DISCUSSION / DISCUSSION

Discussion of "Three-dimensional numerical study of flow structure in channel confluences"[1]

M. Leite Ribeiro, K. Blanckaert, and A.J. Schleiss

The Discussers would like to congratulate the Authors for their interesting work concerning the flow characteristics in channel confluences, performed by means of three-dimensional numerical simulations considering rectangular cross-sections with smooth bed. The model is validated with reasonable agreement with experimental data. The investigation of several geometries (angles and channels widths) and hydraulic conditions (discharge ratios and Froude Numbers) contributes to increase the knowledge on the hydrodynamics in channel confluences.

Although the flow characteristics in channels confluences are well documented in literature (main references are cited by the Authors), the presence of sediment transport and its influence on the morphodynamic features in confluence zones are still not completely understood. The few existing laboratory studies regarding confluence morphology (Mosley 1976; Ashmore and Parker 1983; Best 1988) and the field investigation of flow and morphological features of bed concordant (Roy and Bergeron 1990; Rhoads and Kenworthy 1995; Rhoads and Sukhodolov 2008; Rhoads et al. 2009) and bed discordant (Biron et al. 1993; Leclair and Roy 1997; Boyer et al. 2006) confluences show that the hydrodynamics of confluence zones are highly responsive to the changes in the morphology. One of the most important examples, which has been the subject of a large scientific debate, concerns the presence, number, and intensity of the secondary flow cells driven by the confluence (Fujita and Komura 1989; Rhoads and Kenworthy 1998;Lane et al. 2000; Weber et al. 2001; Parsons et al. 2007).

The Discussers investigated the hydro–morpho–sedimentary processes in channel confluences by means of systematic laboratory tests performed in a 90° confluence flume (Leite Ribeiro et al. 2009, 2010). The experimental set-up illustrated in Fig. 1 was designed based on the main regulated alpine confluences of the Upper Rhone Basin, in Switzerland. Alpine confluences are typically characterized by small steep tributaries often meeting asymmetrically the main channel at the valley bottom at large angles. During morphogenic flood events, tributaries carry important quantities of poorly-sorted sediments (reproduced in the Discusser's tests with the gradation coefficient σ = 4.15), which condition the development of a characteristic morphology.

A complete analysis of the bed morphology development until equilibrium conditions and the three-dynamical flow velocity field measured with an ADVP (acoutic doppler velocity profiler, see (Blanckaert 2010)) demonstrates that the existing knowledge concerning the flow dynamics (well discussed by the Authors) and the morphodynamic processes (Mosley 1976; Best 1988; Leclair and Roy 1997; Boyer et al. 2006; Best and Rhoads 2008) is not applicable to alpine confluences. Figure 2 illustrates a conceptual framework of the morphodynamics of alpine confluences, resulting from our experiments. The model describes five main morphological features, associated to six main flow features. The important difference between the flow depths in the tributary and the main channel leads to the formation of a pronounced bed discordance (*M1*). The presence of a large sediment bar downstream of the confluence (*M2*) is neither related to flow recirculation nor to secondary flow cells, which are both absent in the present case. Instead, the shape of the sediment bar is the result of sediment continuity requirements, e.g., the reduction of the flow area required to increase velocities and the sediment transport capacity. The absence of a marked scour hole (*M5*) is another important morphological feature of alpine confluences. Near-surface flow coming from the main channel (*F1*) is deviated towards the outer bank by the tributary flow (*F3*) in the confluence zone, whereas the near-bed flow originating from the main channel (*F2*) goes straight to the sediment bar. The two-layer flow prevents the formation of the flow recirculation downstream of the confluence. Moreover, it does not lead to the formation of secondary flow cells. The sediment transfer between the tributary and the post-confluence channel mainly occurs near the downstream corner of the confluence due to the formation of a stagnation zone (*F4*) at the upstream confluence corner that causes an asymmetric distribution of the

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M. Leite Ribeiro[2] and A.J. Schleiss. Laboratory of Hydraulic Constructions (LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 18, Switzerland.
K. Blanckaert. Laboratory of Hydraulic Constructions (LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 18, Switzerland; State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China.

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[2]Corresponding author (e-mail: marcelo.leiteribeiro@epfl.ch).

Fig. 1. Experimental set-up and a picture of the confluence zone at equilibrium conditions for one of the tests. In the picture, the coordinate axis is not placed at the origin.

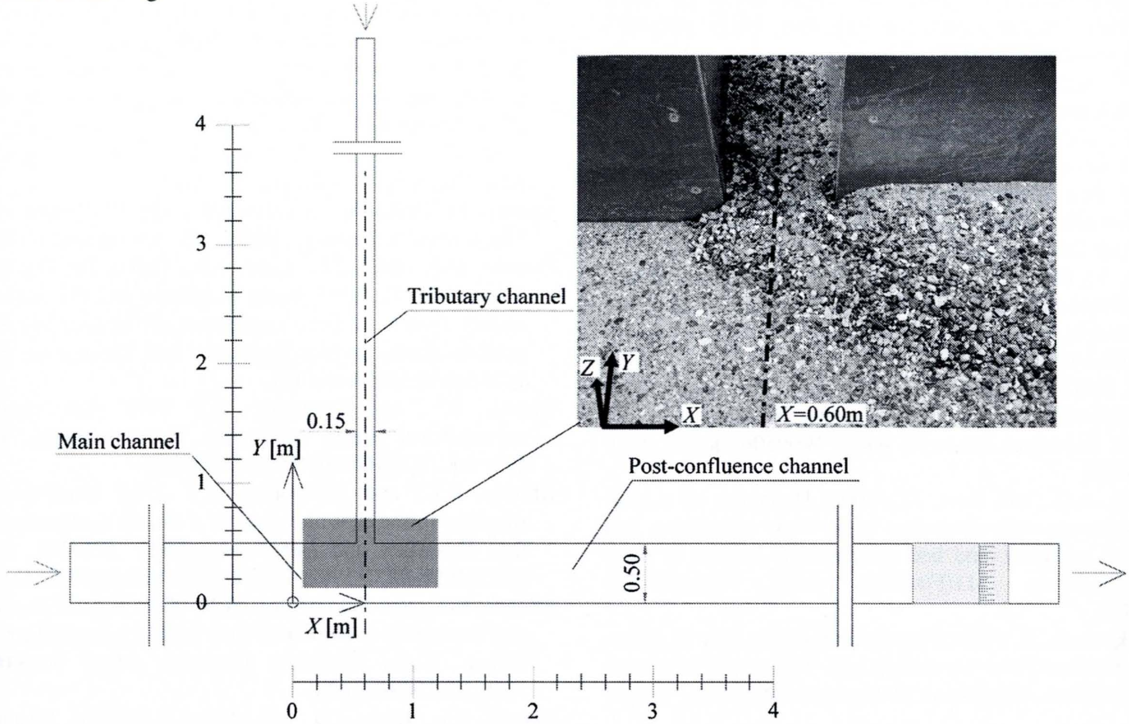
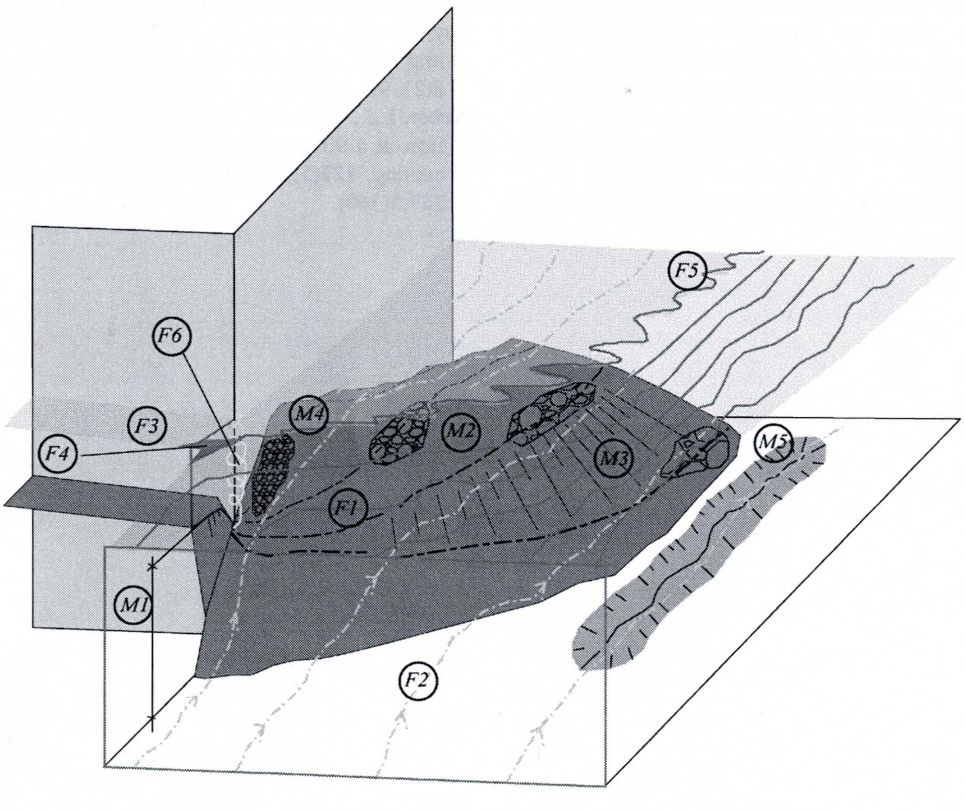


Fig. 2. Conceptual framework of hydro–morpho–sedimentary processes in alpine confluences.



flow and sediment transport. A shear layer (*F5*) forms where flows originating from the tributary and the main channel collide. It is characterized by high turbulence intensity and its outer limit coincides closely with the toe of the sediment bar. In the downstream confluence corner, spiral vortices (*F6*) lift fine material into suspension. Fine materials are then transported near the inner bank (*M4*) while the coarse ones are transported on the face of the deposition bar (*M3*).

References

Ashmore, P., and Parker, G. 1983. Confluence scour in coarse braided streams. Water Resources Research, **19**(2): 392–402. doi:10.1029/WR019i002p00392.

Best, J.L. 1988. Sediment transport and bed morphology at river channel confluences. Sedimentology, **35**(3): 481–498. doi:10.1111/j.1365-3091.1988.tb00999.x.

Best, J.L., and Rhoads, B.L. 2008. Sediment transport, bed morphology and the sedimentology of river channel confluences. *In* River Confluences, Tributaries and the Fluvial Network. John Wiley & Sons, Ltd. pp. 45–72.

Biron, P., Roy, A., Best, J.L., and Boyer, C.J. 1993. Bed morphology and sedimentology at the confluence of unequal depth channels. Geomorphology, **8**(2–3): 115–129. doi:10.1016/0169-555X(93)90032-W.

Blanckaert, K. 2010. Topographic steering, flow recirculation, velocity redistribution, and bed topography in sharp meander bends. Water Resources Research, **46**(9): W09506. doi:10.1029/2009WR008303.

Boyer, C., Roy, A.G., and Best, J.L. 2006. Dynamics of a river channel confluence with discordant beds: Flow turbulence, bed load sediment transport, and bed morphology. Journal of Geophysical Research, **111**(F04007): 1–22. doi:10.1029/2005JF000458.

Fujita, I., and Komura, S. 1989. Visualization of the flow at a confluence. *In* Refined Flow Modelling and Turbulence Measurements. International Association of Hydraulic Research, Tokyo, Japan.

Lane, S.N., Bradbrook, K.F., Richards, K.S., Biron, P., and Roy, A.G. 2000. Secondary circulation cells in river channel confluences: measurement artefacts or coherent flow structures? Hydrological Processes, **14**(11–12): 2047–2071. doi:10.1002/1099-1085(20000815/30)14:11/12<2047::AID-HYP54>3.0.CO;2-4.

Leclair, S., and Roy, A.G. 1997. Variabilité de la morphologie et des structures sédimentaires du lit d'un confluent de cours d'eau discordant en periode d'étiage. Géographie Physique et Quaternaire, **51**: 125–139.

Leite Ribeiro, M., Blanckaert, K., Boillat, J.L., and Schleiss, A.J. 2009. Influence of the momentum flux ratio on confluence morphology. *In* 3rd IAHR Congress "Water Engineering for a Sustainable Environment". *Edited by* IAHR. Vancouver, Canada.

Leite Ribeiro, M., Boillat, J.-L., Schleiss, A.J., and Blanckaert, K. 2010. Experimental study on a widening tributary channel and its influence on the confluence morphology. *In* River Flow 2010. *Edited by* K. Dittrich, Aeberle & Geisenhainer. Braunschweig, Germany. Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany, Vol. II. pp. 961–968.

Mosley, M. 1976. An experimental study of channel confluences. The Journal of Geology, **84**(5): 535–562. doi:10.1086/628230.

Parsons, D.R., Best, J.L., Lane, S.N., Orfeo, O., Hardy, R.J., and Kostaschuk, R. 2007. Form roughness and the absence of secondary flow in a large confluence-diffluence, Rio Parana, Argentina. Earth Surface Processes and Landforms, **32**(1): 155–162. doi:10.1002/esp.1457.

Rhoads, B.L., and Kenworthy, S.T. 1995. Flow structure at an asymmetrical stream confluence. Geomorphology, **11**(4): 273–293. doi:10.1016/0169-555X(94)00069-4.

Rhoads, B.L., and Kenworthy, S.T. 1998. Time-averaged flow structure in the central region of a stream confluence. Earth Surface Processes and Landforms, **23**(2): 171–191. doi:10.1002/(SICI)1096-9837(199802)23:2<171::AID-ESP842>3.0.CO;2-T.

Rhoads, B.L., and Sukhodolov, A.N. 2008. Lateral momentum flux and the spatial evolution of flow within a confluence mixing interface. Water Resources Research, **44**(8): W08440. doi:10.1029/2007WR006634.

Rhoads, B.L., Riley, J.D., and Mayer, D.R. 2009. Response of bed morphology and bed material texture to hydrological conditions at an asymmetrical stream confluence. Geomorphology, **109**: 161–173. doi:10.1016/j.geomorph.2009.02.029.

Roy, A., and Bergeron, N. 1990. Flow and particle paths at a natural river confluence with coarse bed material. Geomorphology, **3**(2): 99–112. doi:10.1016/0169-555X(90)90039-S.

Weber, L.J., Schumate, E.D., and Mawer, N. 2001. Experiments on flow at a 90° open-channel junction. Journal of Hydraulic Engineering, **127**(5): 340–350. doi:10.1061/(ASCE)0733-9429(2001)127:5(340).