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Flow structure at low momentum ratio river confluences

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The flow structure at river confluences is a complex pattern of fluid motion and can be characterized by the formation of secondary circulation. As river confluences play an essential role on flow hydrodynamics and control the movement of sediment through river networks, there has been substantial attention given to this subject in recent decades. However, there is still much debate over how momentum ratio and sediment transport can control secondary circulation and mixing processes. In particular, studies have tended to assume that there is some equilibrium between the bed morphology present and the flow structures that form in the junction region. However, this overlooks the fact that tributaries may be associated with highly varying sediment supply regimes, especially for shorter and steeper tributaries, with temporal changes in sediment delivery ratios (between the main stem and the tributary) that do not follow exactly changes in momentum ratio. This may lead to bed morphologies that are a function of rates of historical sediment supply during sediment transporting events and not the momentum ratio associated with the junction during its measurement. It is quite possible that tributaries with low flow momentum ratio have a relatively higher sediment delivery ratio, such that the tributary is still able to influence significantly secondary circulation in the main channel, long after the sediment transport event, and despite its low flow momentum during measurement. The focus of this paper is low momentum ratio junctions where it is possible that the tributary can deliver large amounts of sediment.

Secondary circulation at junctions is thought to be dominated by streamwise-oriented vortical cells. These cells are produced by the convergence of surface flow towards the centre of the main channel, with descending motion in the zone of maximum flow convergence. Once flow arrives at the bed, it diverges and completes its rotation by an upwelling motion through the surface at the channels margins. Numerical models, laboratory experiments and field studies have confirmed the presence of this motion. However, such studies have focused on situations where the momentum ratio is close to one and there have been fewer investigations of confluences where the momentum ratio is much less than one.

This study presents field investigations in two upper Rhône river confluences in Switzerland, using an acoustic Doppler current profiler (aDcp). These two confluences are characterized by low momentum ratios but potentially higher sediment delivery ratios during extreme events. Results show that sediment delivery from the tributary during extreme events leads to the formation of a tributary mouth bar and associated bed discordance as well as a bank attached bar downstream of the tributary. In both cases, this discordant bed forms a two-layer flow and the water from the tributary penetrates into the upper part of the main river water column. This results in a mixing interface that is shifted toward the outer bank. When this mixing layer detaches from the tributary outer bank, it forms a large recirculation region in the upper part of the water column and a pronounced scour hole at this bank. The bank attached bar that forms downstream during sediment supply events leads to substantial curvature of the main channel flow, even when the flow momentum of the tributary is low and helps to shift the zone of deepest main river flow towards the outer bank.