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# Secondary circulation in river junctions even at very low flow momentum ratios: the legacy effects of point bar formation

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River confluences remain a challenging subject because of their 3D geometry which leads to a complex, three-dimensional mean and turbulent velocity processes. Since secondary circulation plays an important role in flow hydrodynamics and the development of bank erosion, bed scour and bar formation, several numerical models, laboratory experiments and field studies have paid special attention to this subject. However, for small tributaries, associated with low flow momentum ratio, there has been a lack of understanding as to how momentum ratio and sediment supply regime can control the formation of secondary circulation. Of interest here is the possibility that sediment delivery and tributary bar formation in the main channel leaves a morphological legacy that is capable of inducing significant secondary circulation at the junction even if the tributary has a low flow momentum. Laboratory experiments have tended to study the equilibrium morphology formed by the interaction between an imposed flow driven sediment supply regime, rather than the effects of that morphology when tributary flows are lower and there is no sediment supply. This paper tests the hypothesis that even where the flow momentum of a tributary is very low, it is still possible to identify significant secondary circulation because of the legacy of morphological changes associated with higher momentum tributary flow.

Secondary circulation at river confluences is thought to be dominated by streamwise-oriented vortical cells produced by the convergence of the surface flow through the center of the main channel, with downwelling motion in the zone of maximum flow convergence and upwelling motion at the channel margins. Considerable agreement exists among numerical, field and laboratory experiments that secondary circulation is an important element in developing bank erosion, bed scour, bar formation and boundary shear. 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, such as Alpine tributaries, which produce confluences characterized by low momentum ratio and a high sediment delivery ratio during extreme events.

To close this gap, intensive field data collection was used to investigate three upper Rhône river confluences in Switzerland, using an aDcp. Results show that high rates of tributary sediment delivery into the main channel during extreme events, lead to tributary mouth bar formation and associated bed discordance, which creates a two-layer flow. It results in the penetration of the tributary flow into the upper part of the main channel water column. Due to this two layer flow, the mixing layer is shifted toward the opposite bank and is associated with a large recirculation zone as well as a pronounced scour hole at this bank and an inner bank attached bar. Through time, the main channel may erode the inner bank attached bar, reducing bed discordance, and causing the mixing layer to form within the center part of the downstream channel. Analyses of these results confirms that even small tributaries can significantly influence confluence secondary circulation due to the legacy effects of sediment delivery.