s}{\partial \sigma} + \frac{u_s u_n}{(1+N)R} \right) d\sigma - \left( \frac{U_s}{1+N} \frac{\partial U_s}{\partial s} + U_n \frac{\partial U_s}{\partial n} + \frac{U_s U_n}{(1+N)R} \right)$$

$$- \int_{-1}^0 \left[ \frac{1}{1+N} \frac{\partial}{\partial s} \left( \frac{2A_H}{1+N} \frac{\partial u_s}{\partial s} \right) + \frac{\partial}{\partial n} \left\{ A_H \left( \frac{\partial u_s}{\partial n} + \frac{1}{1+N} \frac{\partial u_n}{\partial s} \right) \right\} \right] d\sigma + \left[ \frac{1}{1+N} \frac{\partial}{\partial s} \left( \frac{2A_{H2D}}{1+N} \frac{\partial U_s}{\partial s} \right) + \frac{\partial}{\partial n} \left\{ A_{H2D} \left( \frac{\partial U_s}{\partial n} + \frac{1}{1+N} \frac{\partial U_n}{\partial s} \right) \right\} \right]$$

*Depth-averaged 3D diffusion term**2D diffusion term*

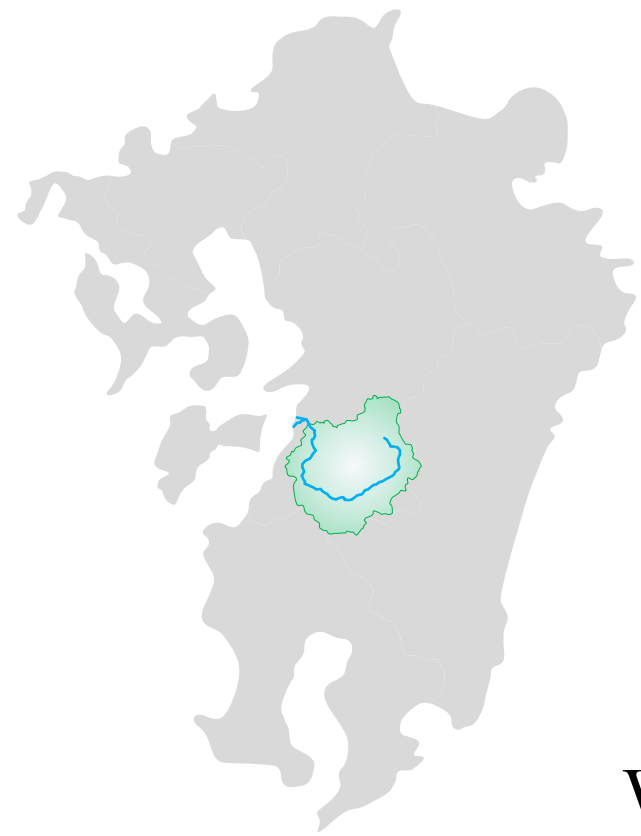
$$G_n = \int_{-1}^0 \left( \frac{u_s}{1+N} \frac{\partial u_n}{\partial s} + u_n \frac{\partial u_n}{\partial n} + \frac{w^*}{D} \frac{\partial u_n}{\partial \sigma} - \frac{u_s^2}{(1+N)R} \right) d\sigma - \left( \frac{U_s}{1+N} \frac{\partial U_n}{\partial s} + U_n \frac{\partial U_n}{\partial n} - \frac{U_s^2}{(1+N)R} \right)$$

$$- \int_{-1}^0 \left[ \frac{1}{1+N} \frac{\partial}{\partial s} \left\{ A_H \left( \frac{\partial u_s}{\partial n} + \frac{1}{1+N} \frac{\partial u_n}{\partial s} \right) \right\} + \frac{\partial}{\partial n} \left( 2A_H \frac{\partial u_n}{\partial n} \right) \right] d\sigma + \left[ \frac{1}{1+N} \frac{\partial}{\partial s} \left\{ A_{H2D} \left( \frac{\partial U_s}{\partial n} + \frac{1}{1+N} \frac{\partial U_n}{\partial s} \right) \right\} + \frac{\partial}{\partial n} \left( 2A_{H2D} \frac{\partial U_n}{\partial n} \right) \right]$$

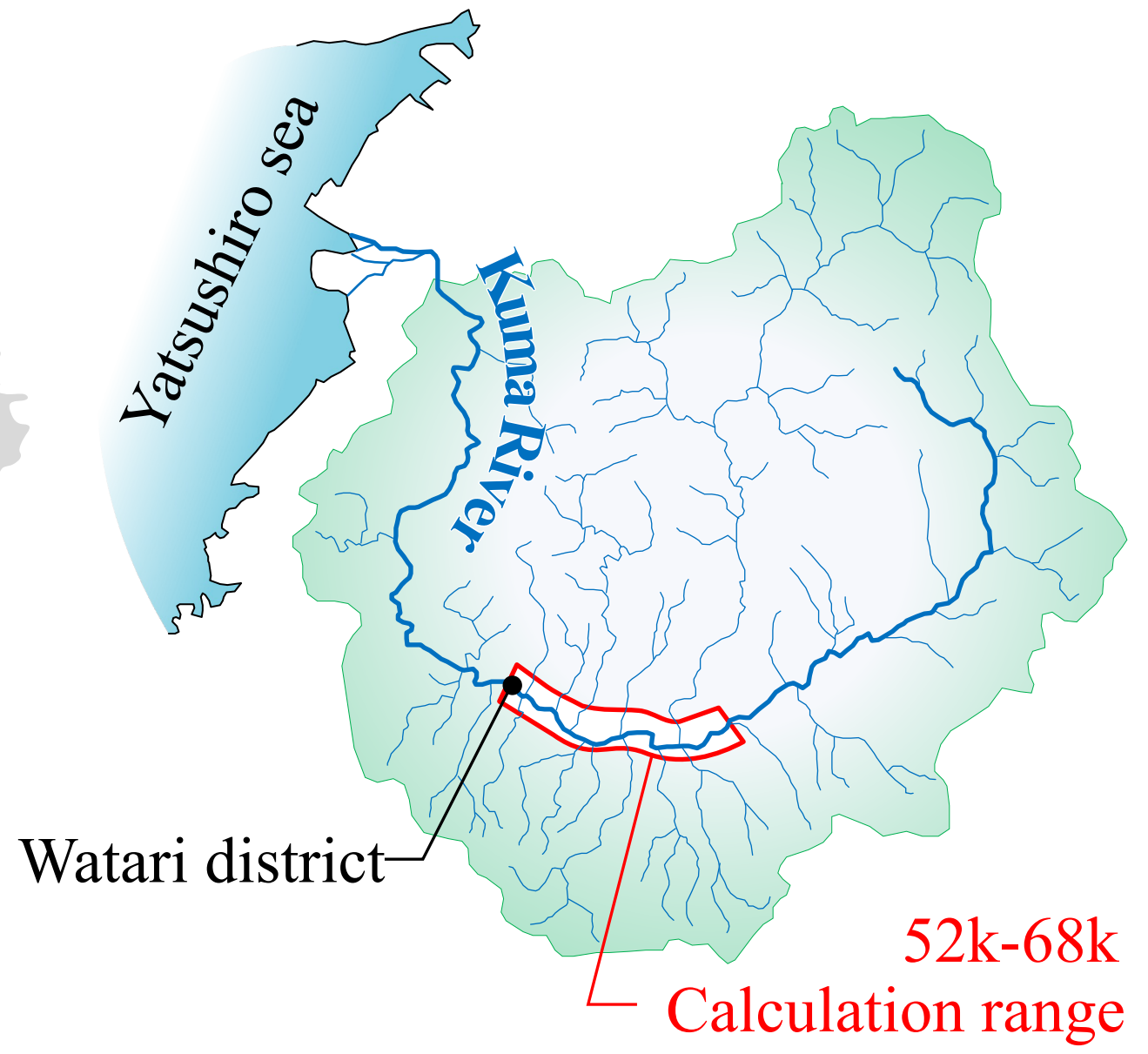




(a) Japan

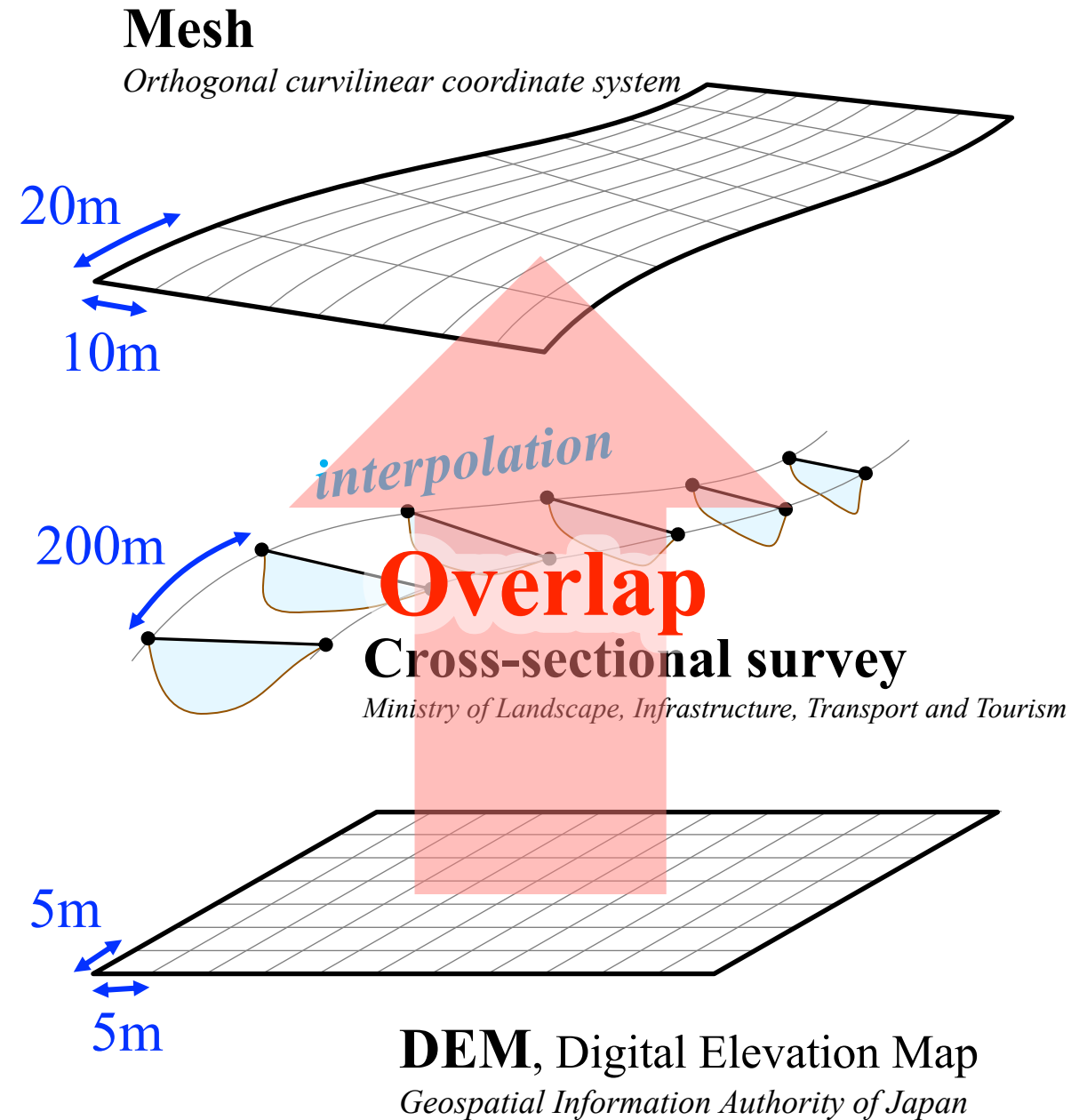


(b) Kyushu region



(c) Kuma River basin

Num. of mesh	Streamwise	767
	Spanwise	151
	Vertical	10
Spatial interval	Streamwise	20.0 m
	Spanwise	10.0 m
Time step	$\Delta t_i$ , internal mode	0.05 sec
	$\Delta t_e$ , external mode	Variable ( $C < 0.2$ )
Mode splitting interval		10.0 sec
$n$	River channel	$0.030 \text{ m}^{-1/3} \text{ s}$
	Inundation area	Next slide







$$n = \sqrt{n_0^2 + \frac{C_D}{2gk} \times \frac{\theta}{100 - \theta} \times D^{4/3}}$$

$\theta$  : house occupancy rate

$k$  : house width

$C_D$  : drag coefficient

$n_0$  : roughness coefficient of ground

$D$  : water depth

$g$  : acceleration of gravity



$$\theta = \frac{A_{house}}{A_{mesh}} \times 100$$

$$k = \sqrt{A_{house}}$$



## 観測データ

解析雨量 (気象庁)

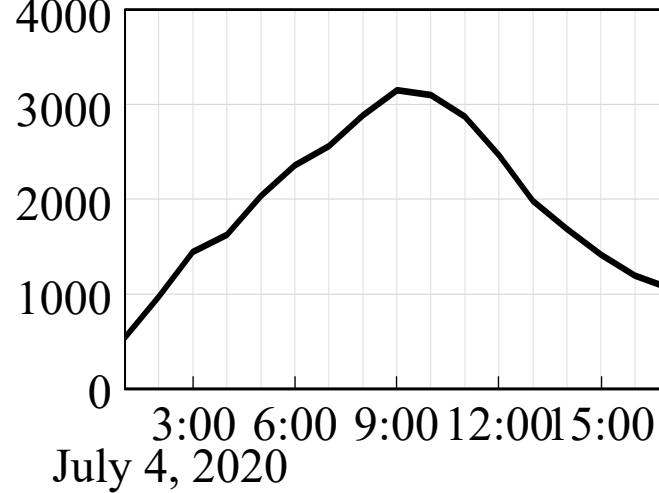
## 流出計算

RRI model (Rainfall-Runoff-Inundation model)

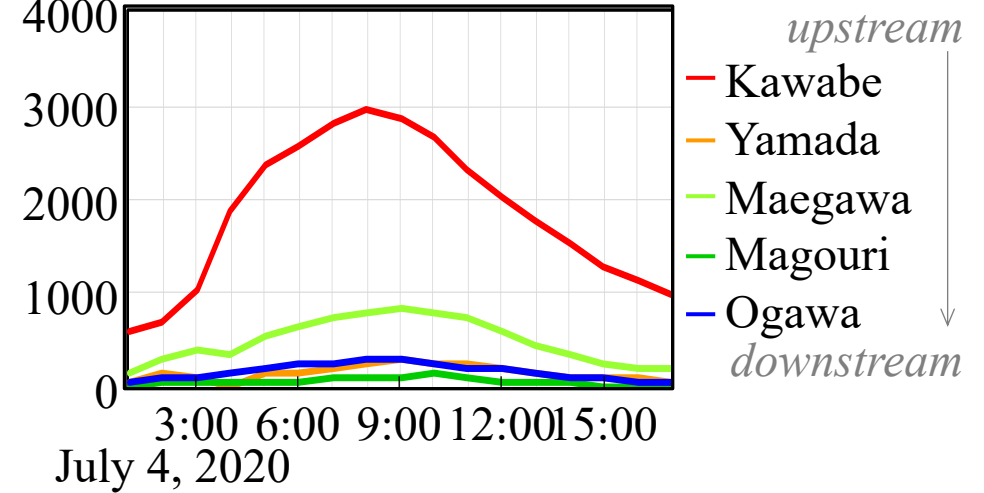
## 1次元不定流計算

MIKE11 (DHI)

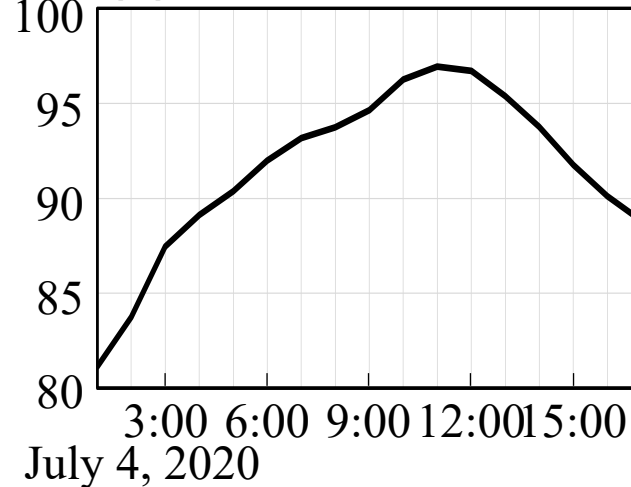
$Q$ [m<sup>3</sup>/s] (a) Upstream B.C.



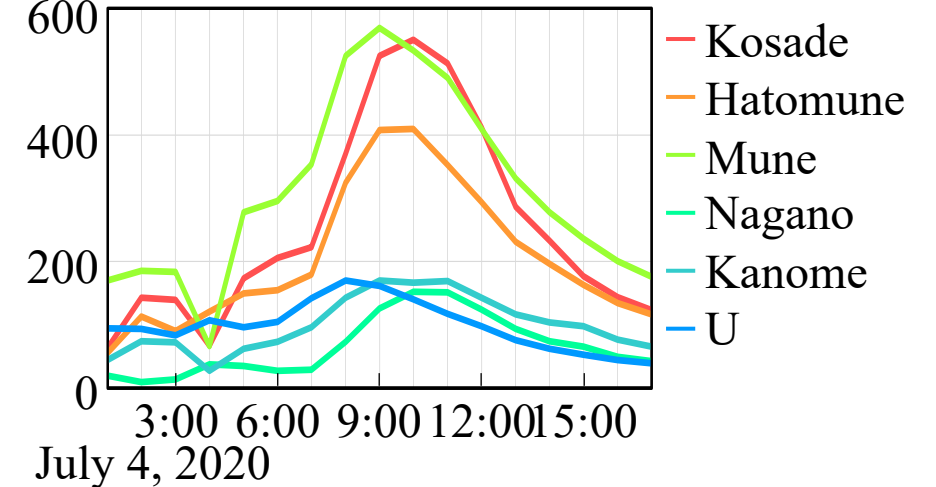
$Q$ [m<sup>3</sup>/s] (c) Upstream B.C. of right branches



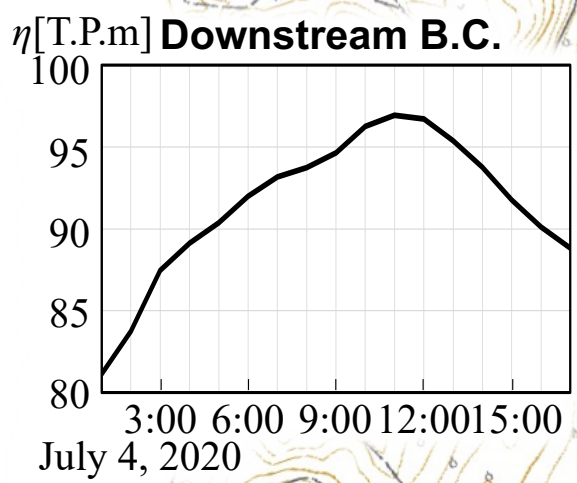
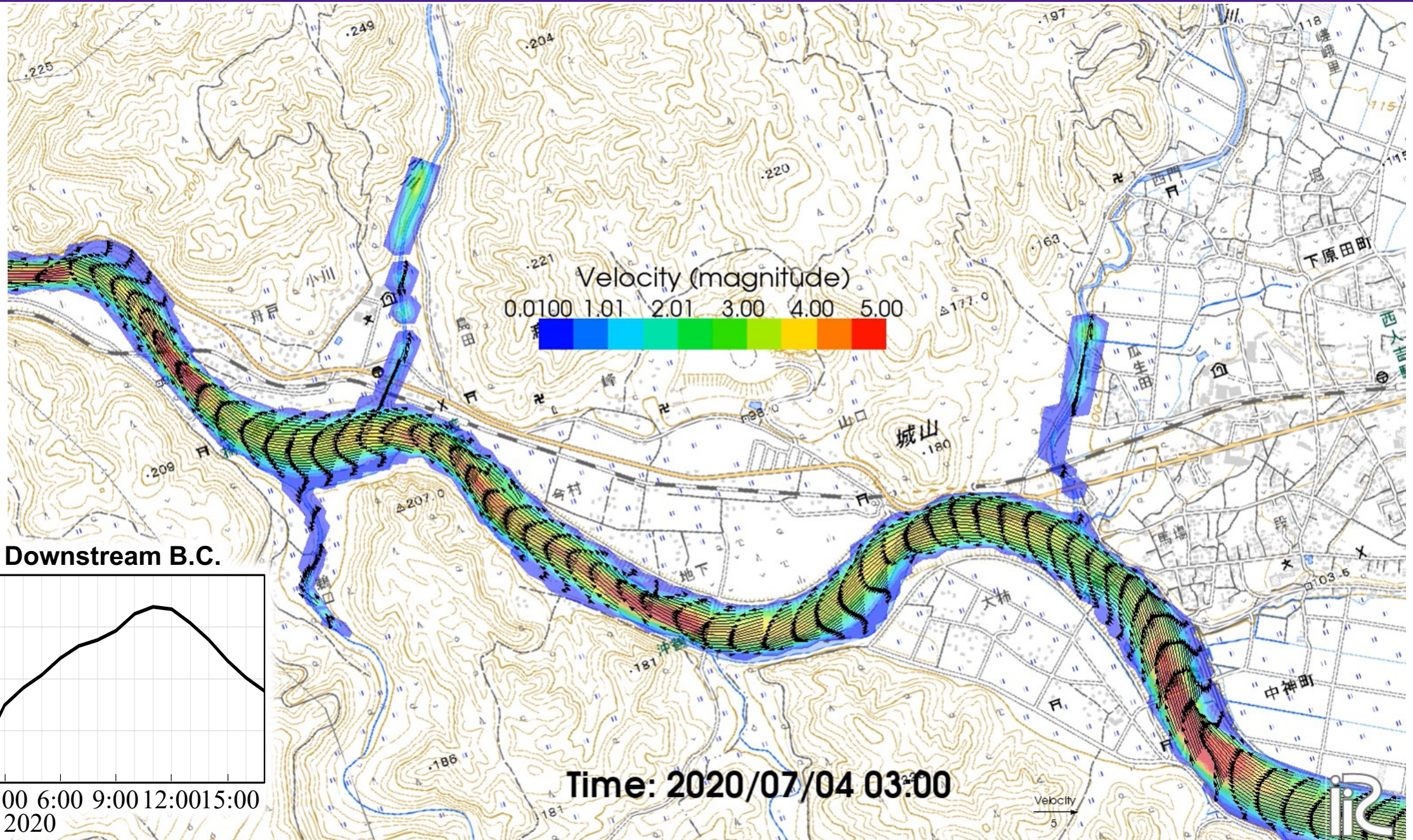
$\eta$ [T.P.m] (b) Downstream B.C.



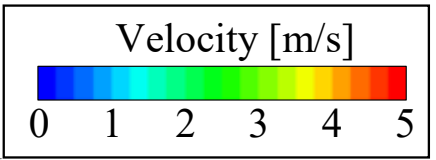
$Q$ [m<sup>3</sup>/s] (d) Upstream B.C. of left branches





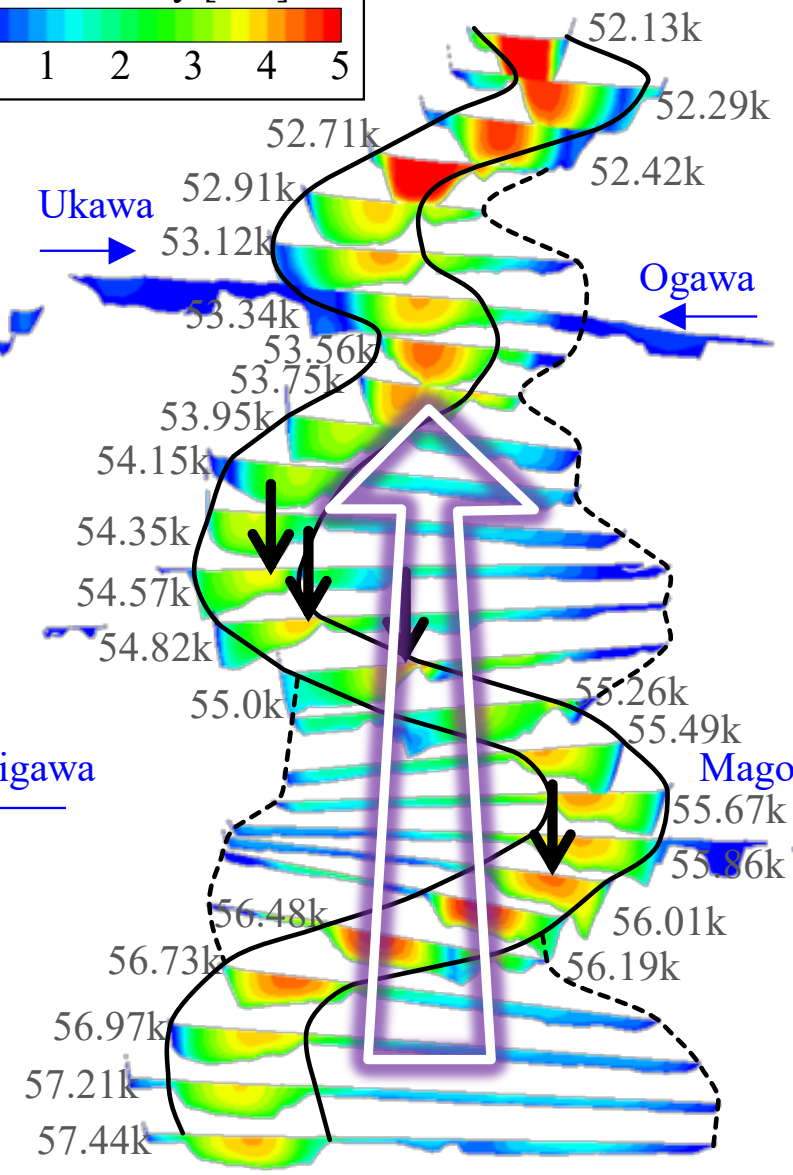
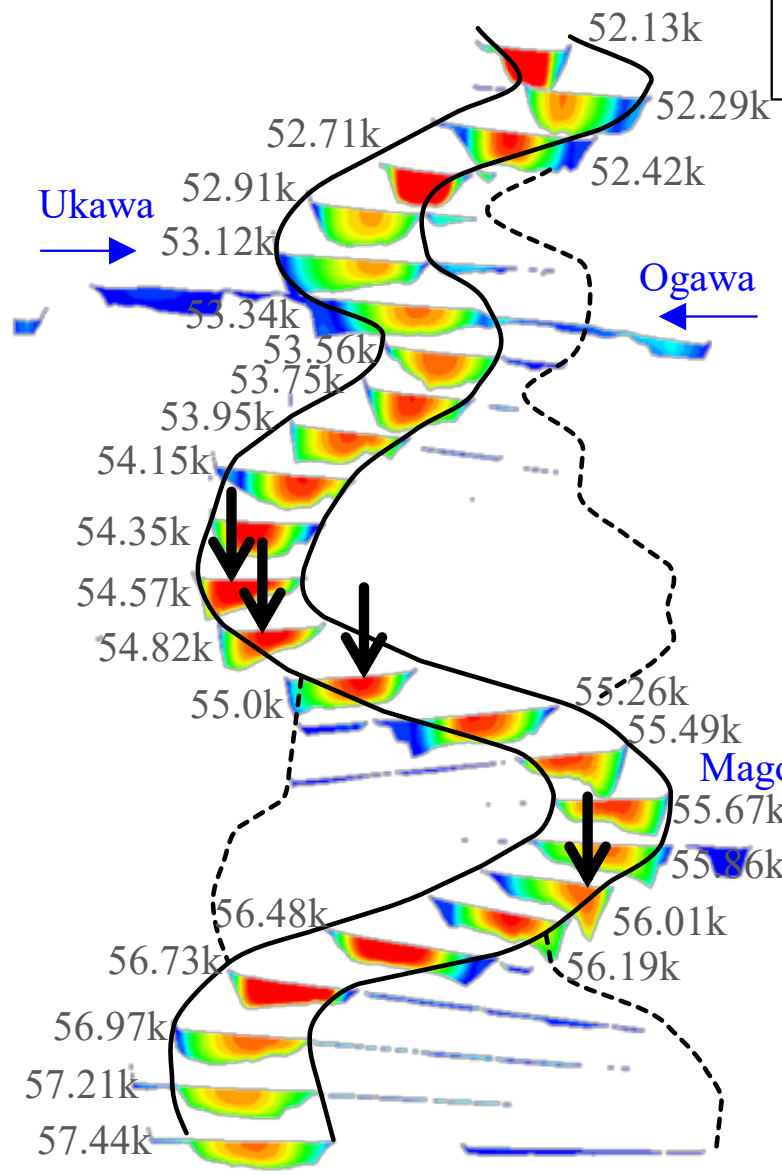






*Velocity peak*  
**外岸側**

*Velocity peak*  
**内岸側**



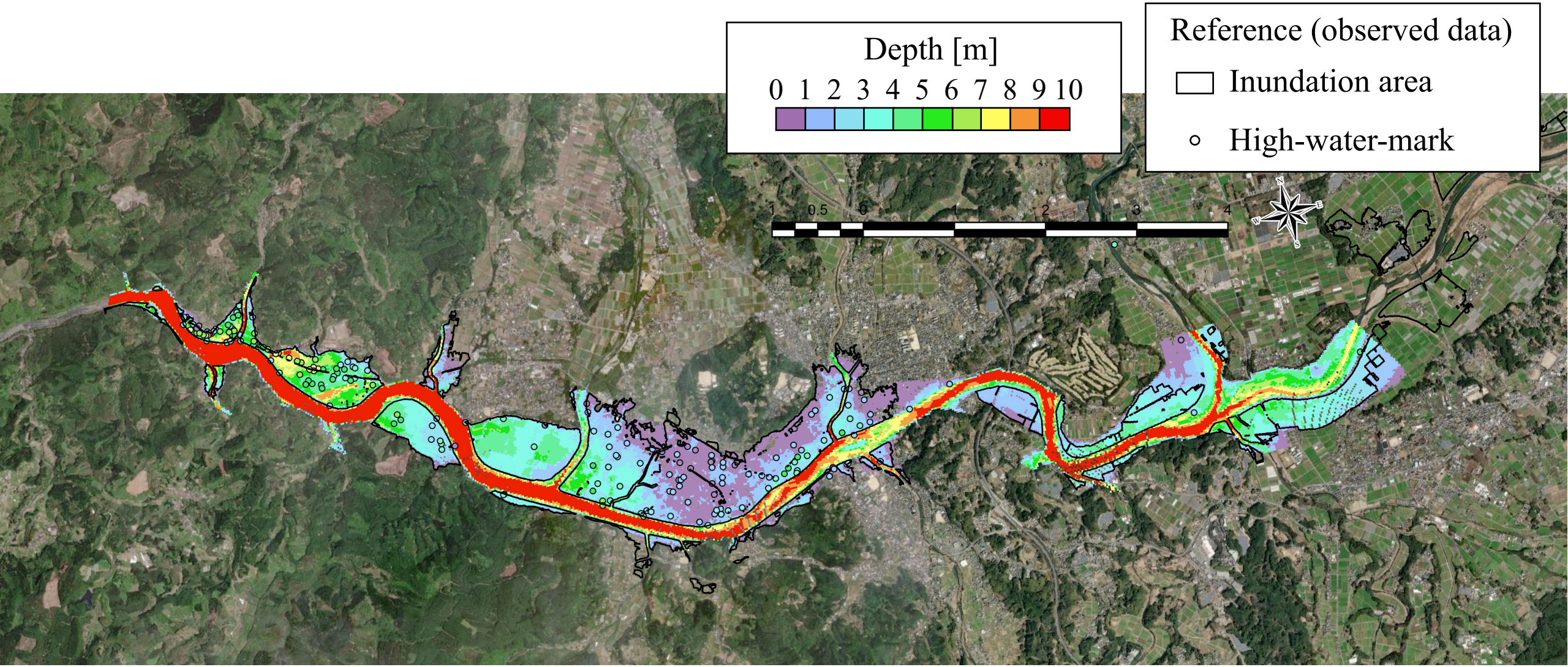
(a) The time of fulfilled channel

(b) The peak of the flood

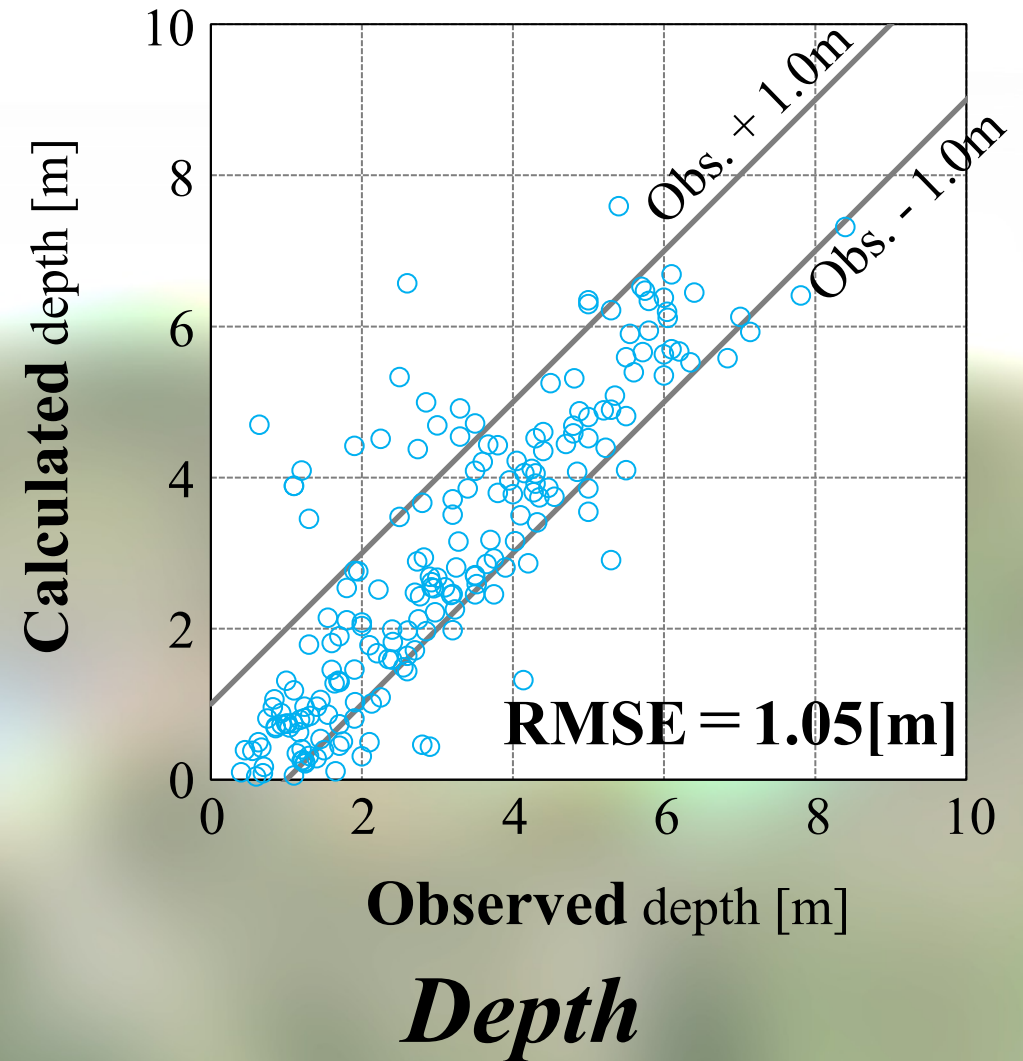
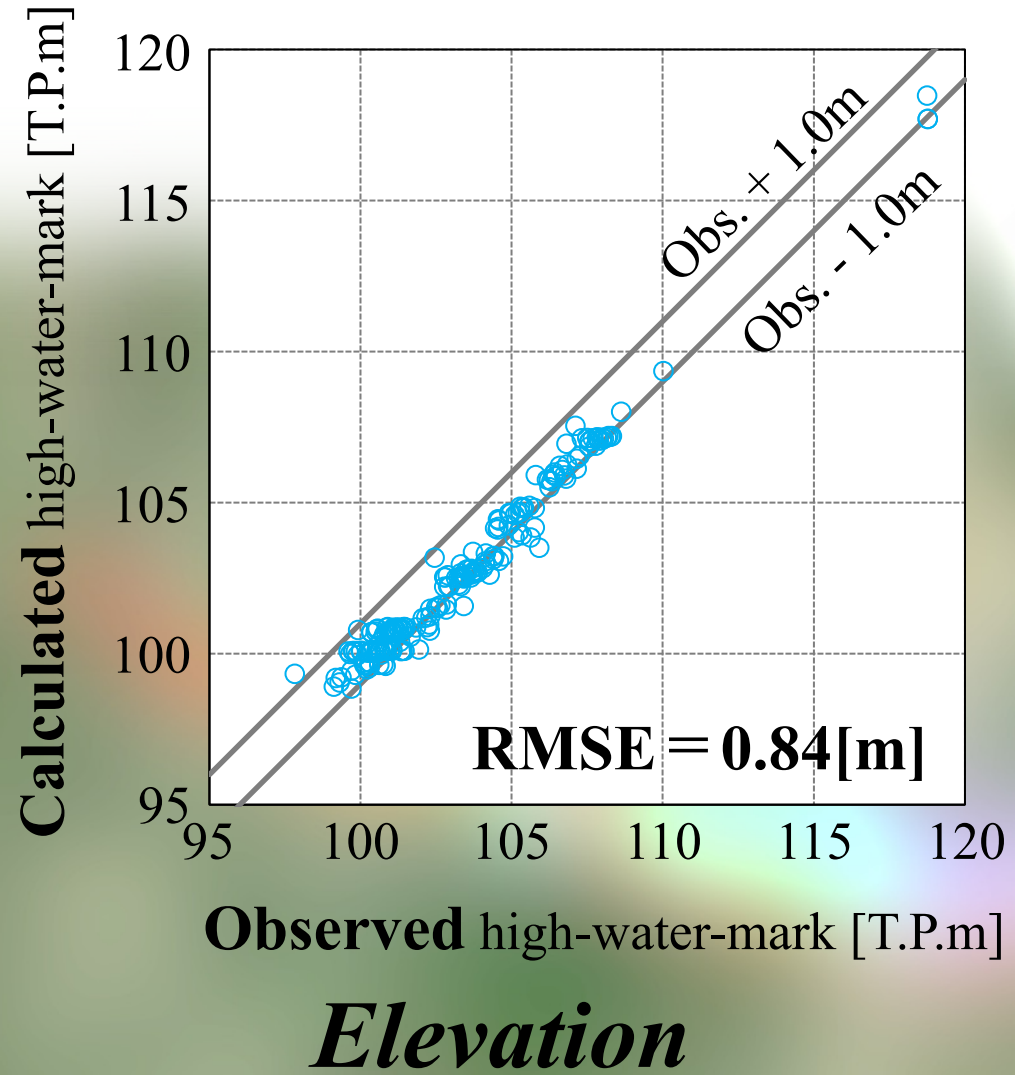




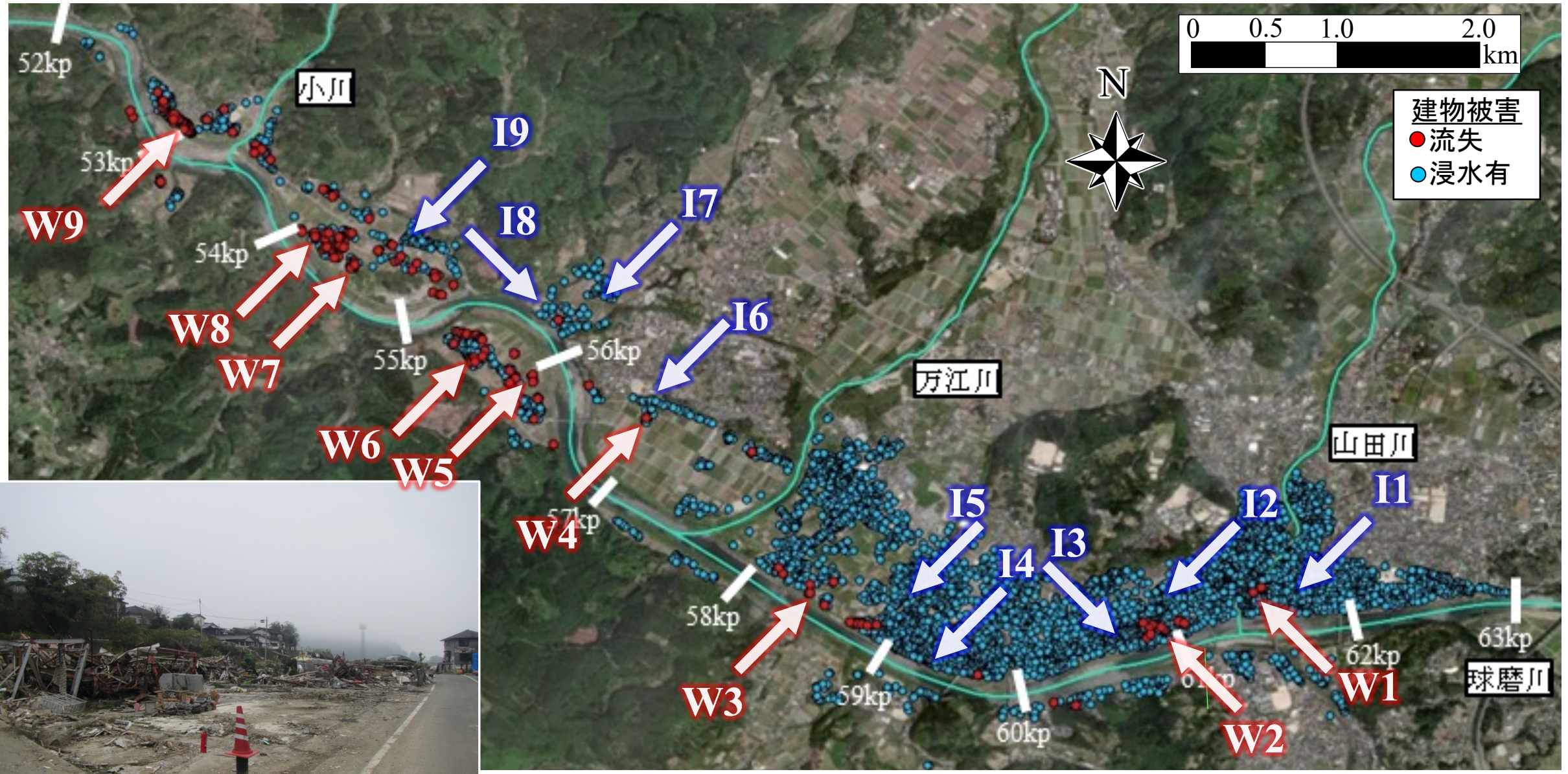








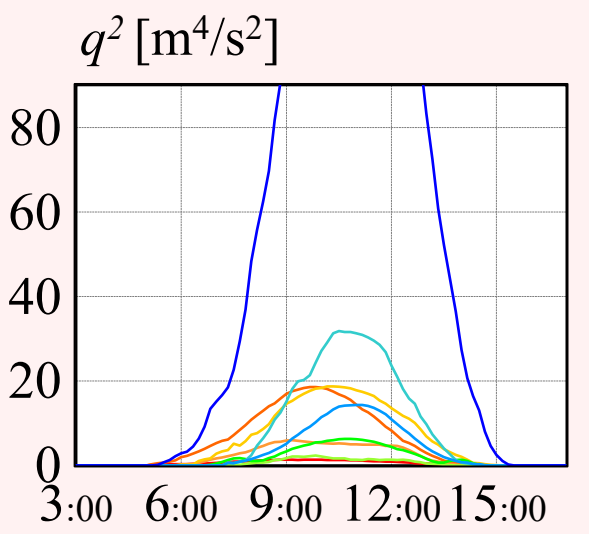
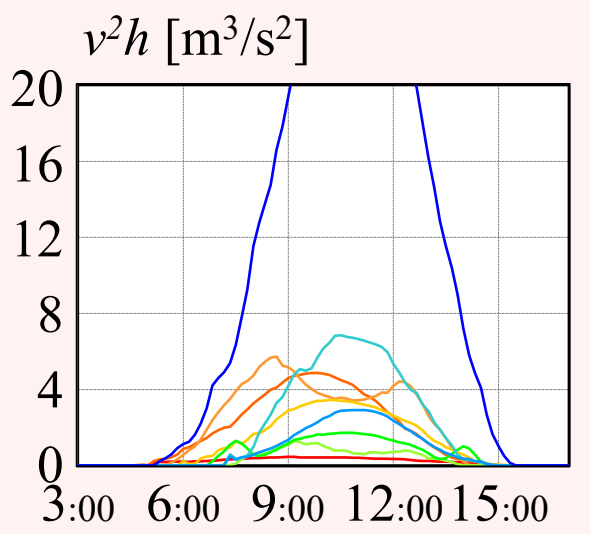
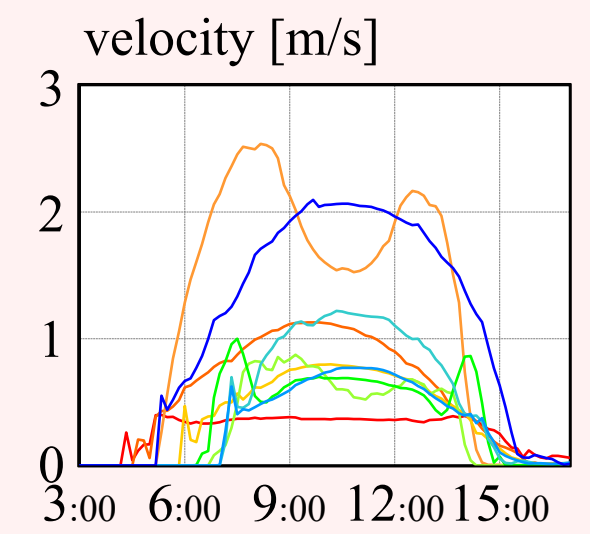
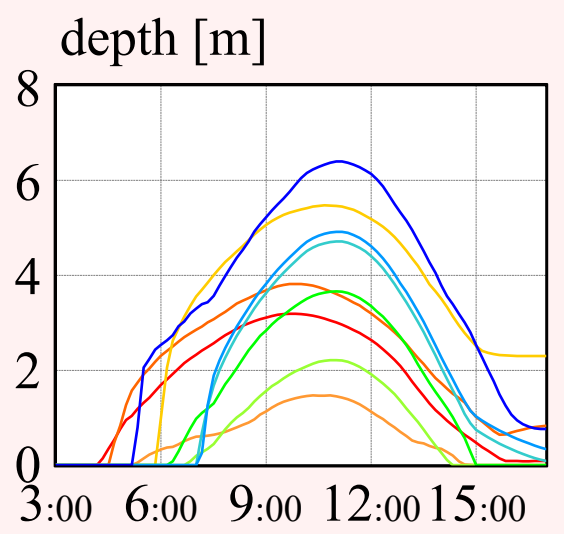




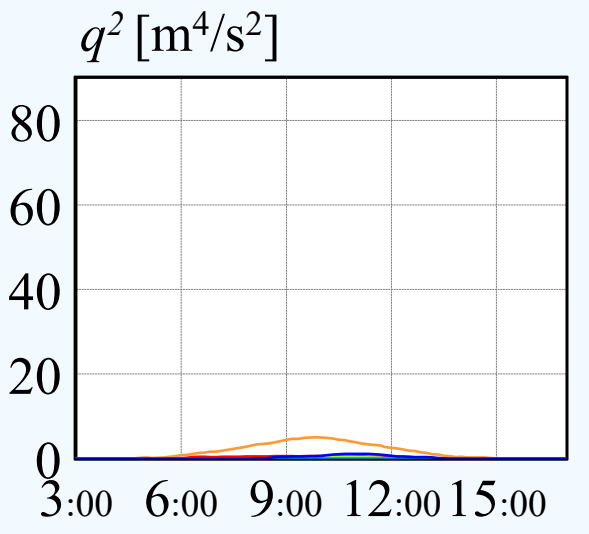
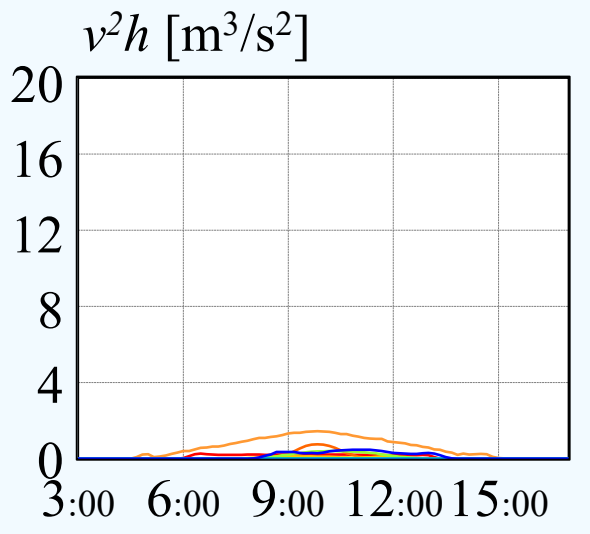
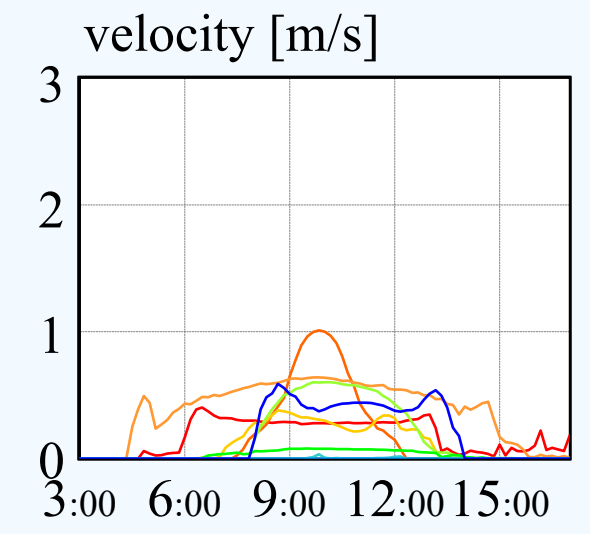
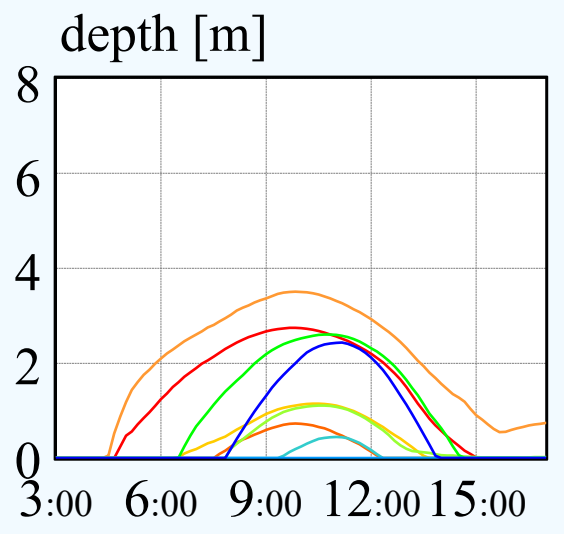
**流出・浸水地点の水理量を抽出して、被害率を評価**



*Washout*



*Inundated*

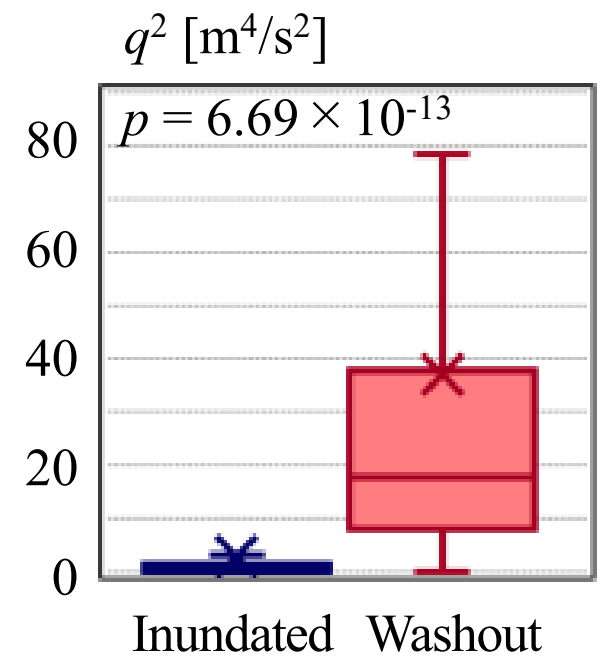
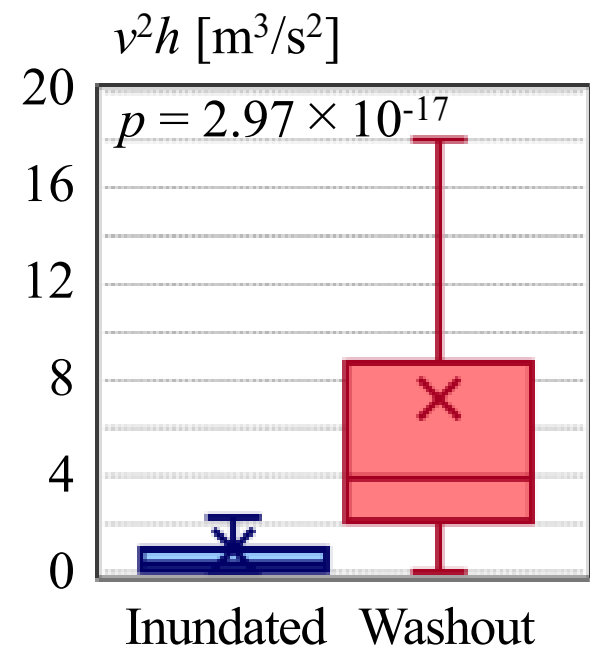
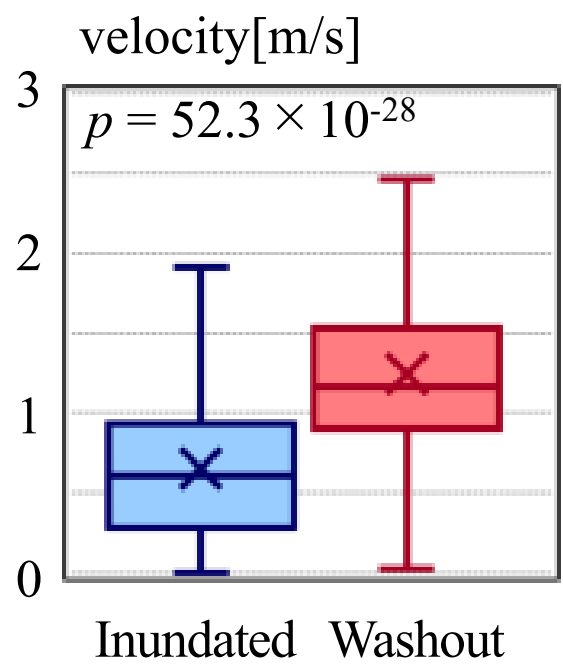
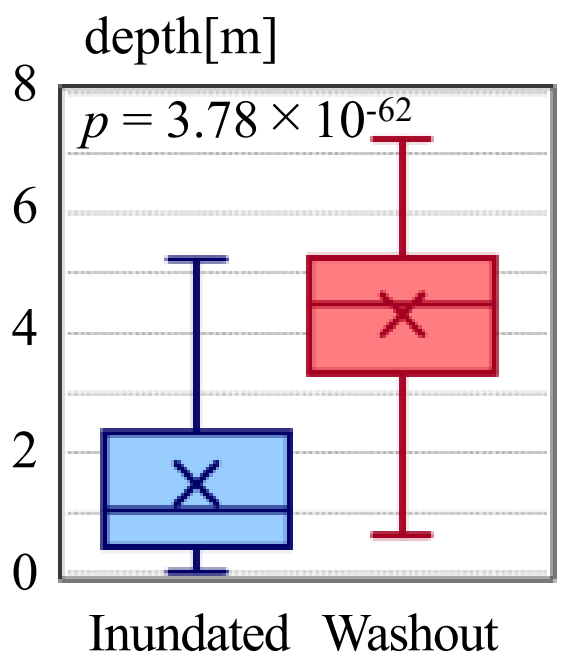


流体力指標

モーメント指標



浸水（計算領域内において建物数n=4110棟）と流失（n=285棟）に分類して分析



有意差OK

有意差OK

有意差OK

有意差OK

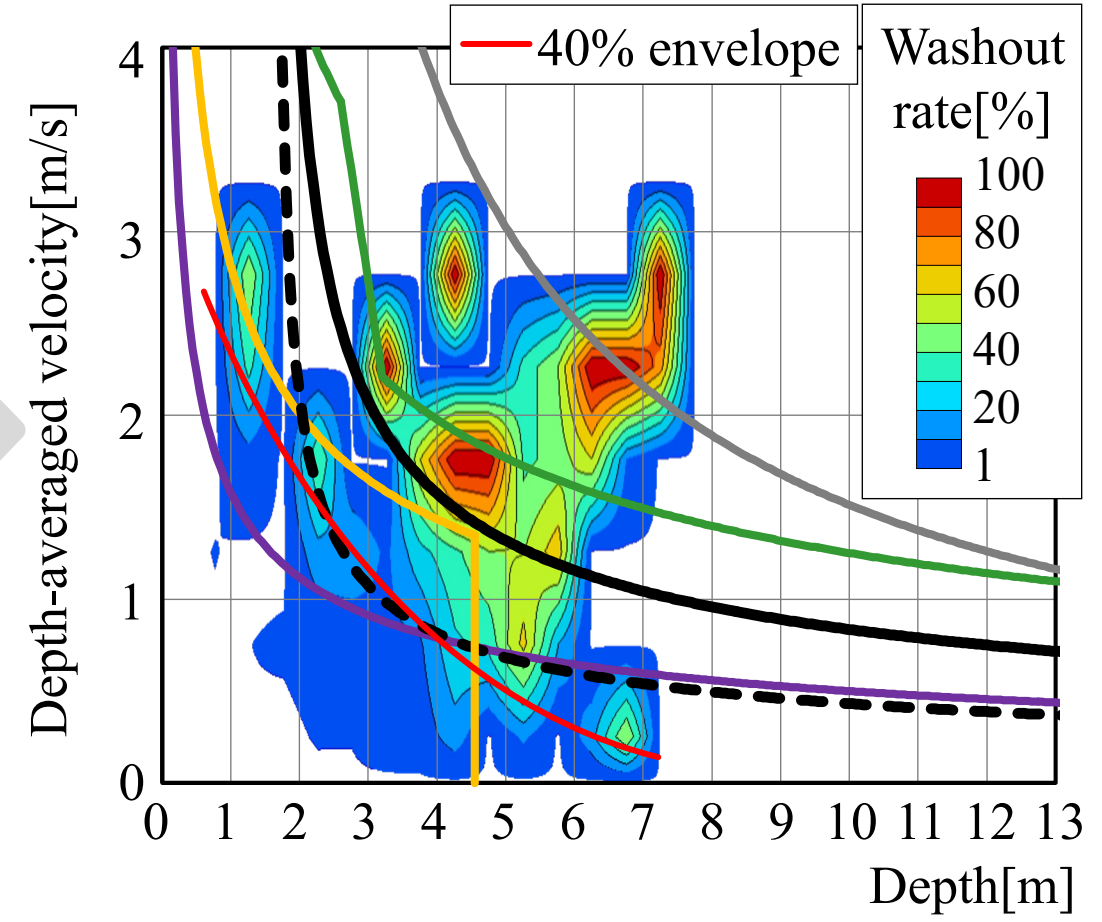
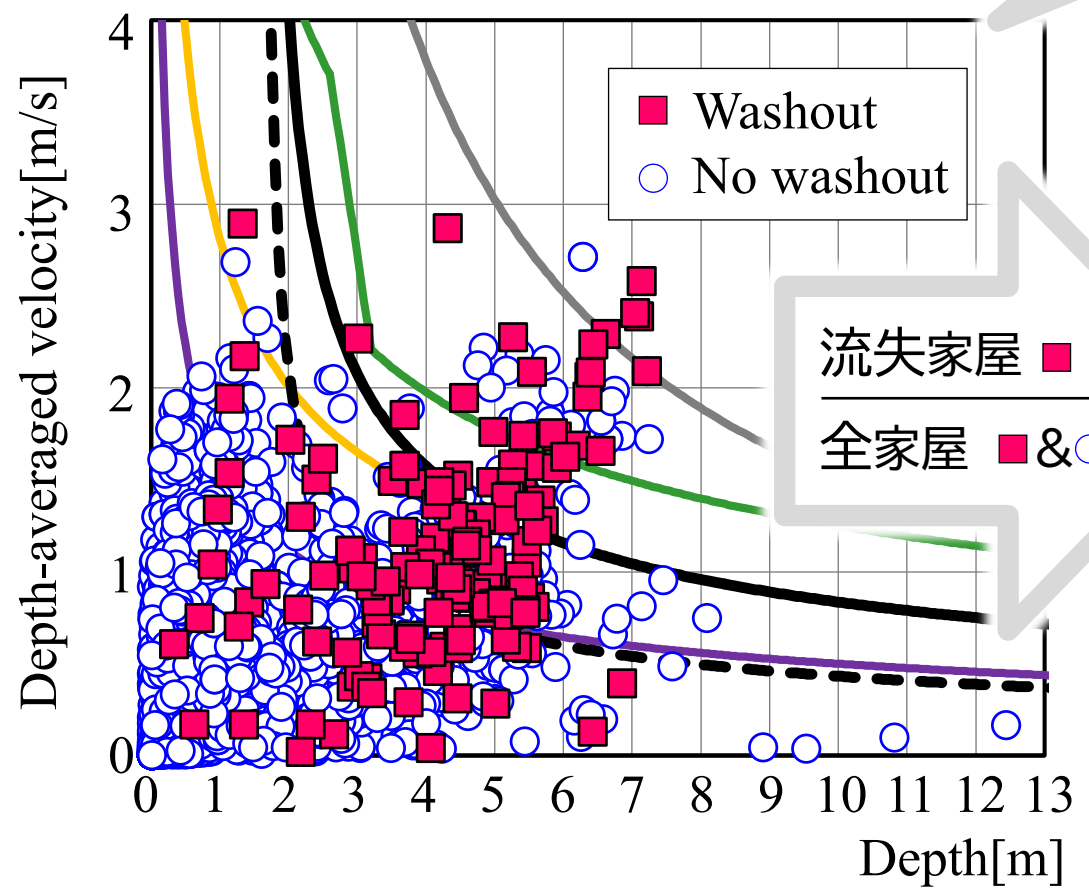
各パーセンタイル値の  
**重複**が相対的に**大**

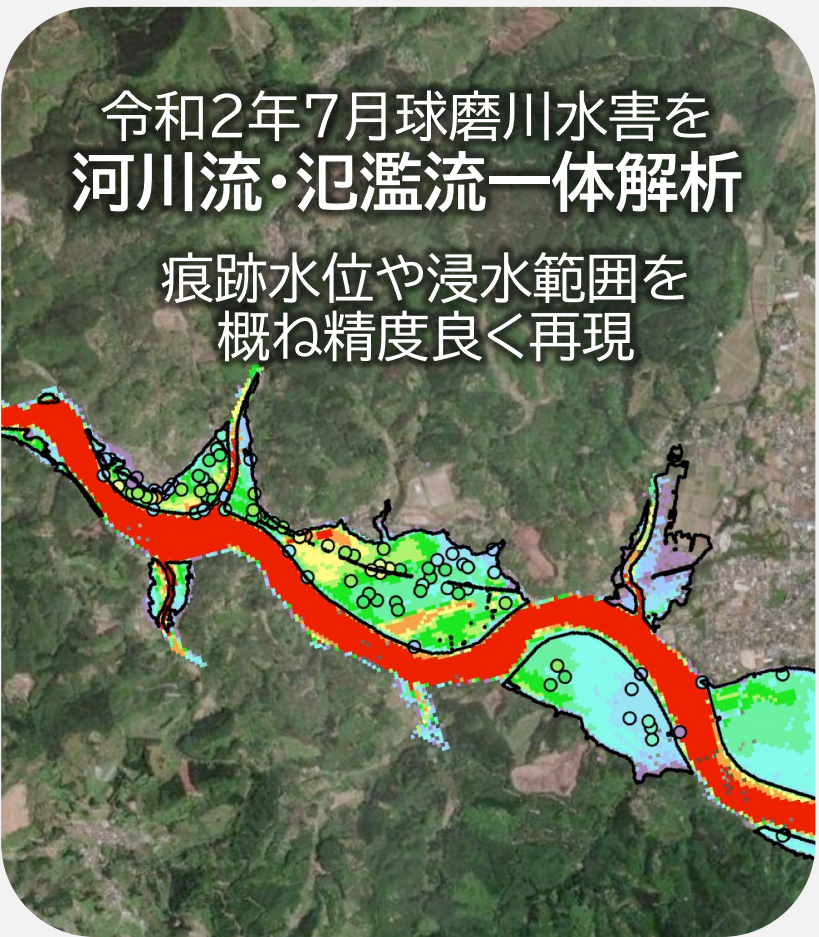
流速と水深を組み合わせた  
**流体力指標**と**モーメント指標**が**有望**

球磨川水害における多量の実績建物被災データから結論

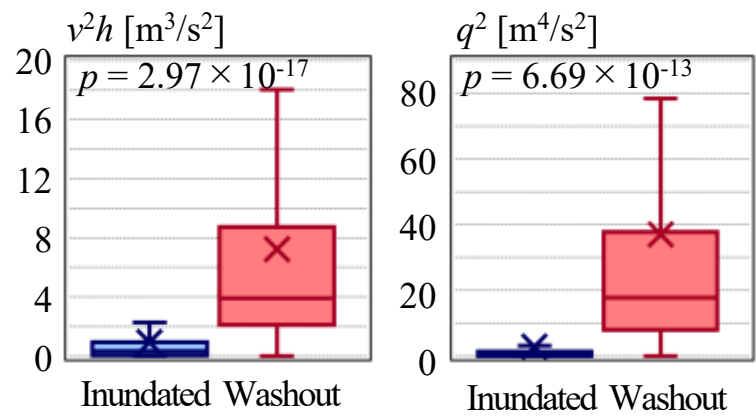
- Collapse (Current seismic standard)<sup>2)</sup>
- - - Collapse (Old seismic standard, ~1981)<sup>2)</sup>
- Slip<sup>2)</sup>      — Topples<sup>2)</sup>
- USACE<sup>22)</sup>      — Satou et.al.<sup>23)</sup>

流失家屋 ■ と 浸水家屋 ○ の分布は重複  
 ∴ 一義的な被災閾値の設定は困難



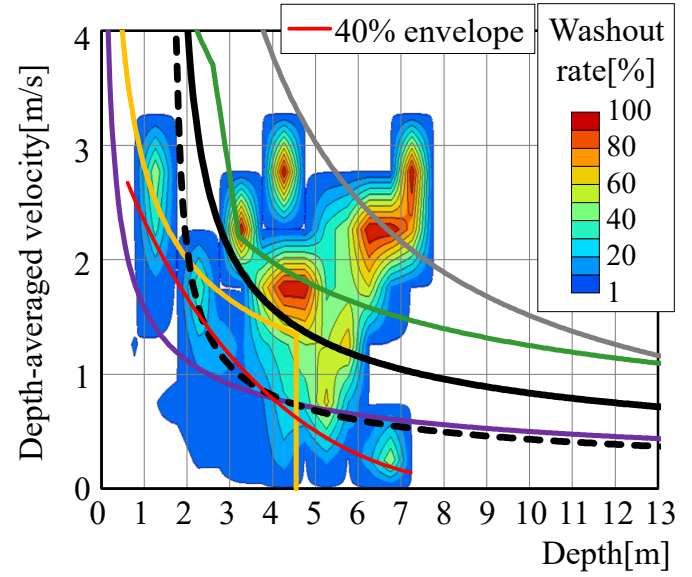


建物の流失・浸水地点の  
水理量には  
統計的に有意な差



流速や水深, 流体力, モーメント指標から  
**建物流失リスクを判定可能**

水理量と流失率の関係  
一義的な閾値設定は困難  
**流失率**の評価が適当



- 三次元計算を実施したが, 既存の枠組みの範疇
- ✓ 建物の影響は粗度係数を介して考慮
- ✓ 建物流失評価は水深平均流速と水深に基づく

今後報告予定

- ✓ 個別の建物と橋梁に作用する流体力算定と流体への反作用を組み込んだ流動計算モデル
- ✓ 建物の構造や適用耐震基準等を考慮した検討