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The effect of small density differences at large confluences

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Introduction

Confluences are fascinating elements in river systems. The merging of tributary rivers produces complex hydrodynamics that can play an important role in sediment transport problems, ecological studies or the routing of a pollutant.

If the two merging rivers originate from different regions they can have different characteristics. One such a characteristic can be the water density.

The influence of many different properties of a confluence on the hydrodynamics has already been investigated. The effect of bed discordance has been described [Biron et al., 1996], as well as that of the momentum ratio [Best & Reid, 1984]. Also a lot of work has been carried out on the mixing layer that may form (van Prooijen & Uijttewaal, 2002).

The effects of density differences, on the contrary, have received little attention. Rare examples are the work by Cook & Richmond (2004) and Lyubimova et al. (2014).

The aim of this research is to see how and when density differences are important in confluences with respect to other occurring flow structures. Non-dimensional flow parameters will be linked to certain types of flow. These non-dimensional parameters can then be used to determine which flow processes can occur.

This research shows the importance that small density differences can have on the local hydrodynamics near a confluence. We explain the processes and present suitable non-dimensional parameters to describe the flow.

Methods

We first considered a schematized confluence with a confluence angle of 0°. Using the Delft3D software the flow in this schematized confluence was numerically computed for various flow cases. These flow cases differed from one another in terms of velocity, velocity difference (between the tributaries), depth, roughness and density difference. The results from these cases were compared to one another and interpreted.

The results from the modeling work were compared to aerial photographs of large confluences to see if similar flow structures could be recognized. Only aerial photographs showing a colour difference between the two tributaries were used. Since it is likely that a colour difference is caused by a sediment concentration difference, it is likely that in such confluences also a density difference occurs.

Finally a numerical case study of the Rio Negro – Solimões confluence near Manaus, Brazil, was undertaken to determine if the same effects also occurred in this confluence. The model results were compared with aerial photographs of the confluence at different flow stages.

Results

The light water flowed over the denser water and the denser water under the lighter water, see Fig. 1. A striking feature is that further away from the confluence apex the denser current has become higher whereas the lighter current has become lower. At some point this causes the interface between the two waters to return to a near-vertical state. As a result of this at the surface initially the light water becomes wider then smaller again.

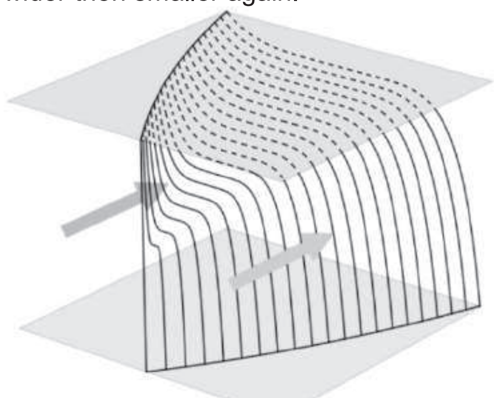

Figure 11 Shape of the interface between dense and light water. The arrows indicate the downstream direction and on which side the dense and light waters enter the confluence area. The two planes indicate the water surface and bed. The vertical line is located at the confluence apex.

The numerical models showed that the lighter water accelerated within the area where denser water was located below lighter water. The denser water decelerated.

A mixing layer could develop if the flow velocities of the tributaries differed. However, if density differences became larger, and thus the velocities normal to the main direction of flow became larger, the mixing layer developed less or even not at all. In Fig. 2 a diagram shows the combinations of the non-dimensional parameters for which coherent structures could and could not develop.

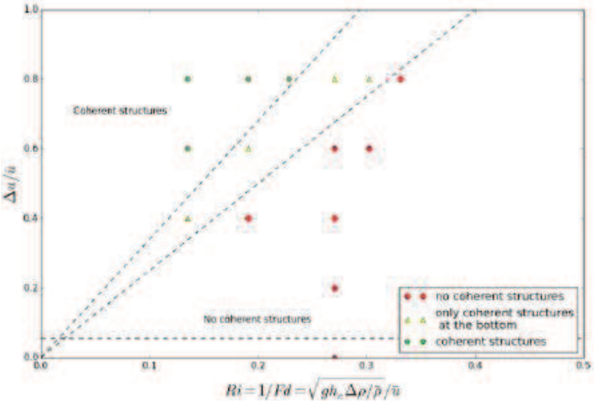

Figure 2 Diagram showing combinations of non-dimensional parameters for which coherent structures may or may not occur

All results mentioned above assume that the width of the downstream river was sufficiently large. If dense or light water reached the opposite bank up- or downwelling occurred at the reached bank respectively.

Figure 12 Aerial photograph of the Irrawaddy – Chindwin confluence, 26 October 2009. Source: DigitalGlobe. Arrows indicate flow direction

We found several photographs of confluences showing similar flow characteristics as those found in the numerical simulations. Fig. 3 shows the confluence of the Irrawaddy and Chindwin rivers in Myanmar. The movement of the interface at the surface can be explained using the theory derived from this research.

Similar profiles could be discerned on photographs of the Benue – Niger confluence in Nigeria. In an aerial photograph of the confluence of the Rhône and Arve rivers a similar process to the one occurring if the downstream river is rather narrow could be seen.

The numerical model runs of the Rio Negro – Solimões confluence showed similar features as the schematized model runs. The denser water flowed under the lighter water. The amount at which this happened differed for different discharge levels.

Photographs showing a profile at the surface between the lighter and denser water like in Fig. 3 lacked. This is because boils of heavier Solimões water at the Rio Negro side of the river disturbed a clear surface pattern. Since the position of these boils did not change over the years they are likely generated by permanent bed forms. Their appearance at the surface does indicate that heavier water is located below the lighter water.

On several oblique photographs of this confluence the absence of the mixing layer was visible. Sometimes floating foam was located between the two waters, indicating downwelling due to the density differences.

Conclusions & recommendations

The goal of this research was to identify the effects density differences could have on the flow downstream of a confluence. It is clear that density differences at a confluence affect the hydrodynamics downstream greatly. Even if these density differences are small the effects can be significant and should not be neglected.

Denser water will flow under the lighter water and lighter water over denser water. If these movements are large they hamper the development of the mixing layer.

The effects were validated using aerial photographs of several confluences. Oblique photographs of the Rio Negro – Solimões confluence were in agreement with the results.

This research shows the importance of density differences for the hydrodynamics downstream of a confluence. However many aspects are still unknown and more research into these is recommended. Especially physical model tests could give enlightening results.

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