

水制、わんど周辺の平均流構造と 大規模組織乱流の役割

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河川における乱流場

➤ 鉛直2次元乱流場

- ・ 粗面上の流れ(砂礫, 植生, 人工粗度)
- ・ 河床高変化を伴う流れ(河床波, 段落ち, 段上がり)

➤ 横断面2次元流れ場

- ・ 断面形状(長方形, 台形, 複断面直線水路)

➤ 平面2次元乱流場

- ・ 平面せん断流れ, 再循環流(急拡, 急縮, わんど)

➤ 3次元乱流場

- ・ 局所流れ(水制, 橋脚, 分合流)
- ・ 湾曲流れ(単湾曲, 蛇行, 複断面蛇行)

解明すべき乱流構造と予測すべき効果

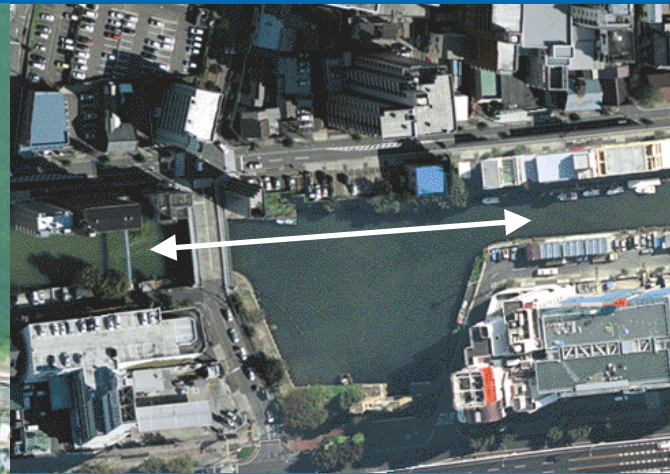
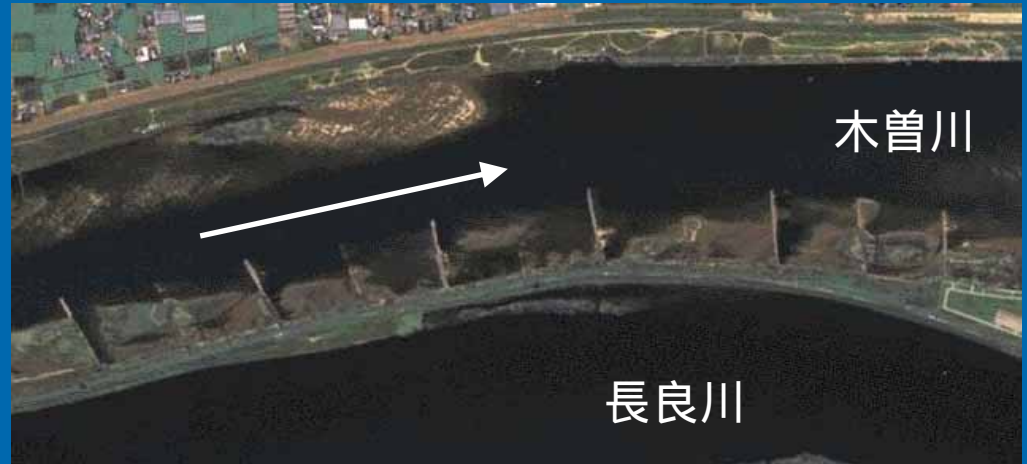
- 流速分布
- 掃流力
- 二次流
- 乱れ強度
- レイノルズ応力
- 組織渦構造
- 水面変動



- 流水抵抗
- 河床変動
- 側岸防御
- 物質拡散
- 浮遊砂堆積
- 生息環境

側岸凹部流れの存在

- 舟運、主水路固定のための水制群
- 人工わんど
- 湾、入り江



庄内川

木曽川

堀川

側岸凹部流れ研究の背景

➤ 汚濁物質の移流拡散への影響

- 河川の移流拡散促進効果
- 凹部内への滞留

➤ 数値モデルの検証

- 水深平均, 3次元, LES

➤ 高水時主流への影響

- 流水抵抗・主水路河床変動の把握

➤ 生物生息環境の提供

- 平水時: 適度な水交換による良好な水質の確保
- 高水時: 静穏域の確保と埋没の抑制

側岸凹部流れ 研究の分類

➤ 形態条件

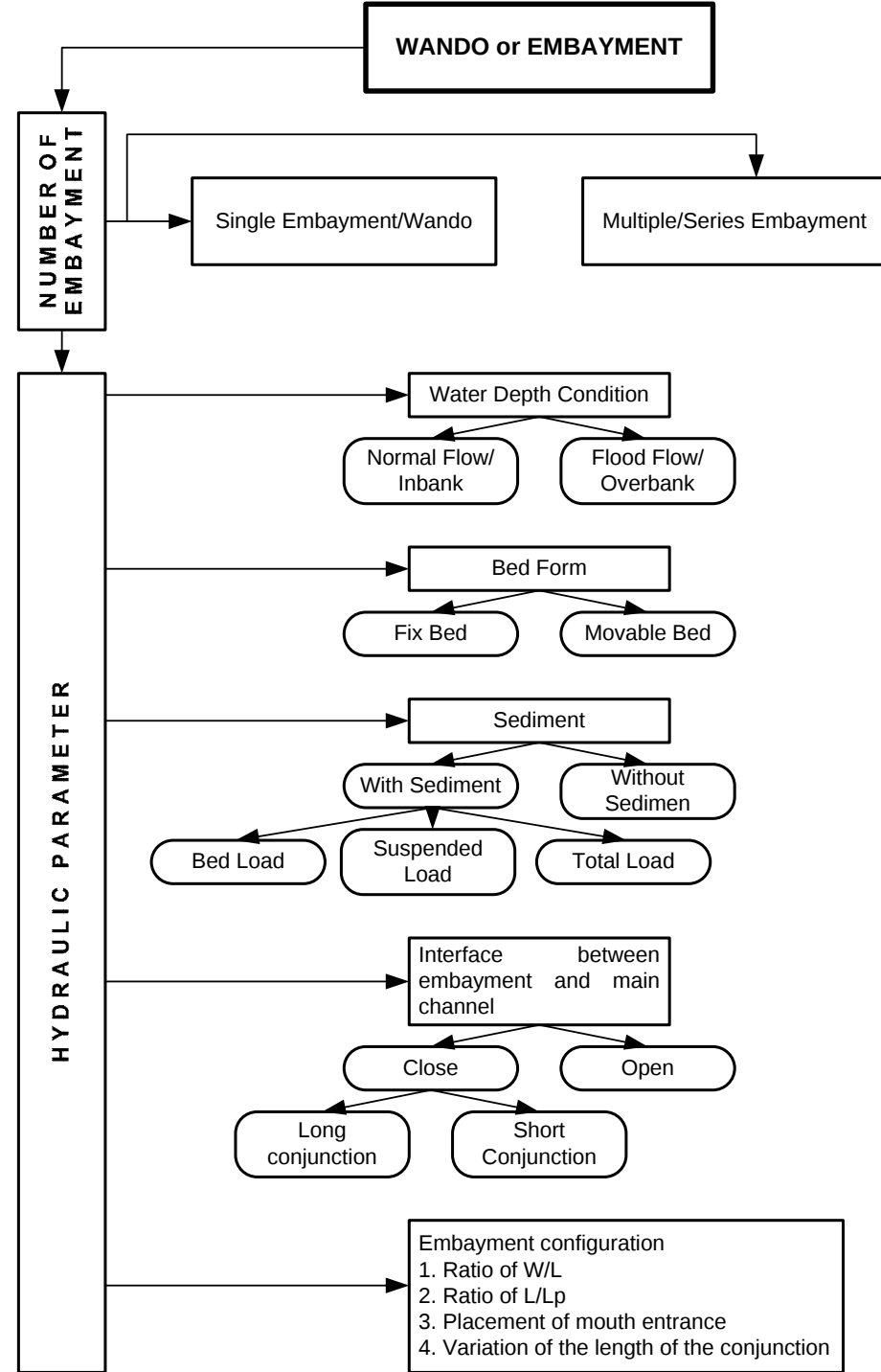
- 単独, 連続
- inbank, overbank
- 固定床, 移動床
- 流砂の有無 (掃流砂, 浮遊砂)
- 境界閉鎖の有無 (short, long)

➤ 幾何条件

- 長さ / 幅比 (W/L)
- 開口比
- 開口位置
- 開口部形状

➤ アプローチ

- 実験 (可視化, 流速, 乱れ, 混合係数)
- 数値計算



Jalil, M. A., Kawahara, Y., Tamai, N. and Kan, K. (1993). "Experimental Investigation of flow in embayment." Proceeding of Hydraulic Engineering, JSCE, Vol. 37, Japan, 503-510.

- Mixing layer is formed at the interface
- Anticlockwise rotating eddies, the large eddies may breakdown into smaller eddies
- The striking mass then divides into 2 parts, one part leaves the embayment and joins the main flow while the remaining mass enters the embayment

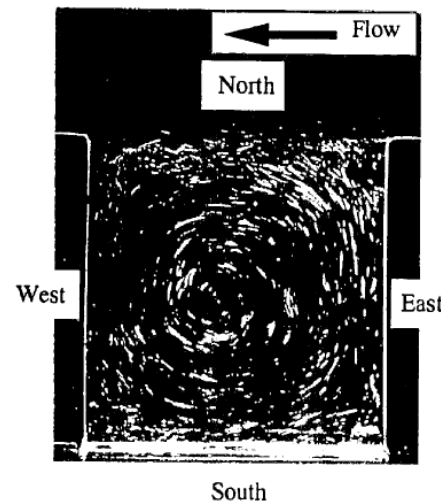


Fig. 5. Path lines of tracers in experiment no. 2 (f2.8, exposure 1/2 s).

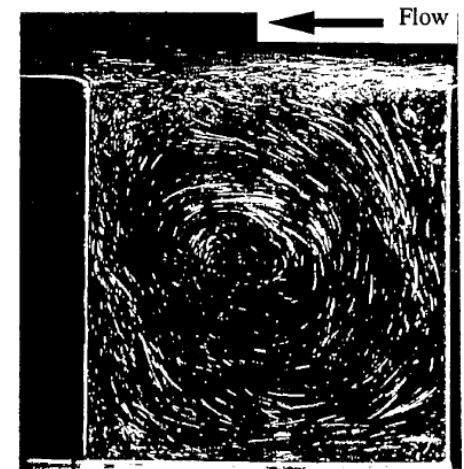


Fig. 6. Path lines of tracers in experiment no. 3 (f2.8, exposure 1 s).

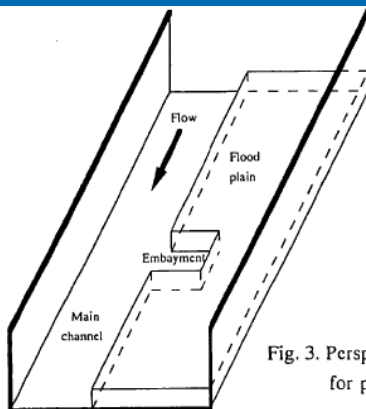


Fig. 3. Perspective view of the test section for point velocity measurements

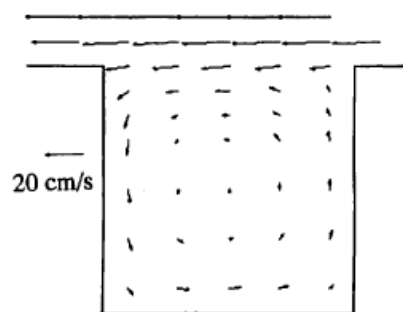


Fig. 7. Velocity field in z_3 plane for low flow condition.

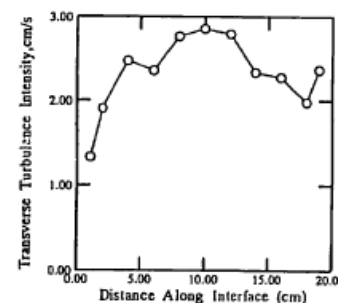


Fig. 8. Transverse turbulent intensity in z_3 plane along the interface.

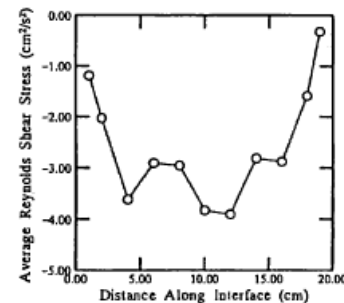
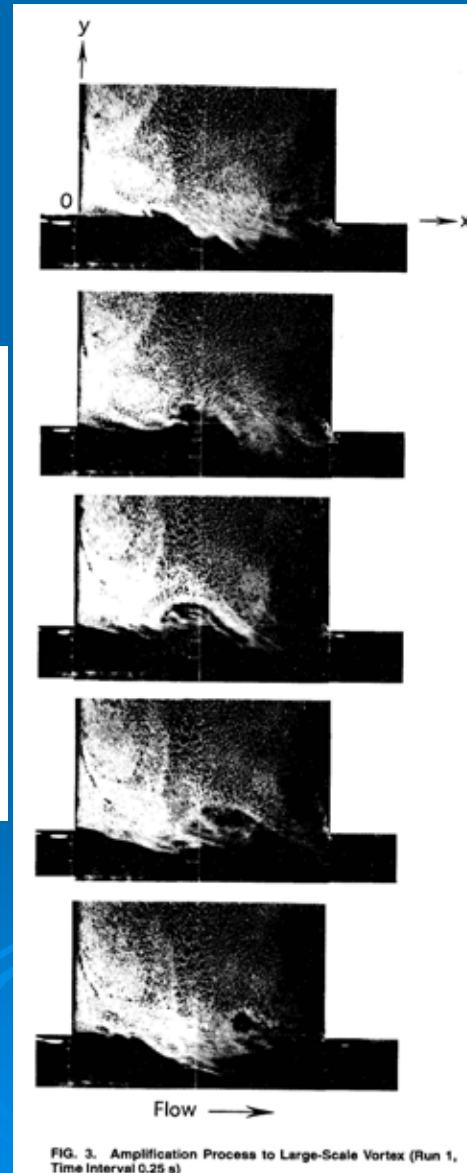
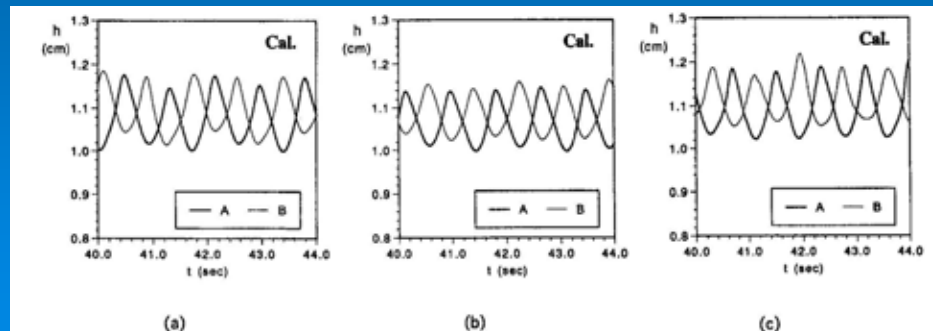
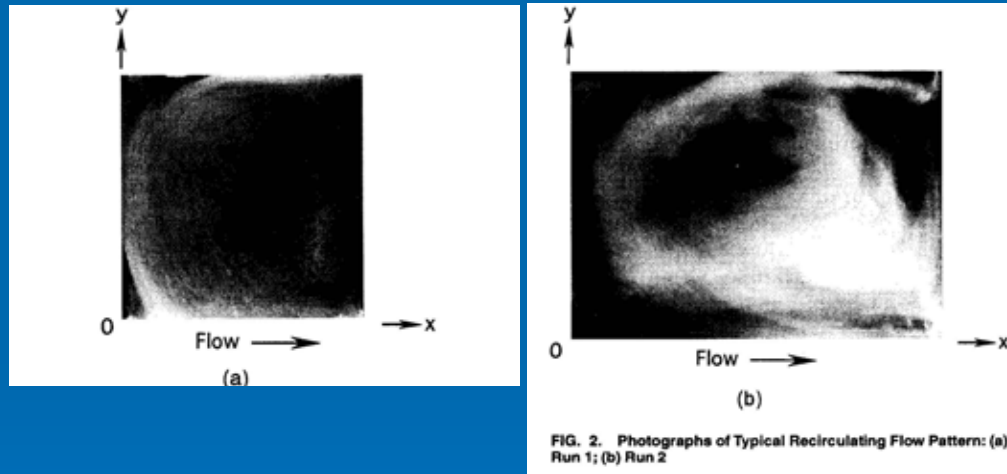
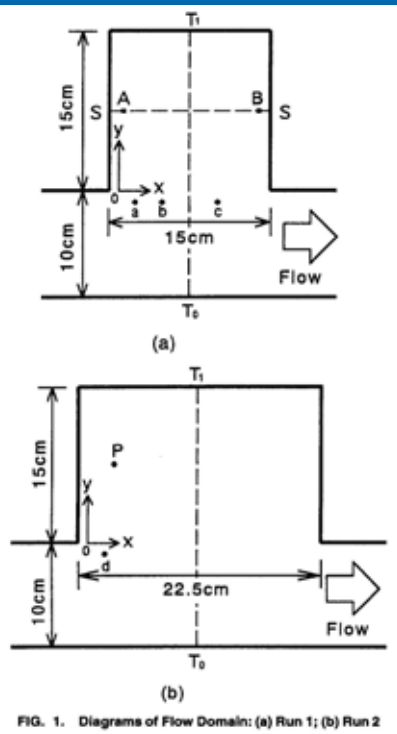


Fig. 9. Average Reynolds shear stress in z_3 plane along the interface.

Kimura, I. and Hosoda, T. (1997). "Fundamental Properties of flows in open channels with dead zone." Journal of Hydraulic Engineering, ASCE, Vol. 123(2), 98-107.

- Two types of circulating flow (one main circulation and two sub-circulations in the corner) can be seen in the embayment.
- The period of vortex generation caused by shear-layer instability is shorter than the period of the seiche. The vortex caused by the instability is amplified to a large-scale vortex selectively by the interaction between the seiche and the instability.



Muto, Y., Imamoto, H. and Ishigaki, T. (2000). “Velocity Measurements in a straight open channel with a rectangular embayment.” Proceeding of 12th Congress of APD-IAHR, Bangkok, Thailand, 353-362.

- Aspect ratio of the embayment determines the shape and stability of circulating flow induced there, and this influences the exchange process.

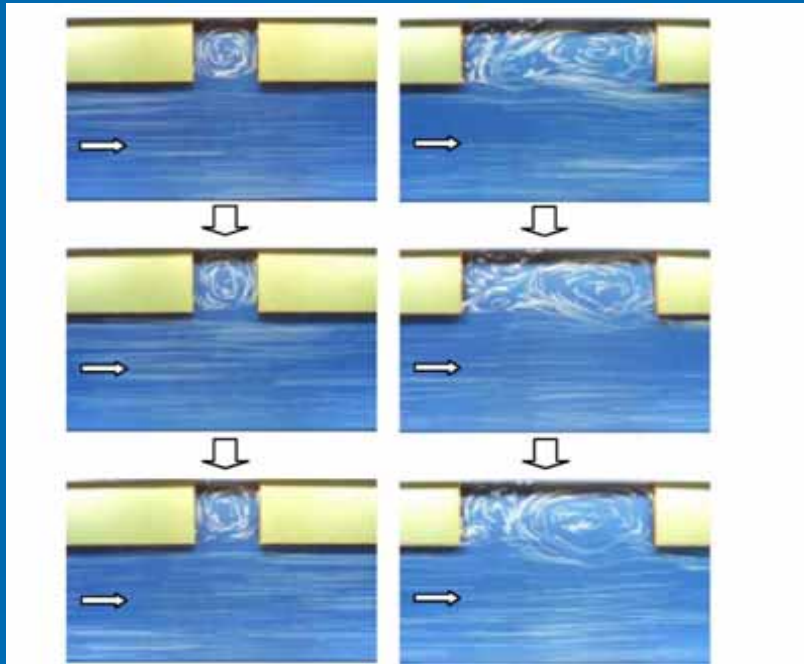


Figure 8: The Circulation and the Exchange ($L/W=1$, left, and 3, right)

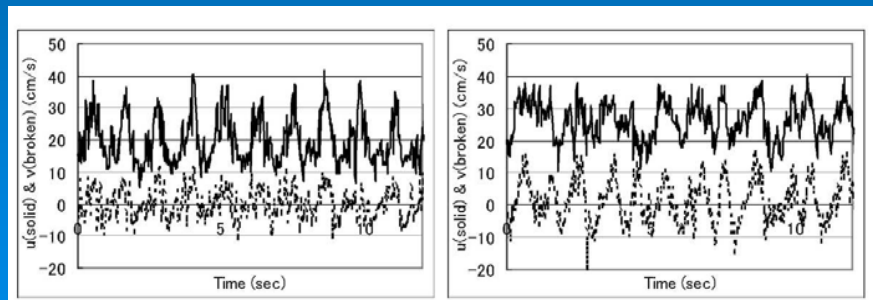


Figure 9: Temporal Velocity Fluctuation at the Interface ($L/W=1$, left, and 3, right)

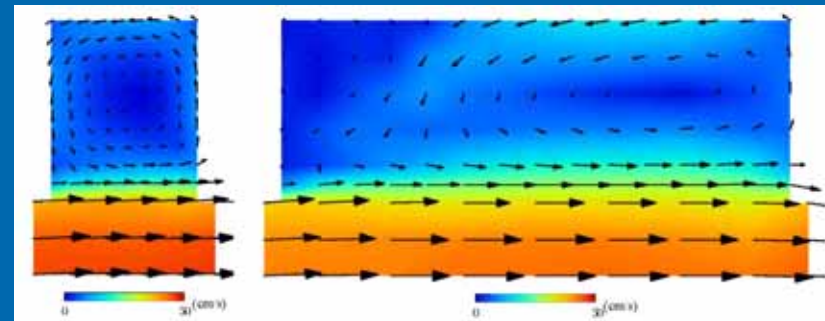


Fig. 2 Velocity distribution for inbank flow ($L/W=1$, left, and 3, right)

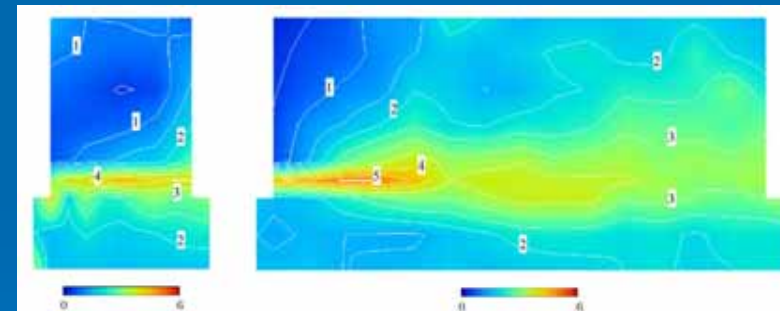


Fig. 3 Turbulence intensity u' / u^* for inbank flow ($L/W=1$, left, and 3, right)

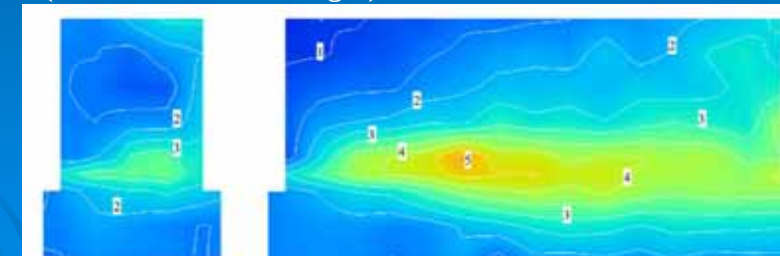


Fig. 4 Turbulence intensity v' / u^* for inbank flow ($L/W=1$, left, and 3, right)

Nezu, I., and Onitsuka, K. (2001). "LDA Measurements of side cavity open channel flows; Wando models in rivers", Proc. of the 8th Int. Symp. on flow modeling and turbulence measurements, Tokyo, Japan, 169-176.

➤ LDV measurement, $L/W=3,5,10$

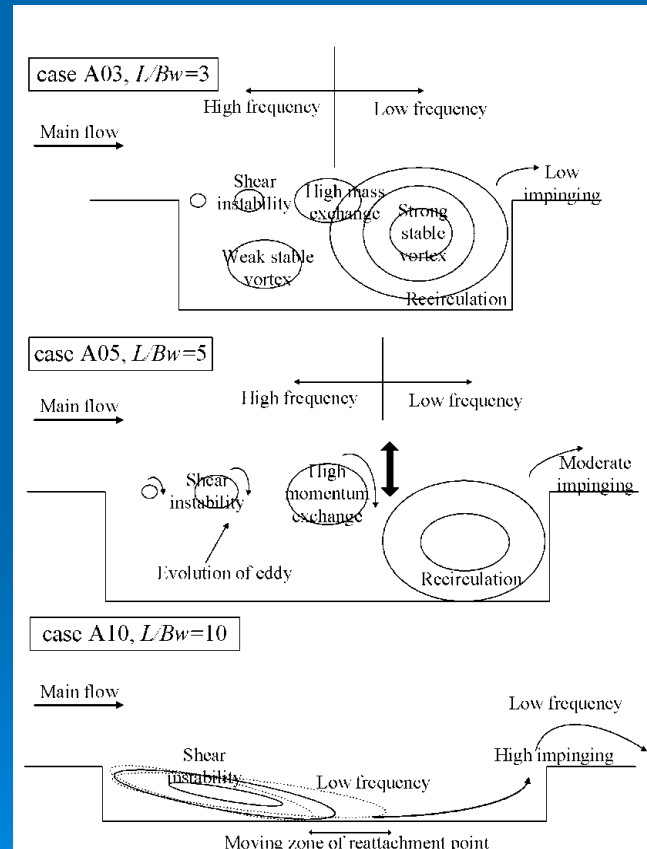
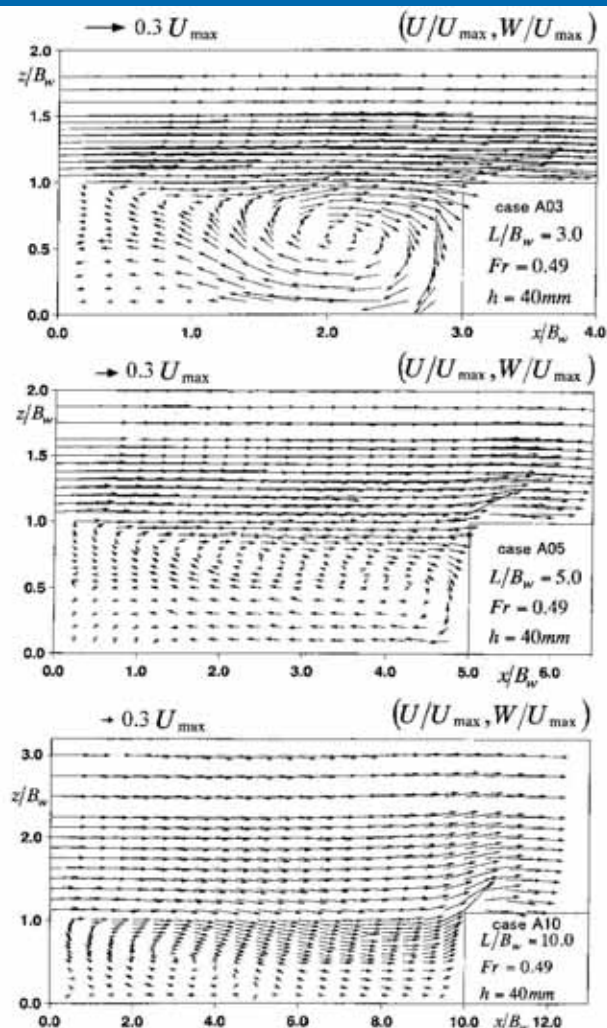


Figure 9. A New Eddy Model of Side Cavity

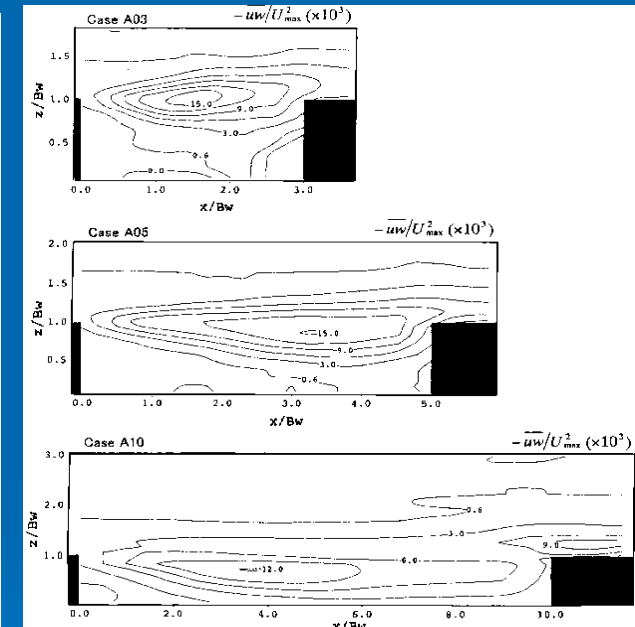
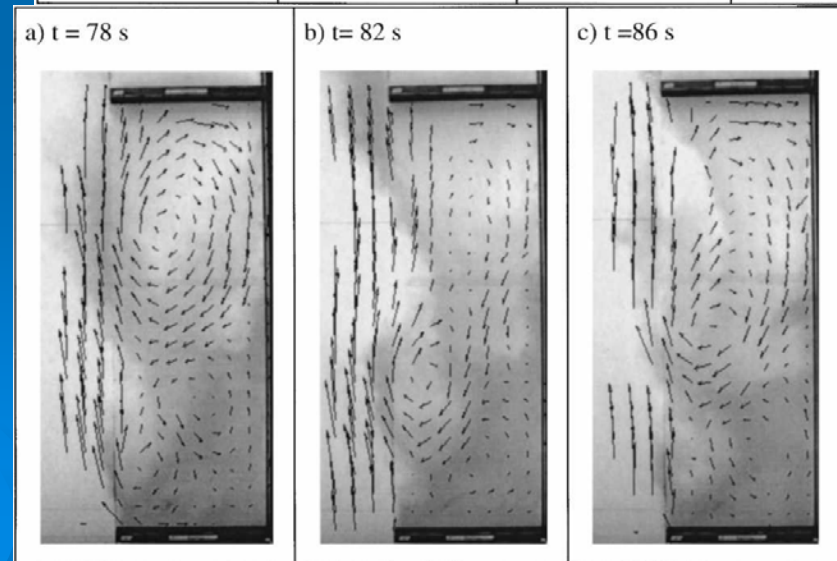
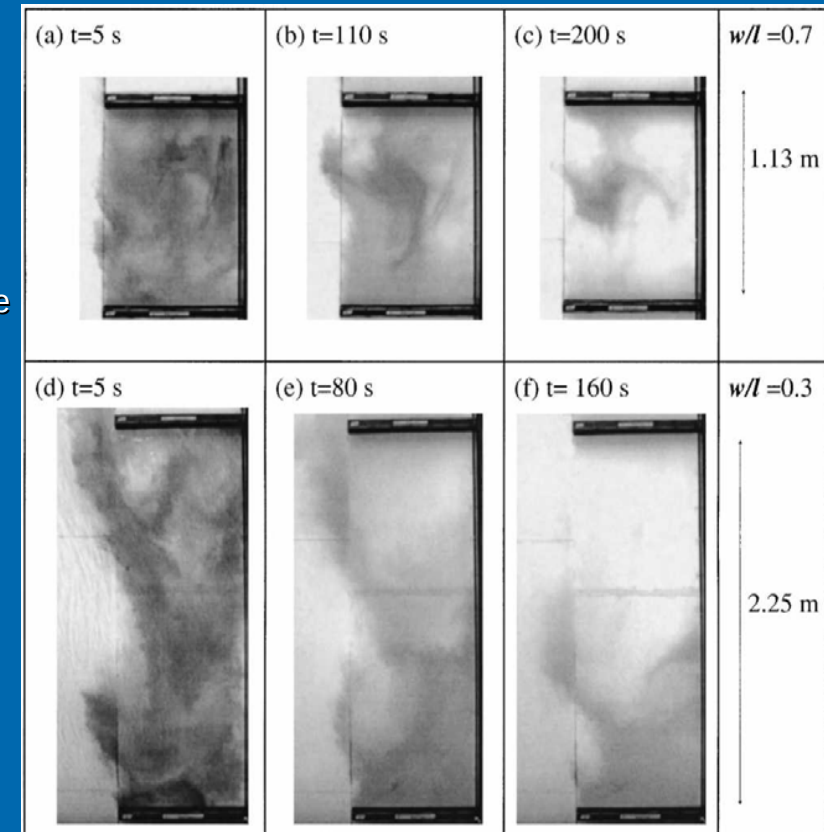
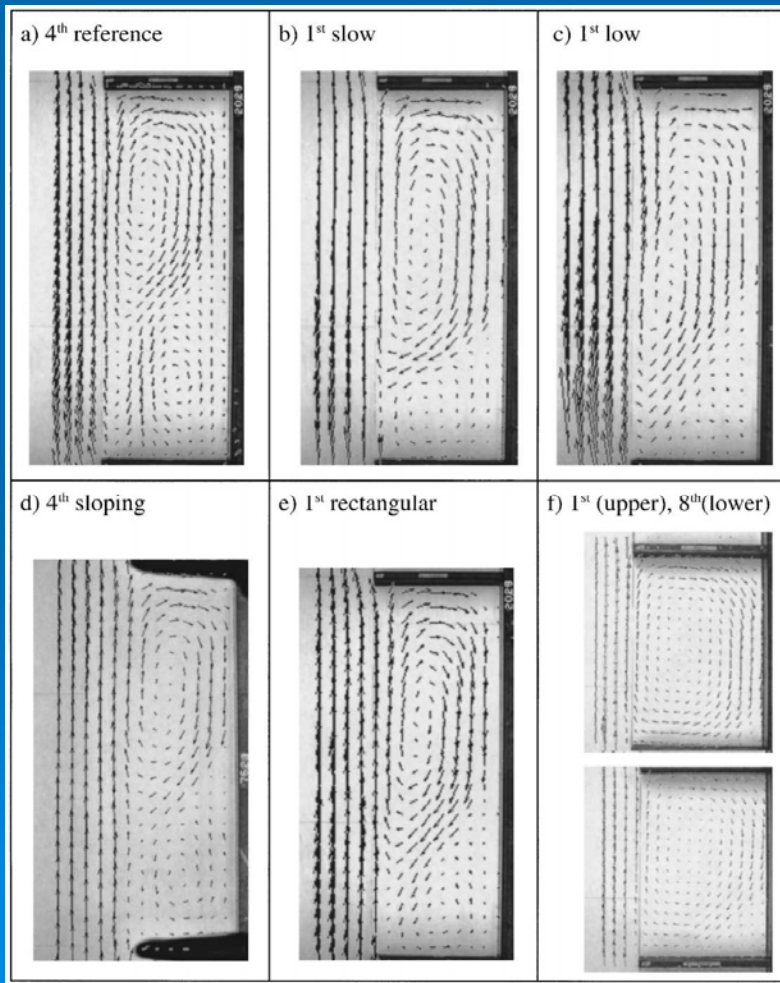


Figure 4. Spanwise Reynolds Stress - uw

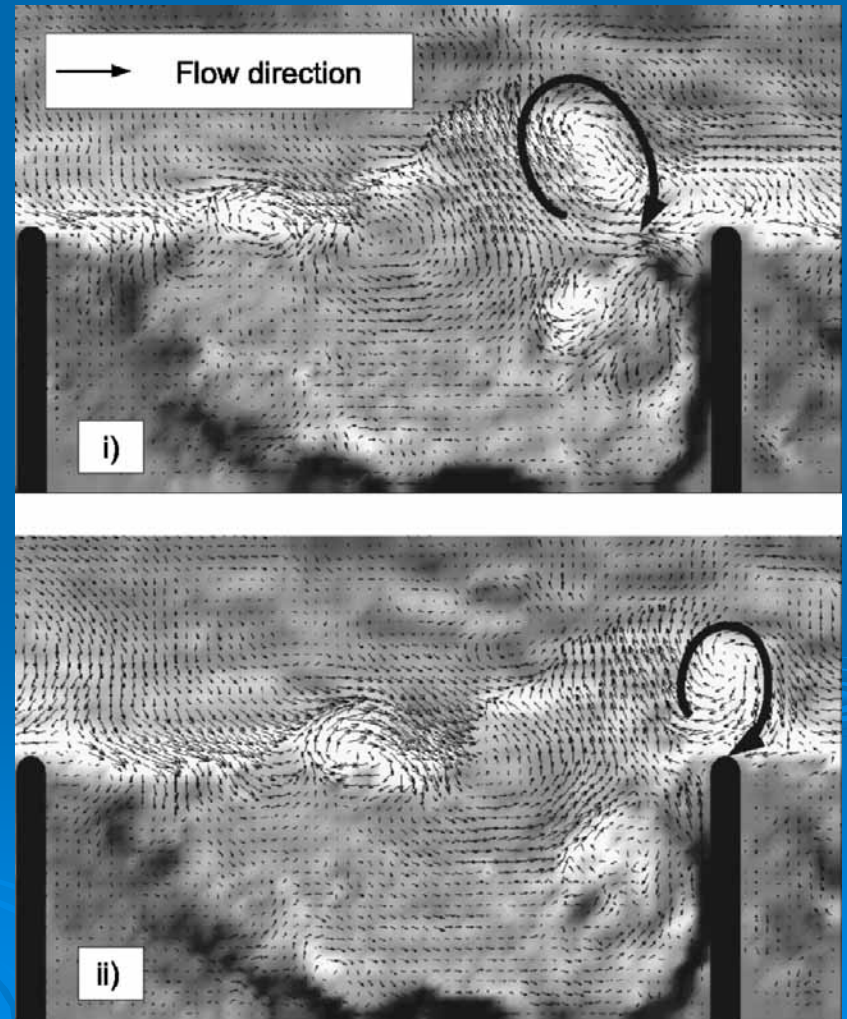
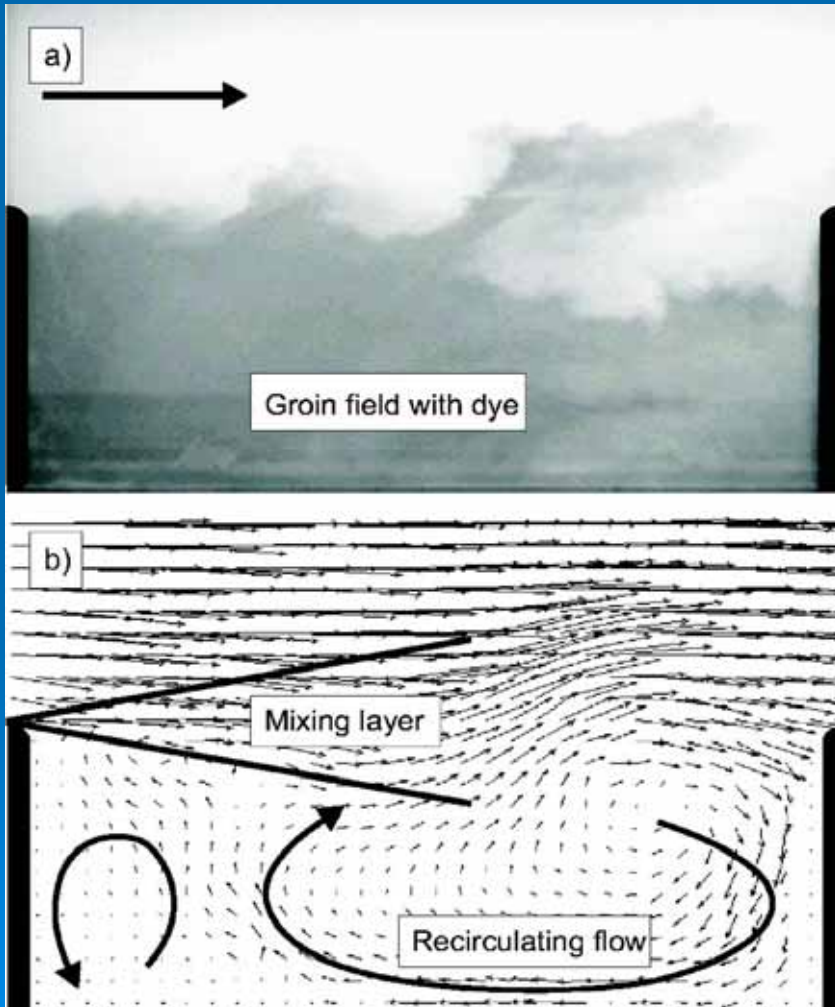
Figure 3. Time-Averaged Velocity Vector

W. S. J. Uijtewaal, D. Lehmann, and A. Van Msazijk, (2001). "Exchange Processes Between A River and Its Groyne Fields: Model Experiments." Journal of Hydraulic Engineering, 127(11), 928-936.

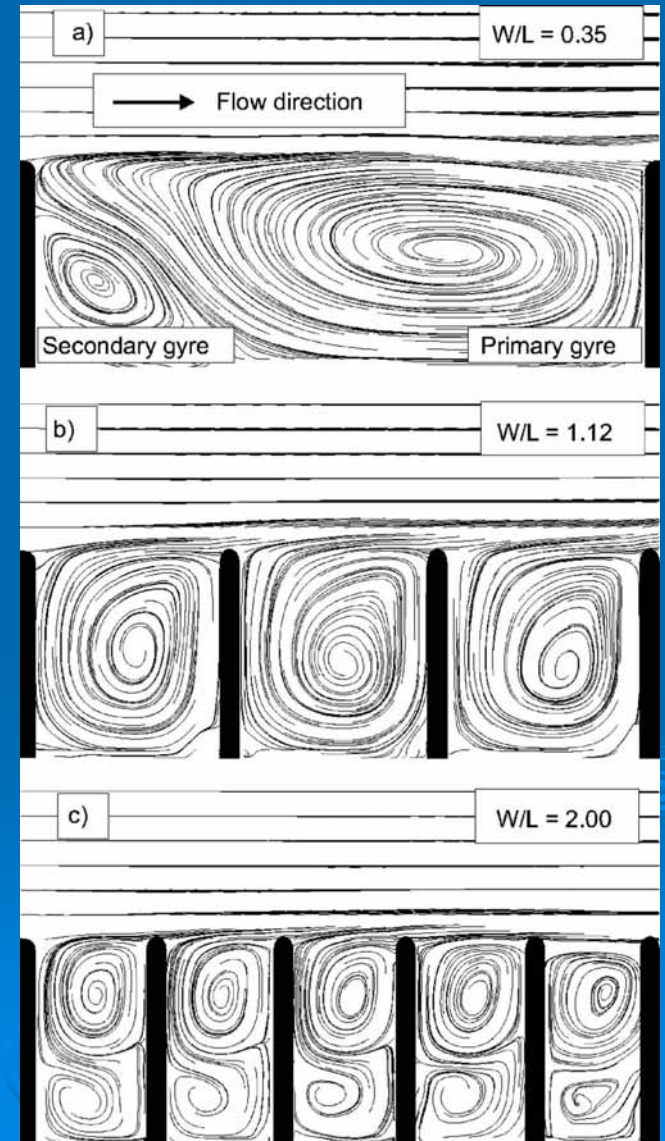
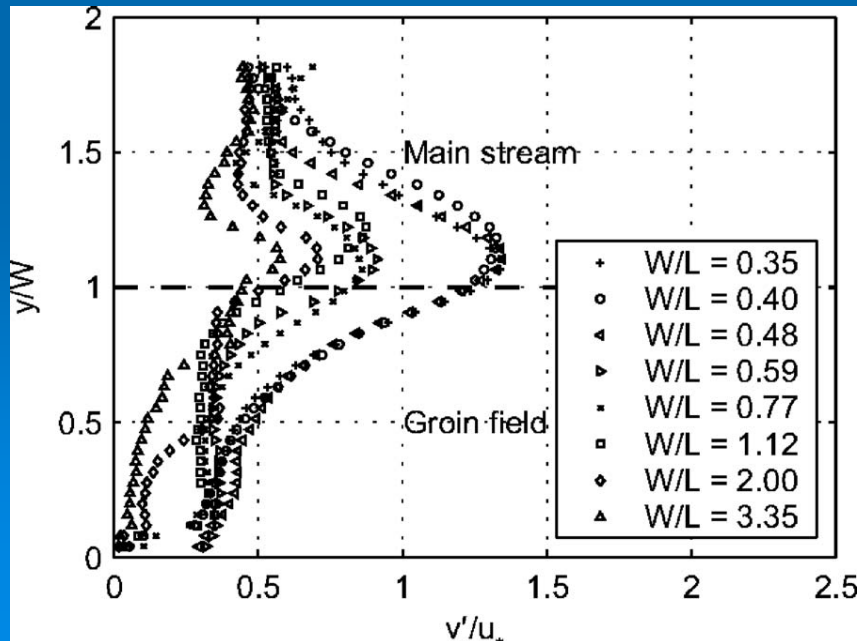
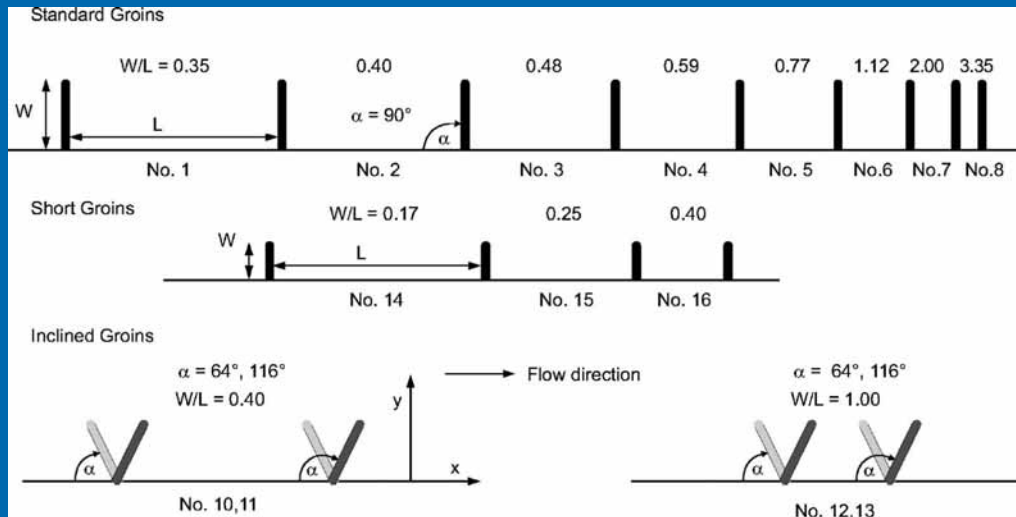
- The flow is far from stationary and that the large turbulence structures in the mixing layer play a prominent role in the exchange process.
- the exchange with the center of the gyre in the small groyne field is relatively slow.



V. Weitbrecht, S. A. Socolofsky and G. H. Jirka (2008), Experiments on Mass Exchange between Groin Fields and Main Stream in Rivers, Journal of Hydraulic Engineering, Vol. 134, No. 2, 173–183

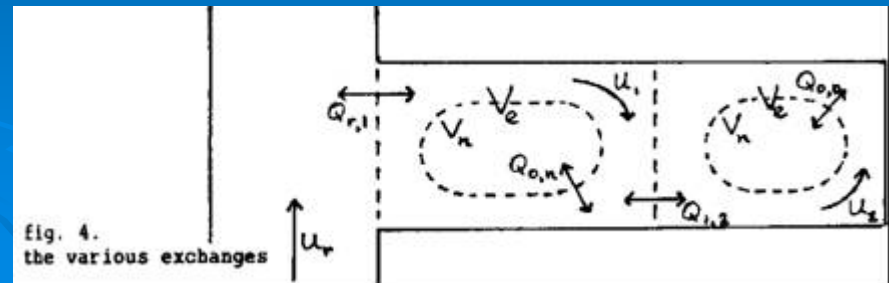
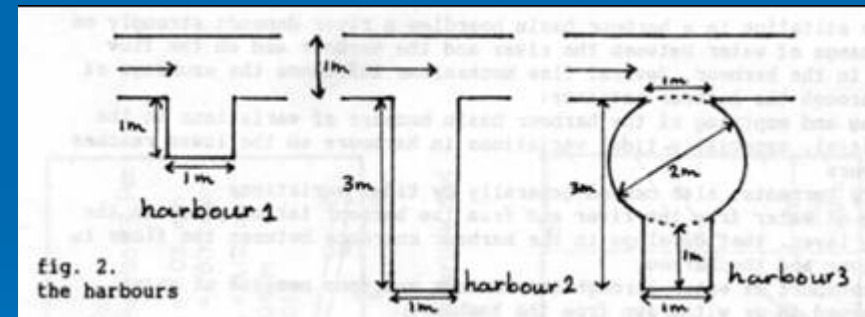
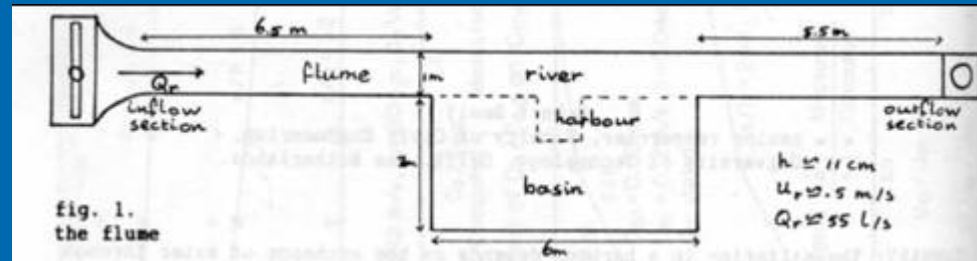
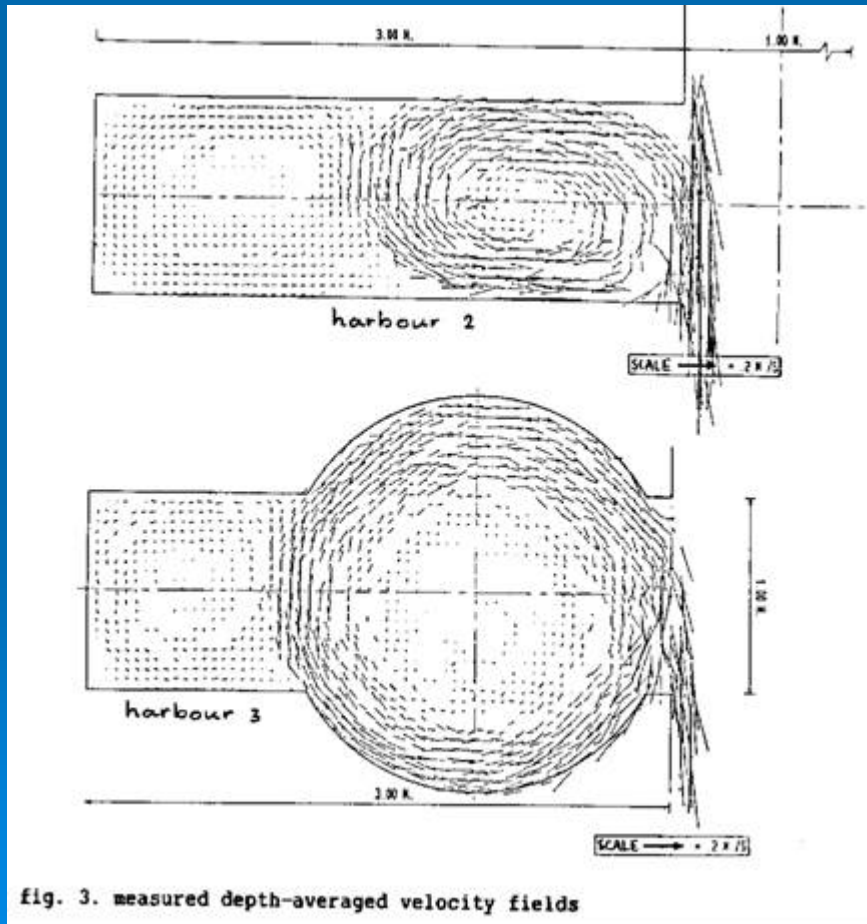


V. Weitbrecht, S. A. Socolofsky and G. H. Jirka (2008)



Boij, R. (1989) "Exchange of mass in harbour.", IAHR 23, Ottawa, Canada, D69-D74.

- Two eddies appear if W/L is less than 0.5 which primary eddy is much faster than secondary eddy.



Mizumura, K. and Yamasaka, M. (2002). “Flow in open-channel embayments.” Journal of Hydraulic Engineering, ASCE, Vol. 128(12), 1098-1101.

- A sand particle upstream was trapped by the embayment and finally flowed out to the main stream. This happened very rarely.
- A sand particle upstream was trapped by the embayment and accumulated there. This happens very often and causes sedimentation in the embayment.

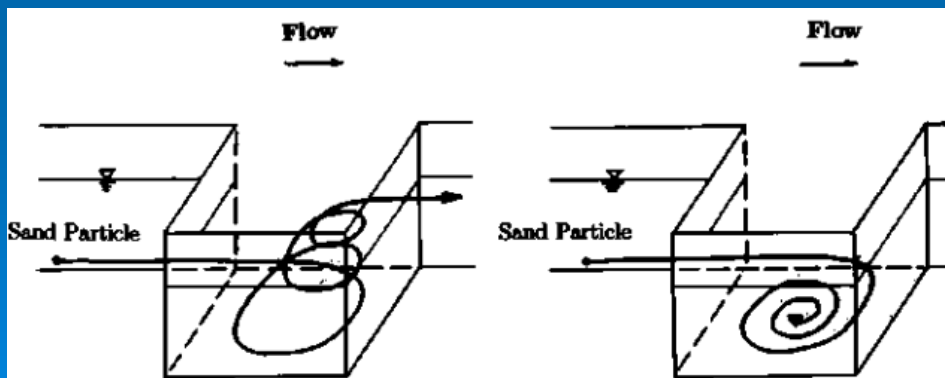


Fig.3 Left-hand side shows sketch of sand particle movement which goes back to main channel and right hand side gives sketch of sand particle movement which accumulates in embayment

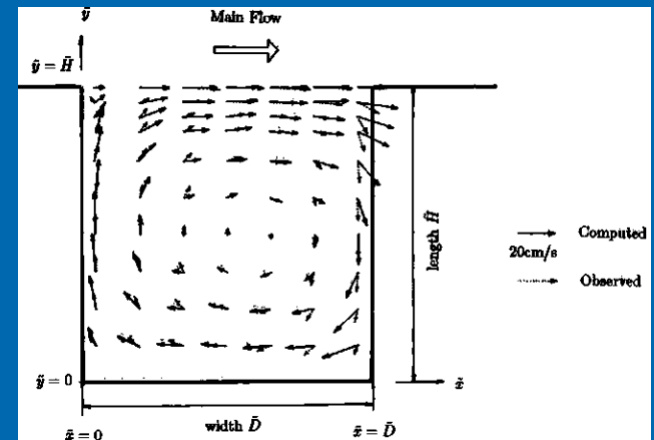


Fig.1 Ddefinition sketch of coordinate system and computed and observed flow velocity in square embayment

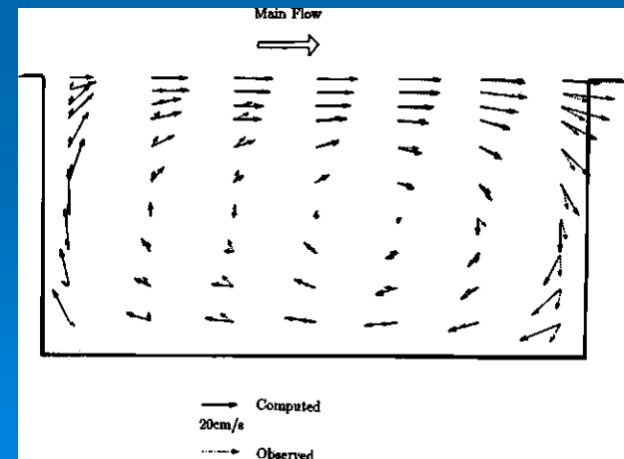


Fig.2 Computed and observed flow velocity in rectangular embayment

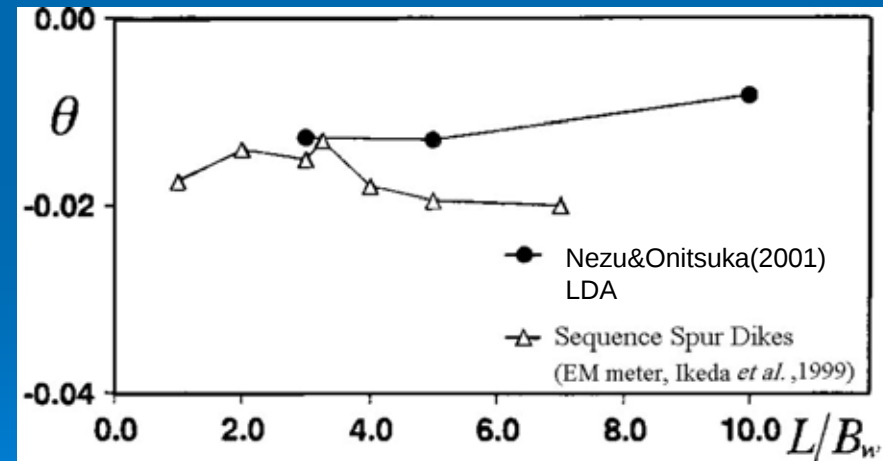
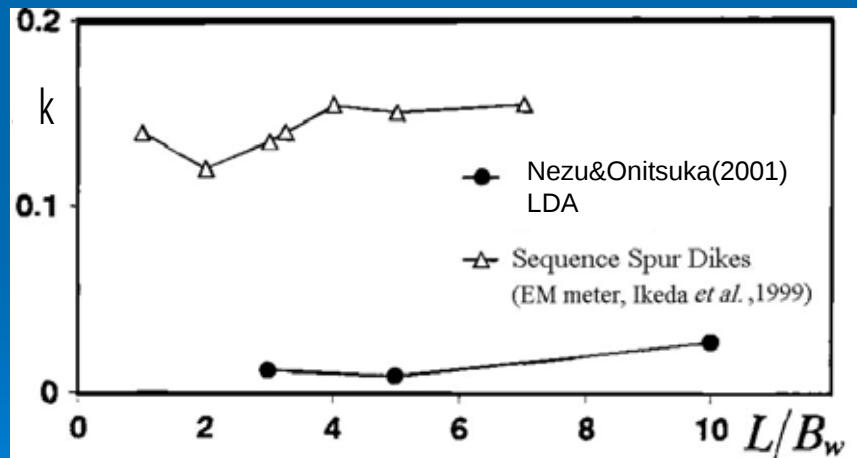
凹部界面における交換係数

- 質量交換係数 (mass exchange coefficient)

$$k = \frac{1}{UL} \int_0^L |v| dx$$

- 運動量交換係数 (momentum exchange coefficient)

$$\theta = \frac{1}{U^2 L} \int_0^L |uv| dx$$



	L/W=1	L/W=3
質量交換係数 k	0.0148	0.0220
運動量交換係数 θ	0.0116	0.0158

Muto et al. (2000)

染料濃度変化による交換係数

➤ Dead-zone model

$$\frac{dC}{dt} = -\frac{kU}{W} \frac{h_E}{h_D} (C - C_s)$$

k : 無次元連行係数

C : 死水域の濃度

C_D : 主流域の濃度

U : 平均主流速

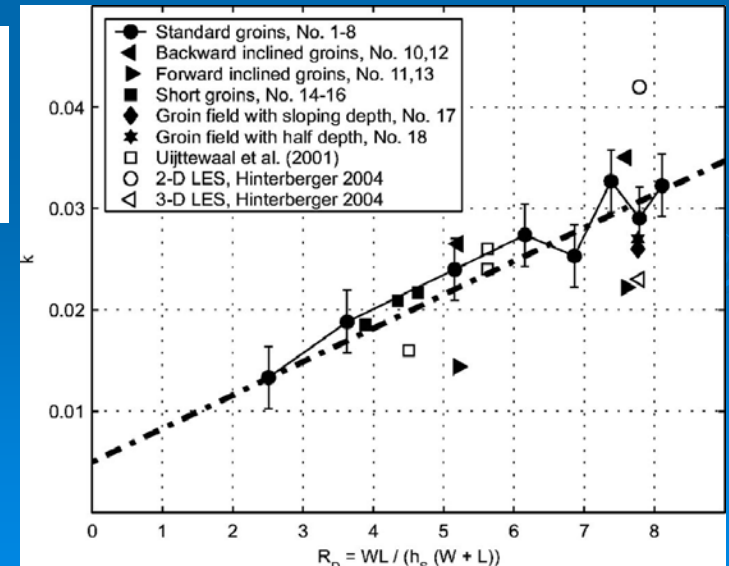
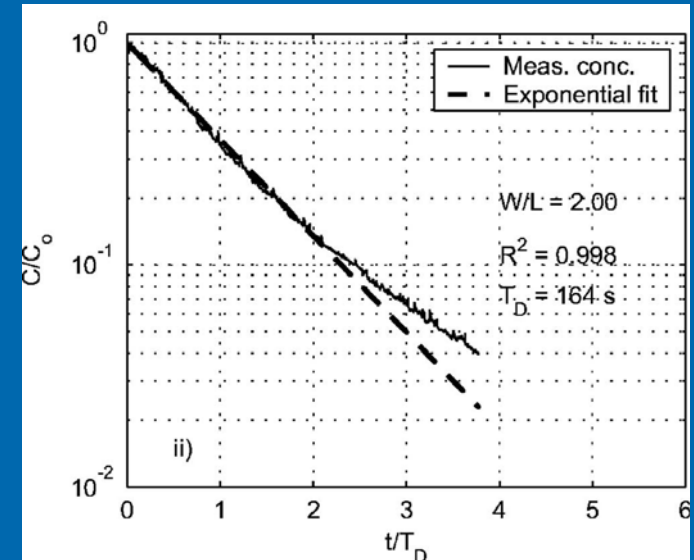
W : 凹部奥行き長さ

h_E : 境界部水深

h_D : 凹部内水深

$$\ln\left(\frac{C}{C_0}\right) = \frac{-t}{T_D} + A$$

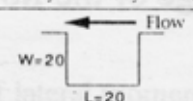
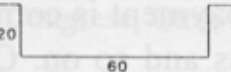
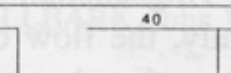
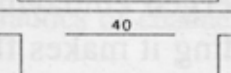
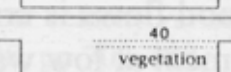
$$k = \frac{W}{UT_D} \frac{h_D}{h_E}$$



V. Weitbrecht et al. (2008)

Kawahara, W., Nakagawa, K., Kan, K. (1995) "Experimental study of flows in embayments.", HYDRA 2000, 391-396.

Table 1 Experimental conditions.

CASE	Geometry of Embayment (cm)	Q (l/s)	U_m (cm/s)	H_m (cm)	H_e (cm)
1		5.93	32.28	4.69	4.63
2		3.86	26.80	3.63	3.62
3		3.99	27.48	3.67	3.63
4		3.90	27.23	3.58	3.54
5		3.78	26.32	3.61	3.59
6		2.95	23.12	3.19	3.19

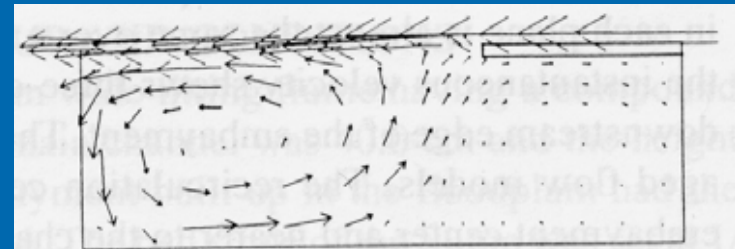


Fig. 4 Velocity distribution in Case-3.

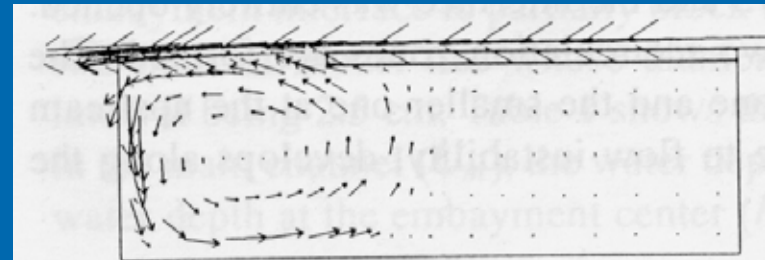


Fig. 5 Velocity distribution in Case-4.

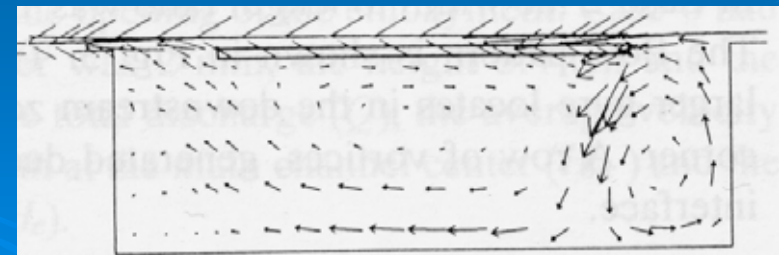


Fig. 6 Velocity distribution in Case-5.

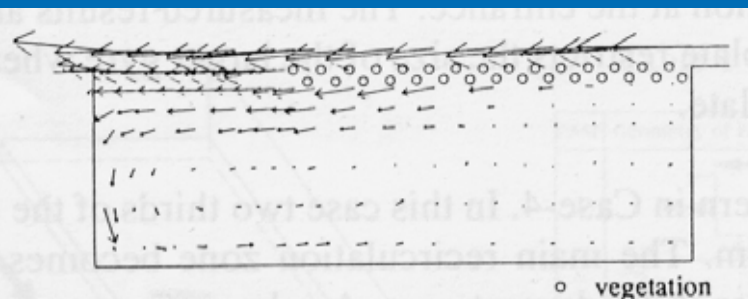


Fig. 7 Velocity distribution in Case-6.

Nezu, I., and Onitsuka, K. (2002). "PIV Measurements of side cavity open channel flows; Wando models in rivers." Journal of Visualization, Volume 5, Issue 1, 77-84.

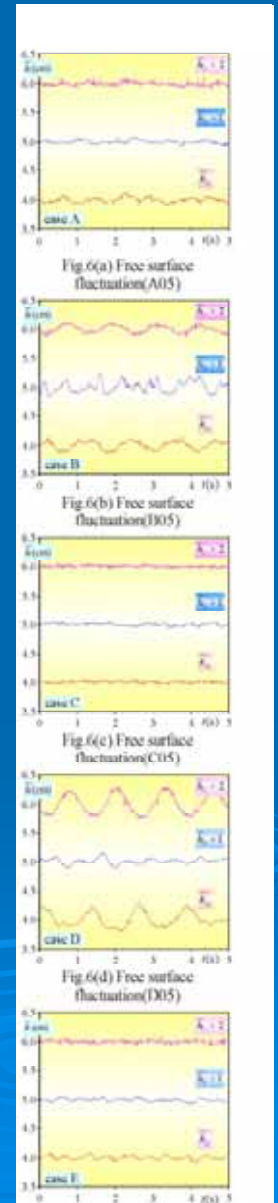
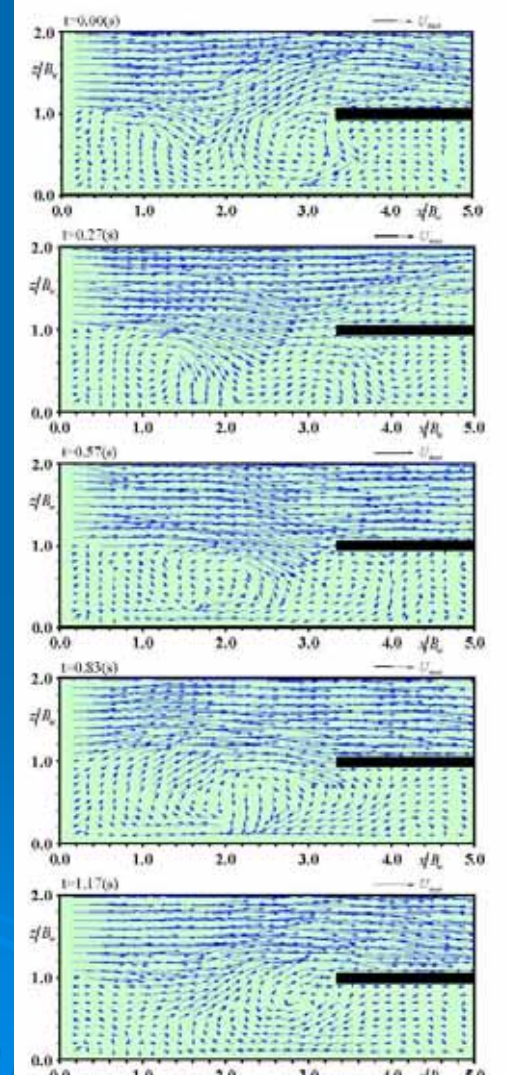
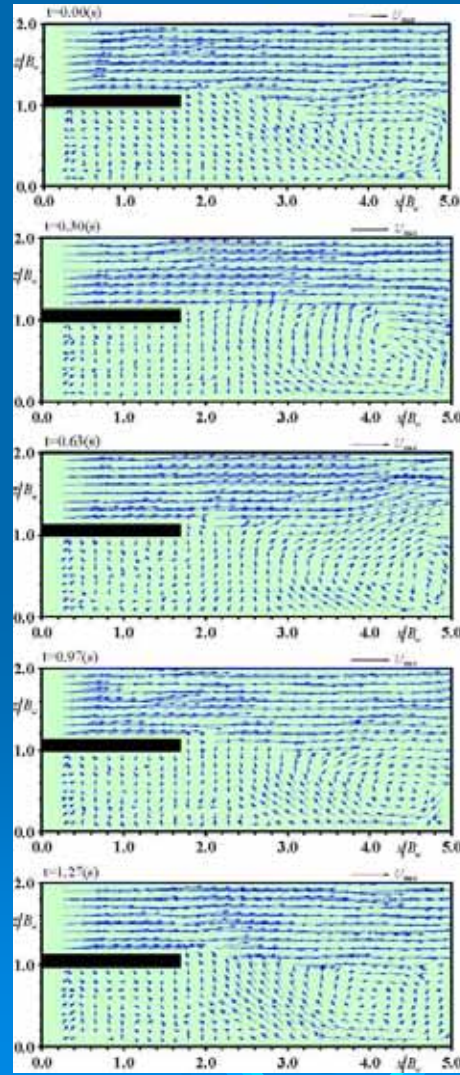
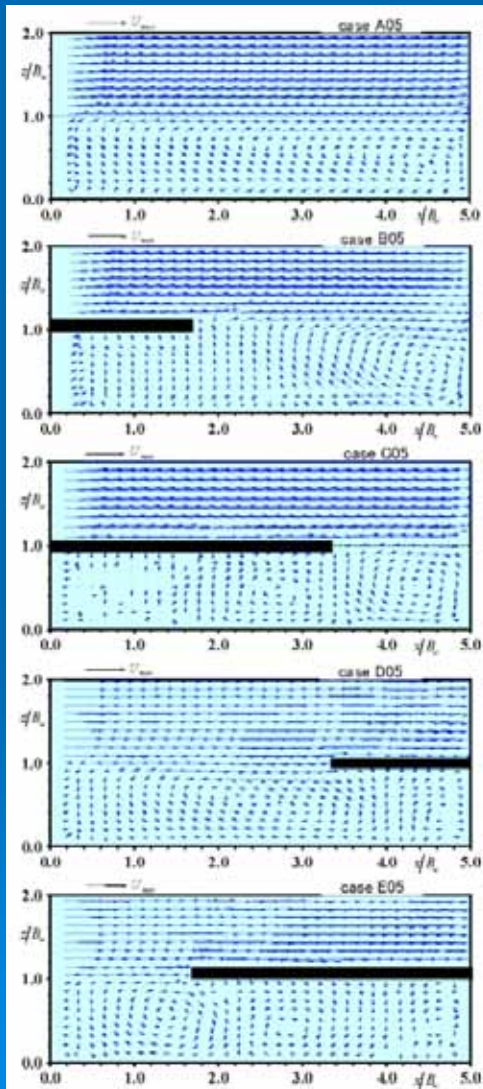
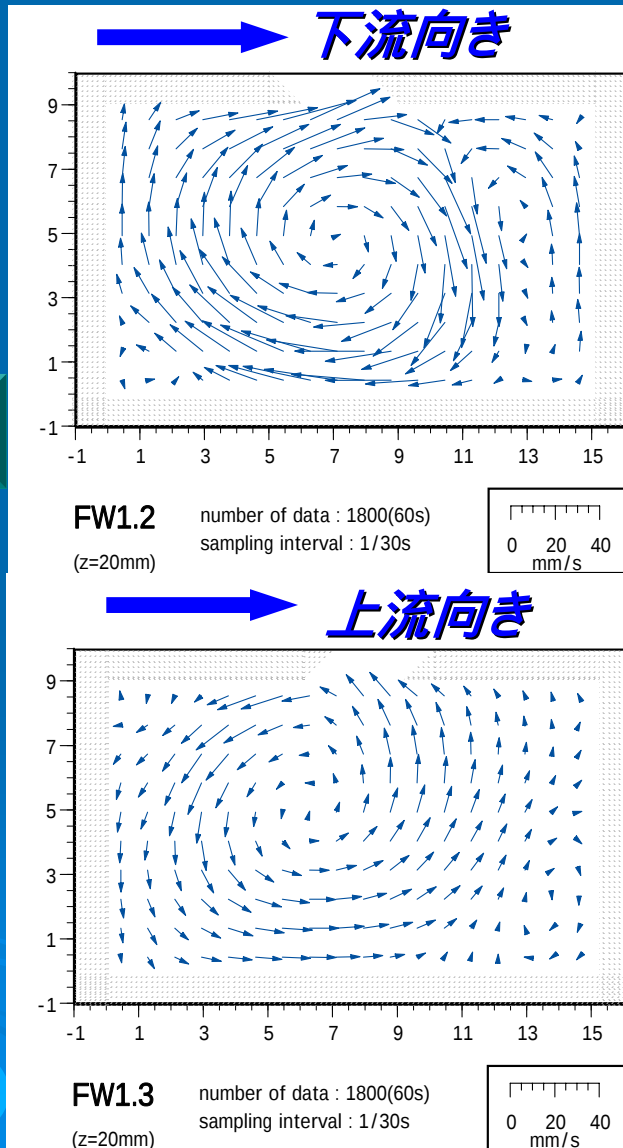
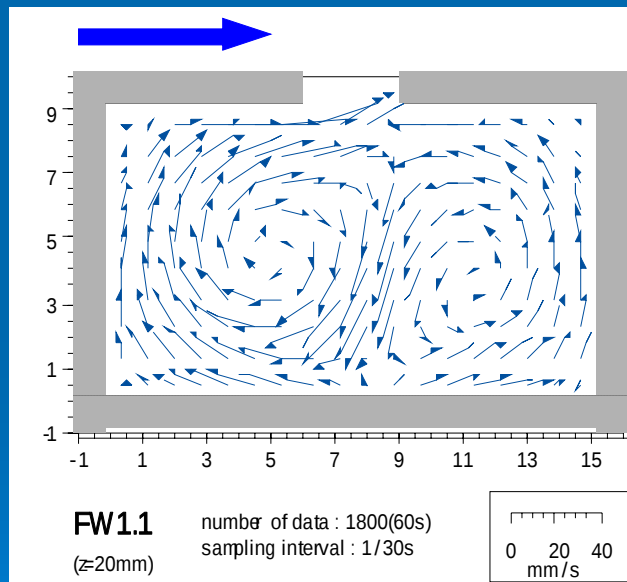
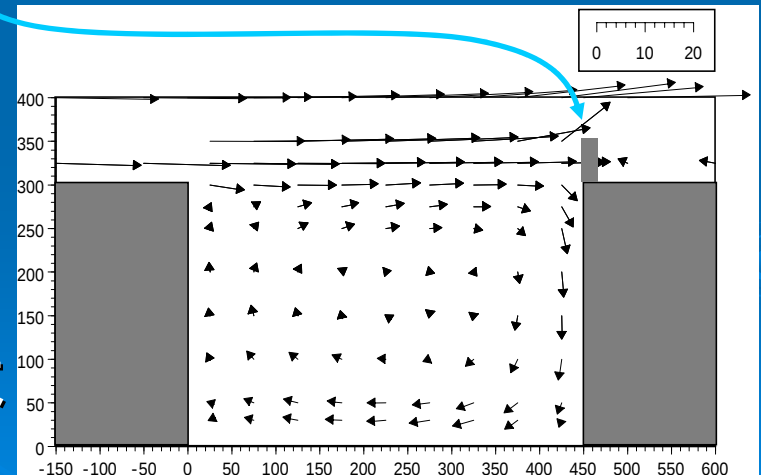
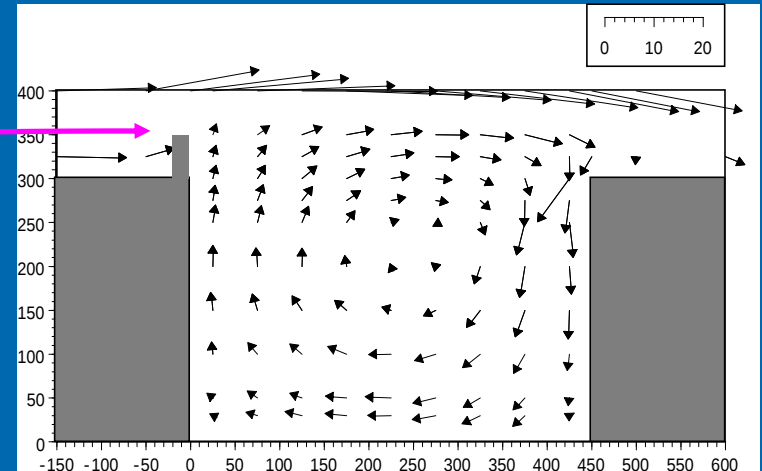
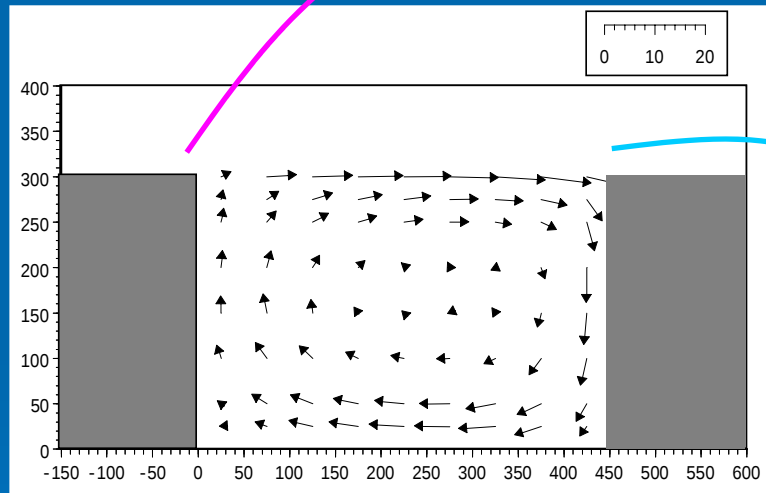


Fig.6(e) Free surface

閉そく型わんど開口部角度の影響



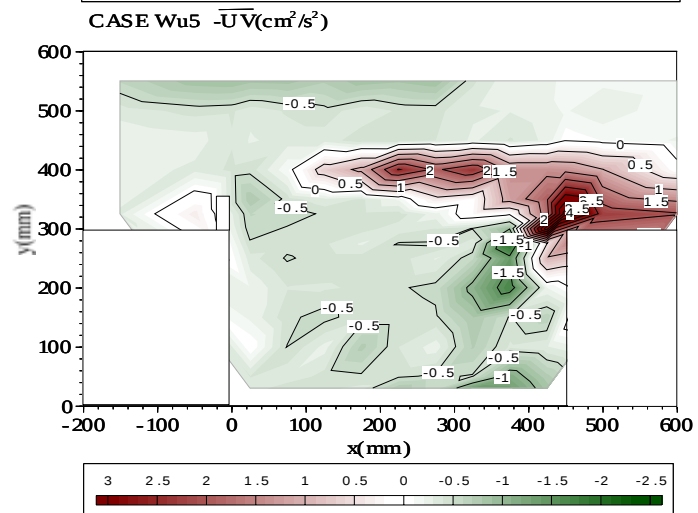
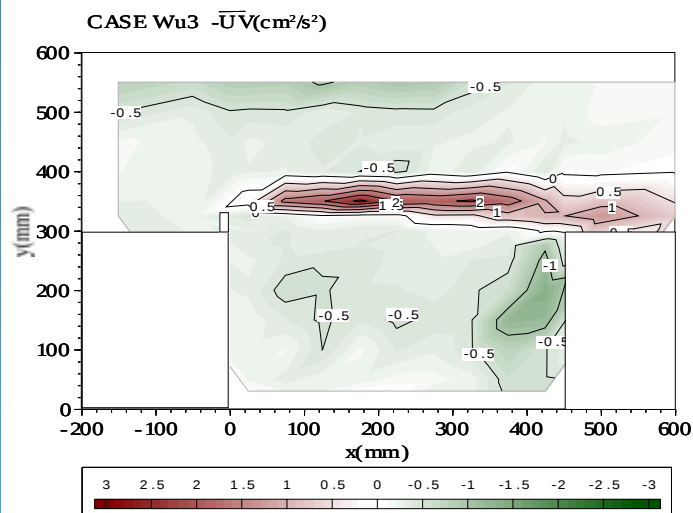
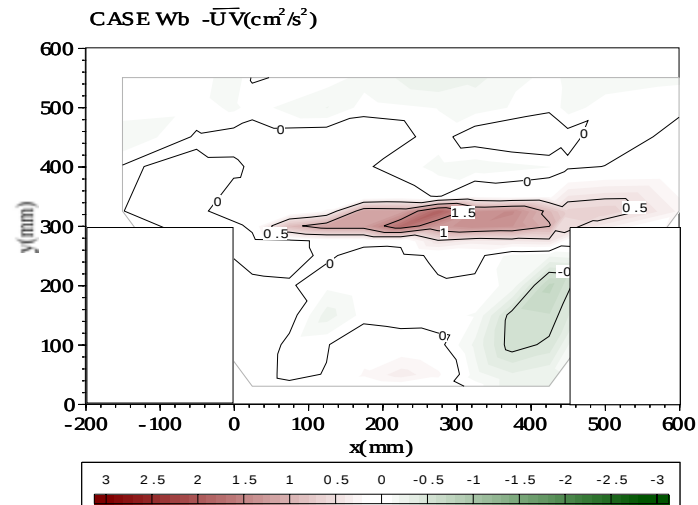
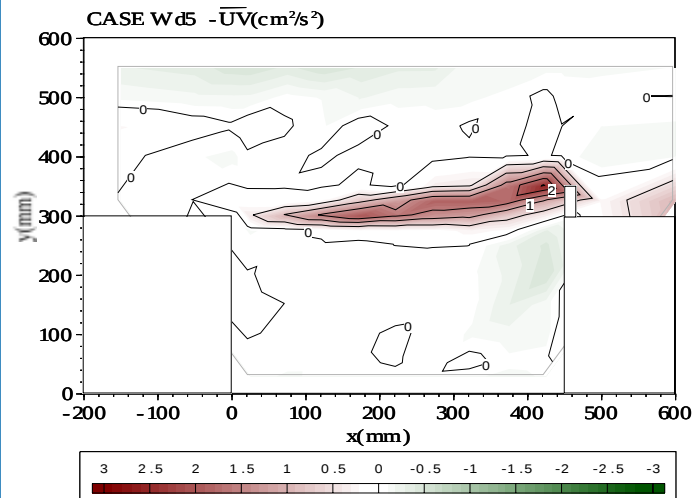
わんど上下流の突起の影響



- 上流側突起により循環流が増大
- 下流側突起により流入が減少

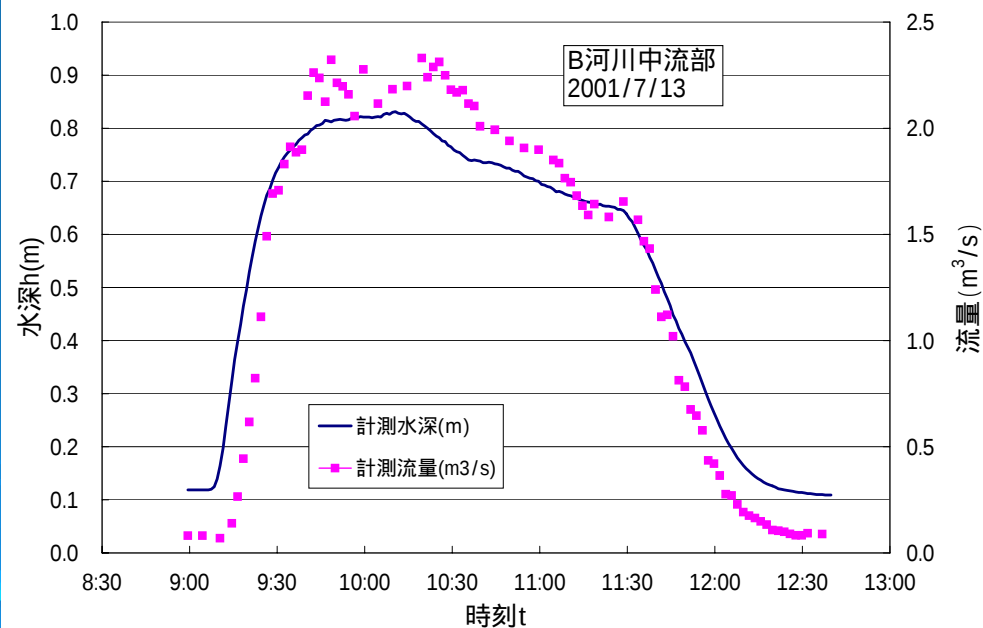
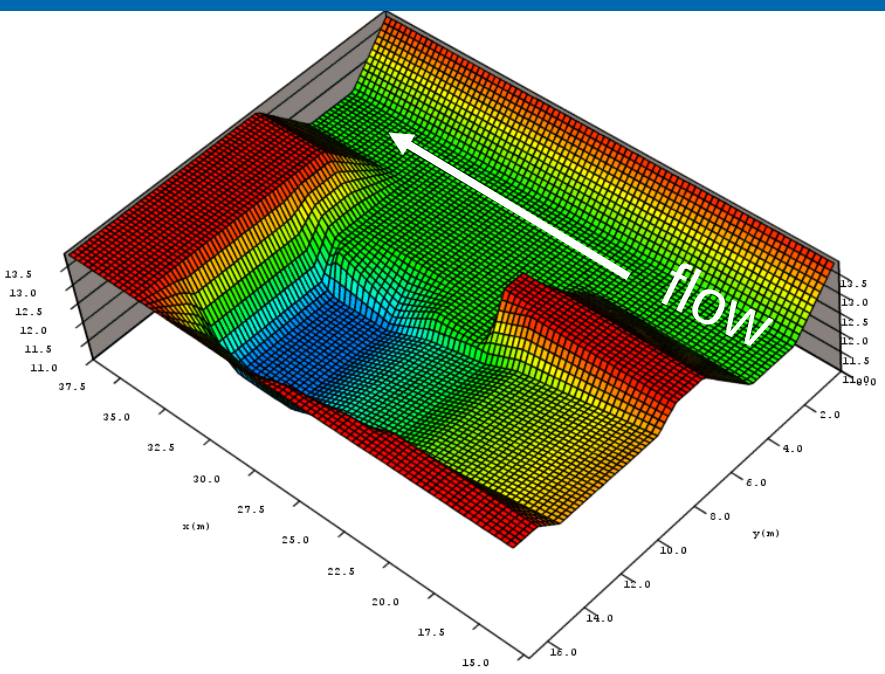
わんど上下流の突起の影響

➤ レイノルズ応力

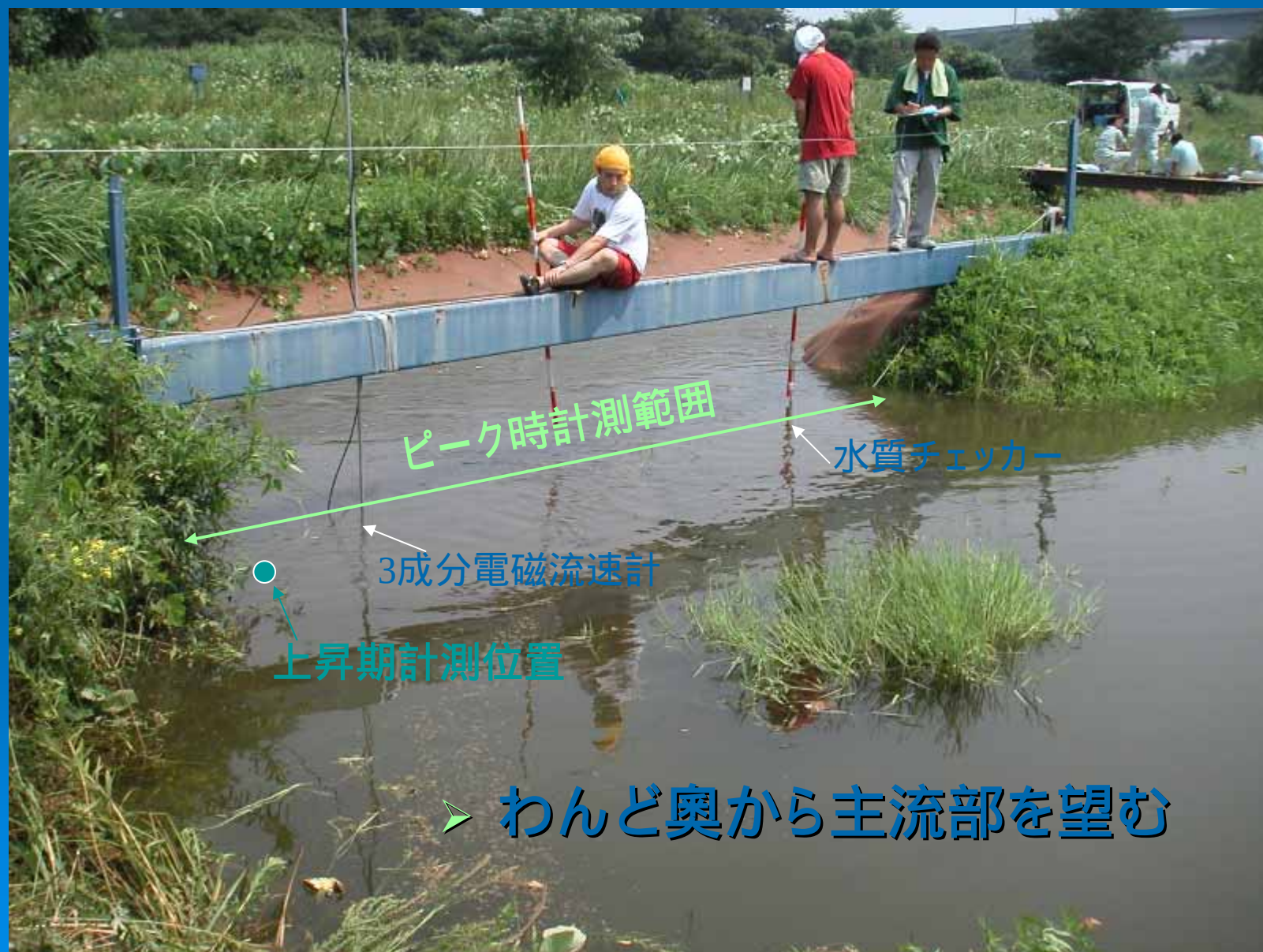


自然共生研究センター わんど研究ゾーンでの出水実験

- 主水路底面幅2.4m，側壁傾斜1：2
- わんど開口部長さ約7.9m，奥行き約3.5m
- 基底流量 $0.1\text{m}^3/\text{s}$ ，ピーク流量 $2.5\text{m}^3/\text{s}$
- 上昇期が約30分，ピーク流量の定常状態が約1時間



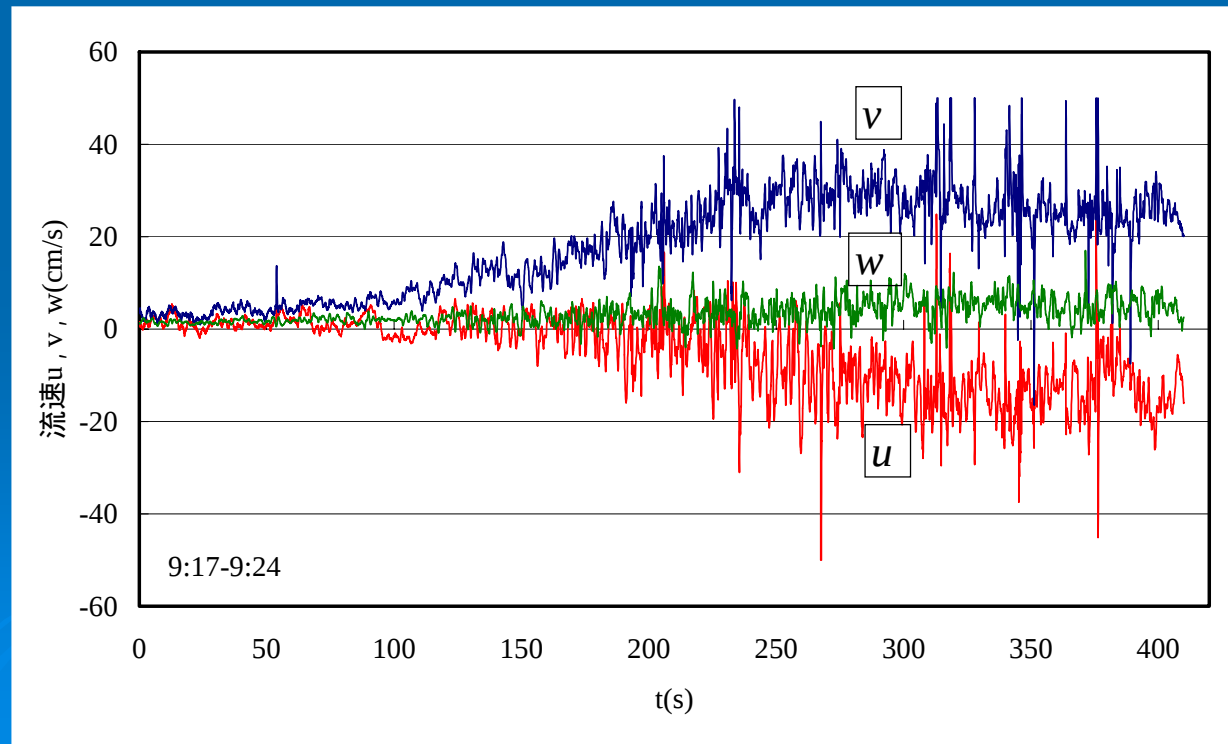
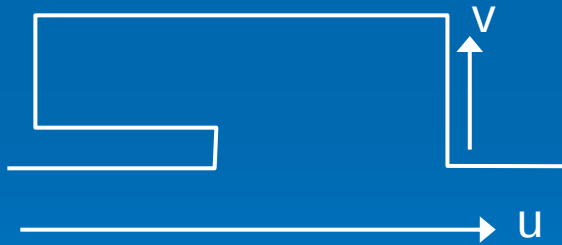
計測わんどの状況



➤ わんど奥から主流部を望む

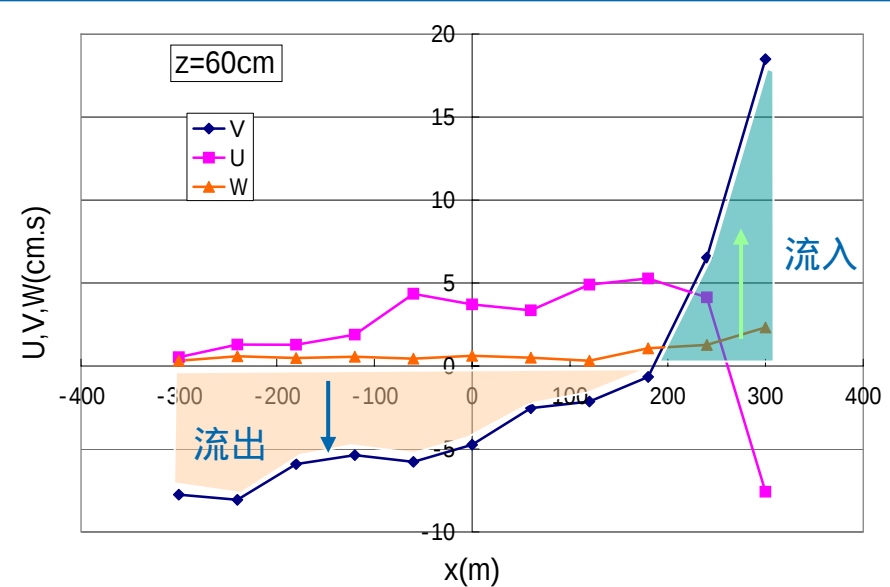
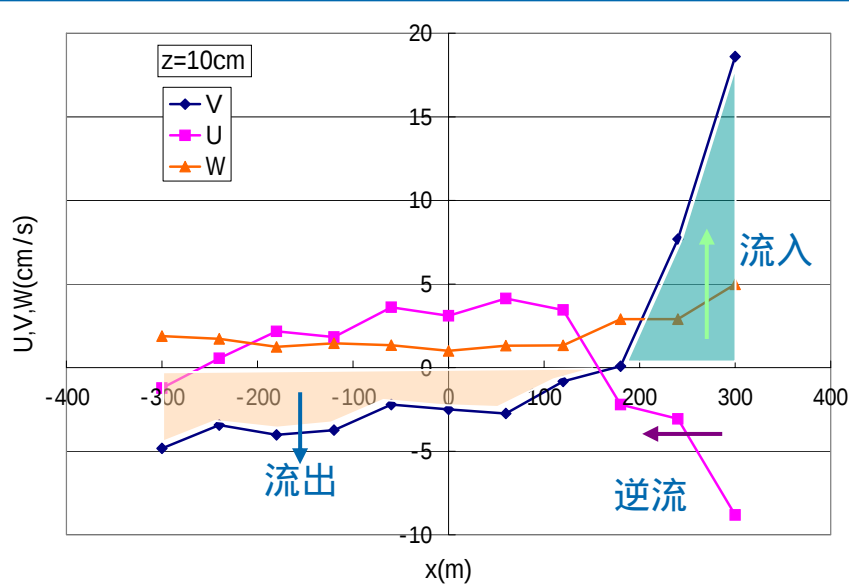
水位上昇期の流速変化

- わんど下流側は水位上昇開始初期に変化
- 横断方向流速 v : 正の値 = わんど内への流入
- 主流速: 負の値 = 逆流



ピーク流量時の平均流速

- 上流部でわんどからの流出，下流部でわんど内への流入が生じ，水交換が行われている

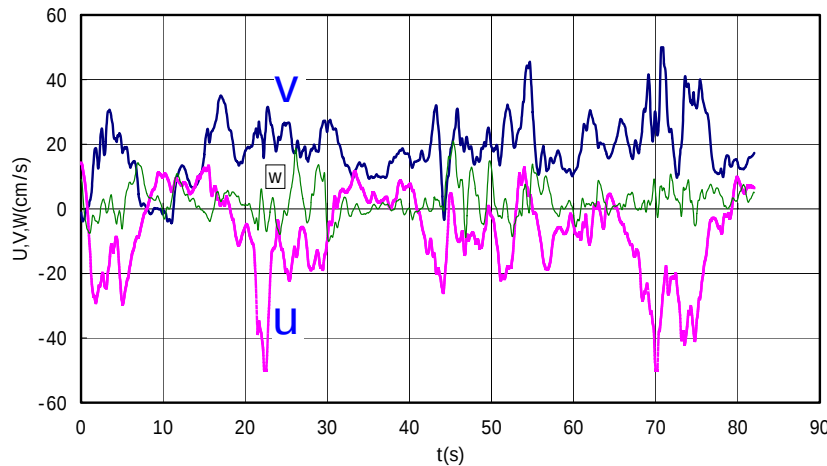


わんど開口部の大規模流速変動

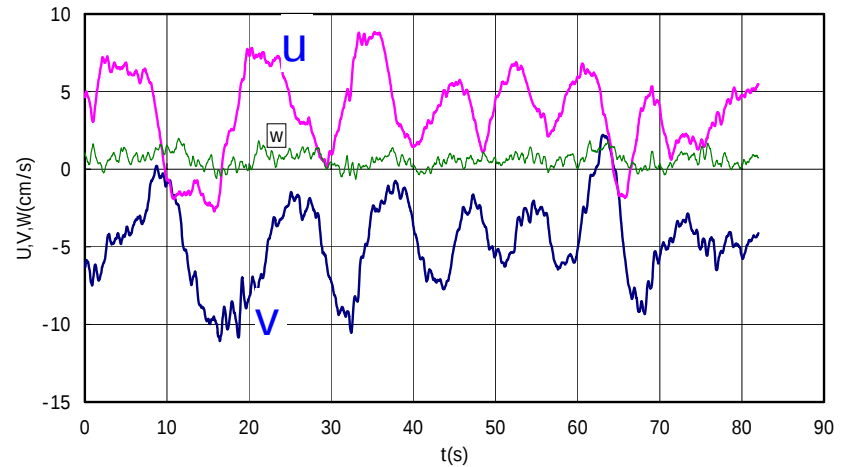
- 中央: 周期10秒程度
- 周辺: 周期20秒から30秒程度 + 高周波変動
- u と v の位相は 90° 程度ずれている



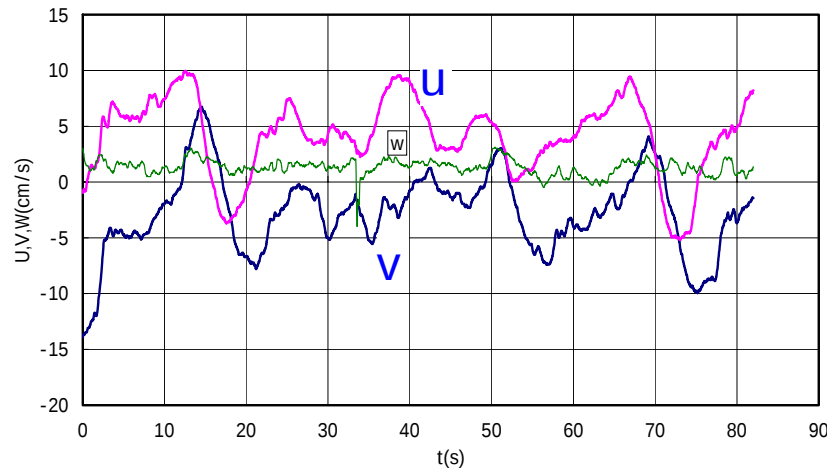
$x=300\text{cm}, z=60\text{cm}$



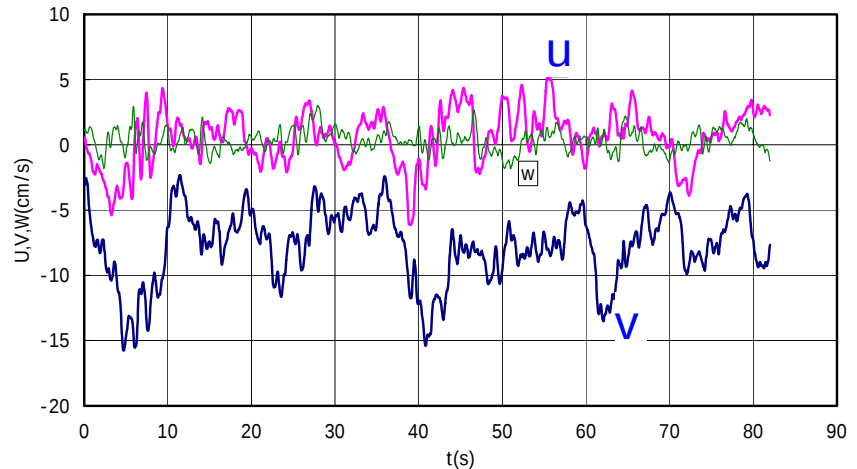
$x=0\text{cm}, z=60\text{cm}$



$x=-60\text{cm}, z=60\text{cm}$



$x=-300\text{cm}, z=60\text{cm}$



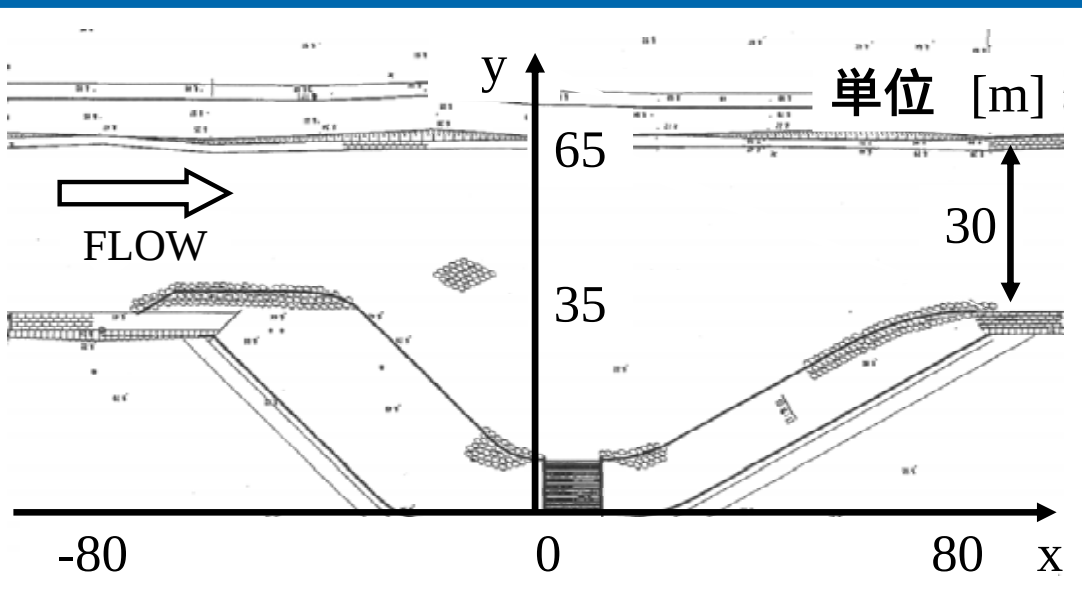
人工わんどの例

- 矢田川(愛知県) -

- 開口部100m, 奥行き25m, 高水時は開口部140m, 奥行き35m
- 開口部上流側にはひし形の置石工
- 開口部が徐々に閉塞されつつある
- 流れの制御により閉塞を防ぐことは可能か



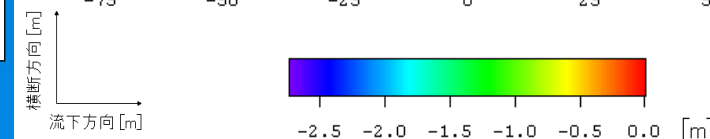
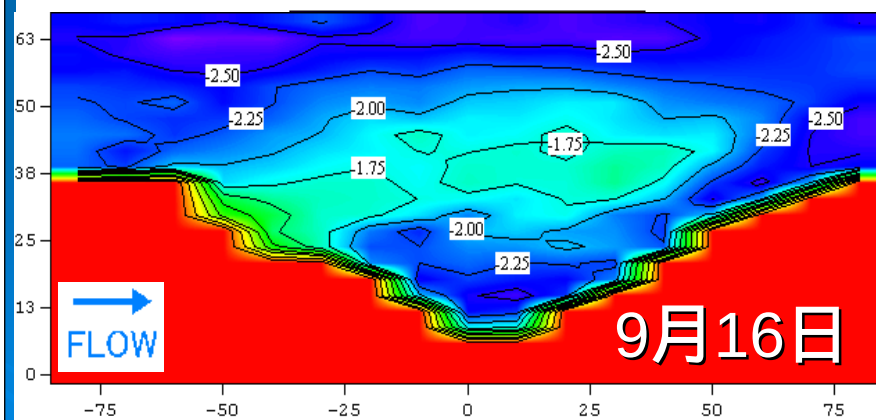
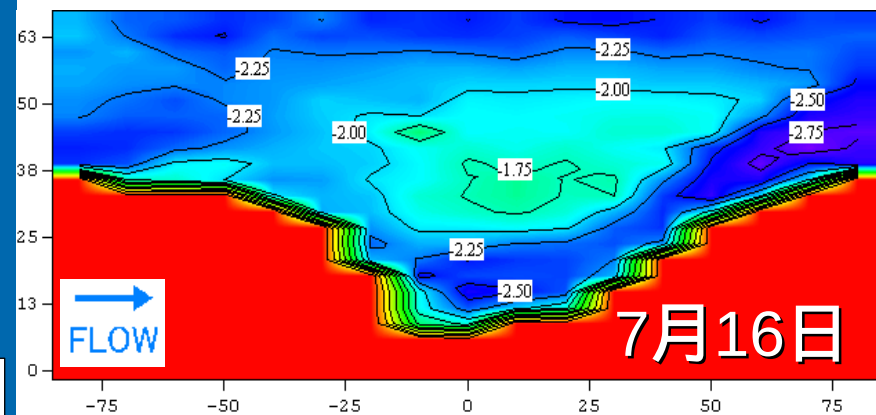
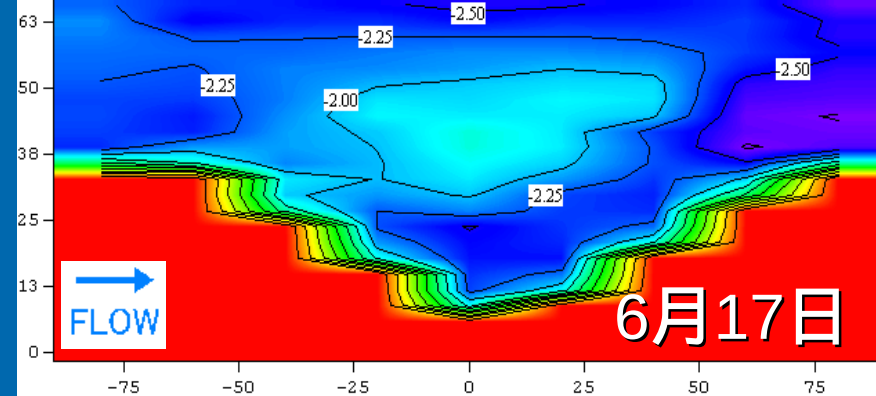
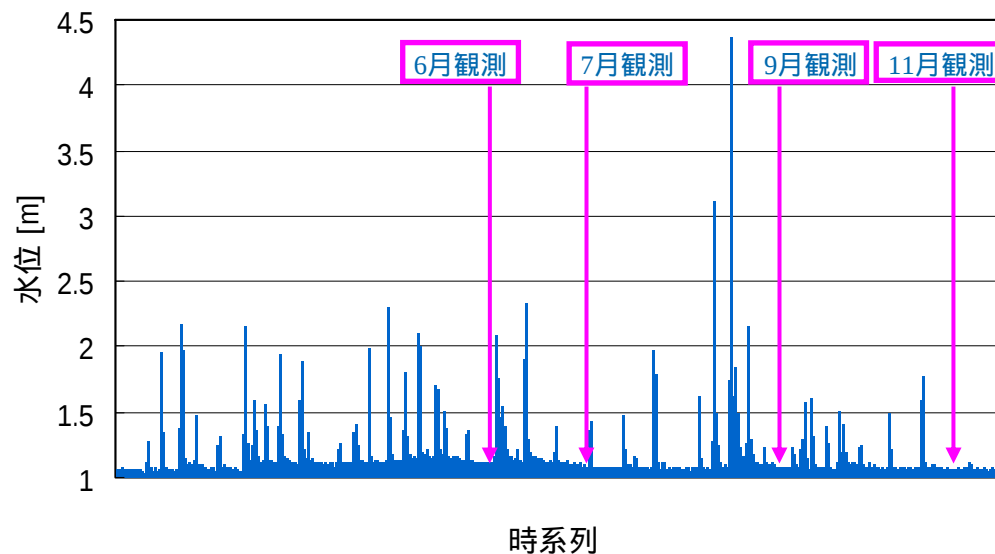
2008年6月

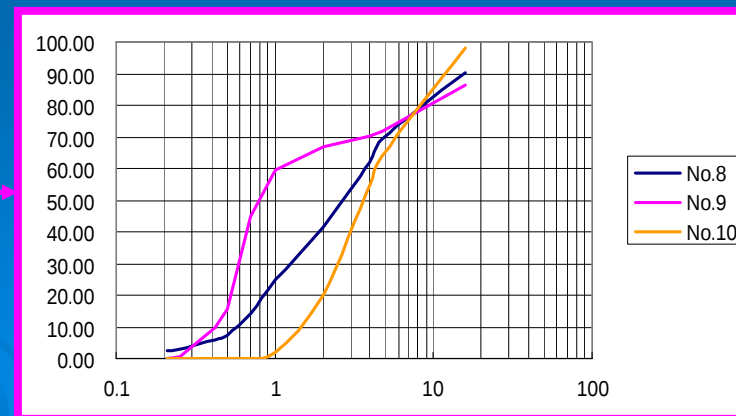
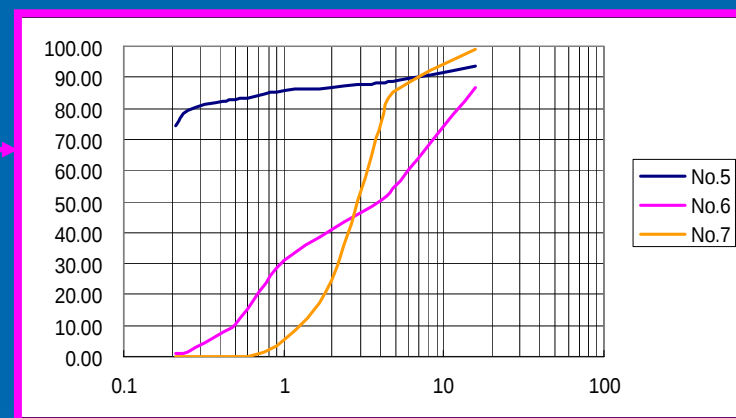
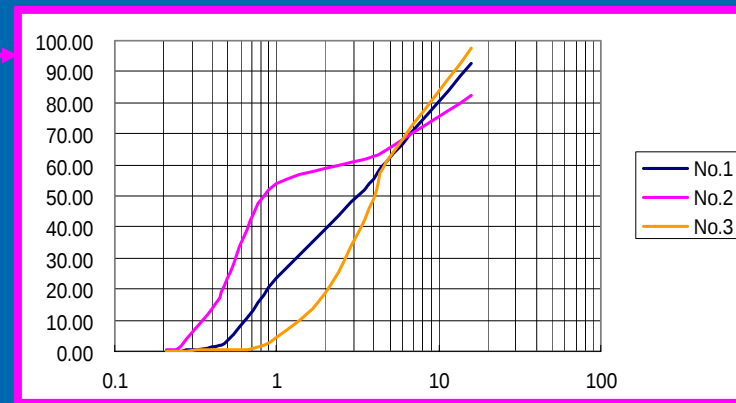
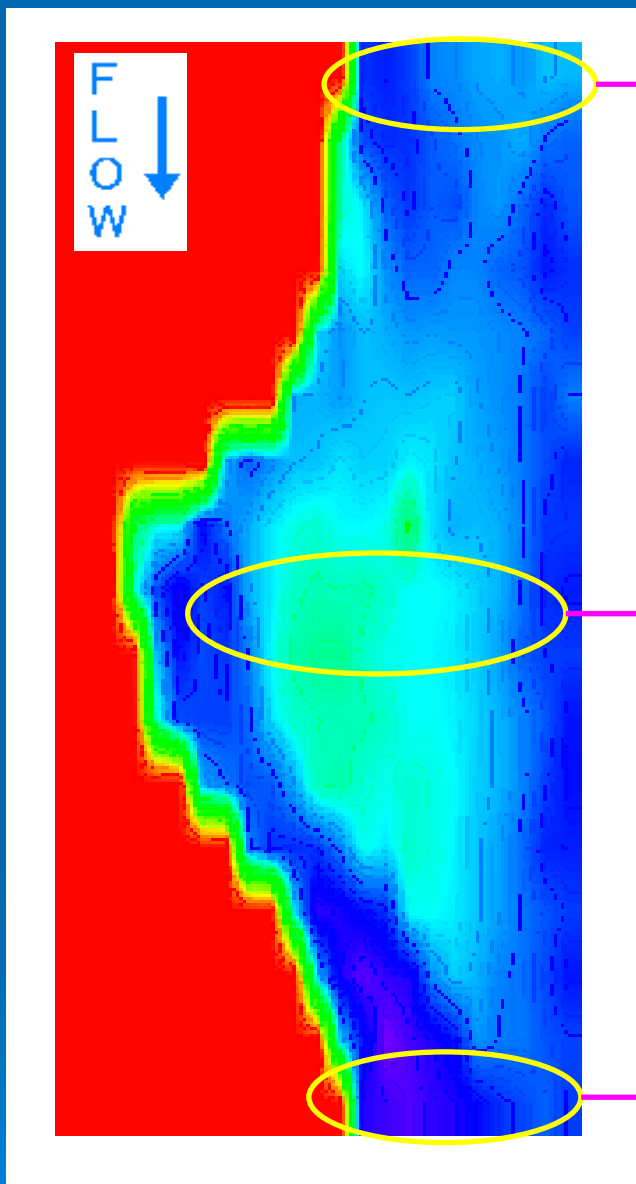


2008年9月

河床形状变化

- 3月～10月の間で水位1.5m以上の出水は月に3回から5回
- 8月末には水位4.37mの大規模な出水

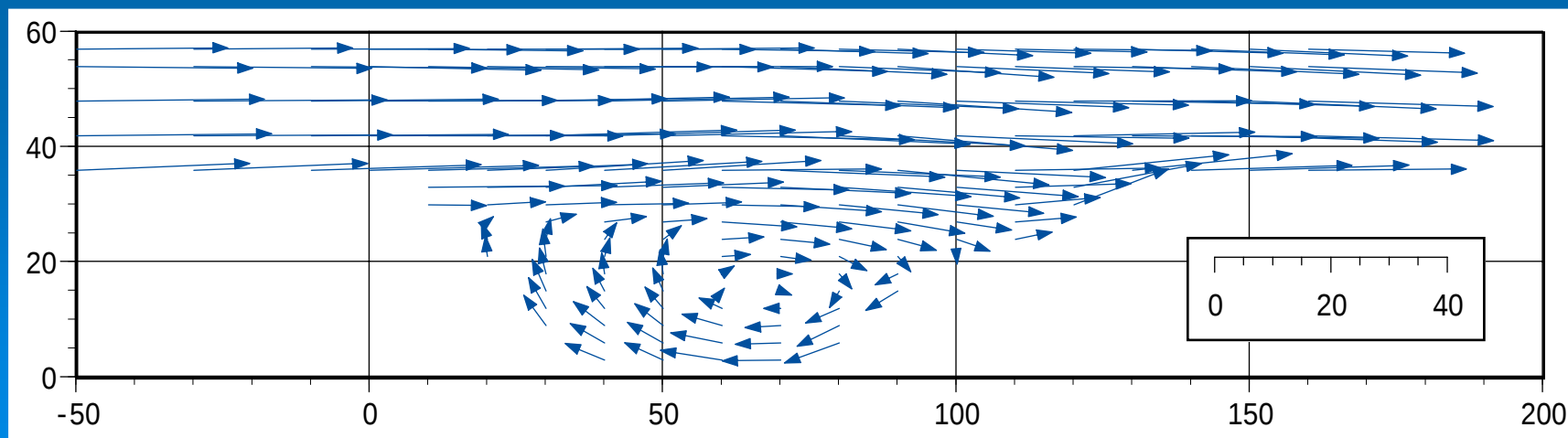




粒度分布

模型実験

- 矢田川わんどの歪み模型を作成し、流速の計測を行った
- 出水時の流速ベクトル



側岸凹部流れ構造のまとめ

➤ 1次混合

- 主流と凹部の境界におけるケルビン・ヘルムホルツ不安定渦の移流と発達
- セイシュとの相互作用
- 質量交換係数は1次混合で説明可能か？

➤ 2次混合

- 時間平均流れパターンに見られる再循環流
- 開口部が閉鎖的な場合支配的となる

今後の課題

- 大規模組織渦は2次元数値計算でほぼ再現可能となっているようであるが:
- 3次元性の影響 - 水深変化と底面摩擦
- スケール効果 - 実河川では長周期変動
- 閉鎖性の開口部の影響
- 凹部上部を越流するケース
- 掃流砂への影響, 浮遊砂の連行・堆積機構
- 流れと土砂堆積の制御法