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CRAS2A-3376; No. of Pages 12
ARTICLE IN PRESS

C. R. Geoscience xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Comptes Rendus Geoscience

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Hydrology, Environment

A field study of the confluence between Negro and Solimões Rivers. Part 1: Hydrodynamics and sediment transport

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ARTICLE INFO

Article history:
Received 26 April 2016
Accepted after revision 21 September 2017
Available online xxx

Handled by François Chabaux

Keywords:
Environmental hydraulics
River confluences
Hydrodynamics
Sediment transport
Amazon basin

ABSTRACT

Confluences are a common feature of riverine systems, where are located converging flow streamlines and potential mixing of separate flows. The confluence of the Negro and Solimões Rivers ranks among the largest on Earth and its study may provide some general insights into large confluence dynamics and processes. An investigation was recently conducted about that confluence in both low and high-flow conditions using acoustic Doppler velocity profiling (ADCP), water quality sampling and high-resolution seismic data. First, the study gained insights into the characterization of the basic hydrodynamics parameters about the confluence as well as of those affecting sediments transport. Second, the analysis of the results showed that common hydrodynamic features noted in previous confluence studies were herein observed. Finally, some differences between low-flow and relatively high-flow conditions about the transfer of momentum from the Solimões to the Negro side of the Amazon Channel were identified.

1. Introduction

Confluences are a common feature of riverine systems, where are located converging flow streamlines and potential mixing of separate flows. As the flows from two tributaries merge and adjust to the confluences planform geometry, substantial changes to the flow hydrodynamics and bed morphology occur within and immediately downstream of the confluence (Mosley, 1976). Within a confluence the region where the local hydrodynamics are influenced by the convergence and realignment of the combining flows at the confluence is known as the Confluence Hydrodynamic Zone (CHZ) (Kentworthy and Rhoads, 1995).

The fluid dynamics about confluences have a highly complex three-dimensional flow structure, which generally includes a zone of flow stagnation near upstream junction corner, an area of flow deflection as tributary flows enter confluence a shear layer and/or a mixing interface between the two converging flows; a possible zone of separated flow about the downstream junction corner(s); flow acceleration within the downstream channel; and flow recovery at the downstream end of the CHZ as illustrated in Fig. 1 (Best, 1987; Trevethan et al., 2015a).

It is generally acknowledged that the hydrodynamics and morphodynamics (i.e. patterns of erosion and deposition)

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https://doi.org/10.1016/j.crte.2017.09.015
1631-0713/

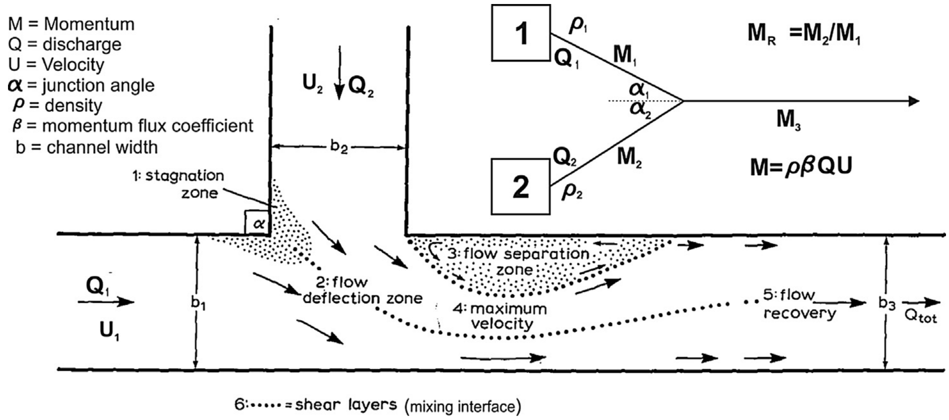

Fig. 1. Descriptive model of flow dynamics and key hydrodynamic features about a confluence, slightly modified from Best (1987) (Trevethan et al., 2015a).

within the CHZ are influenced by (1) the planform of the confluence; the junction angle of confluence, (2) the momentum flux ratio of merging streams (M_R) and (3) the level of concordance between channel beds at the confluence entrance (Best, 1987; Mosley, 1976). Further, any differences in the water characteristics (e.g., temperature, conductivity, suspended sediment concentration) between the incoming tributary flows and subsequent possible stratification lead to the development of a mixing interface and may also impact the local processes about the confluence (Biron and Lane, 2008; Rhoads and Kentworthy, 1998). Within the near-field of the confluence, the shear layer and the mixing interface are typically coincident, but in some cases the mixing interface may extend further downstream than the shear layer (Rhoads and Sukhodolov, 2008). Depending on the angles between the two incoming rivers with the downstream channel, and their momentum flux ratio, the mixing interface may display Kelvin–Helmholtz or wake mode type flow characteristics (Rhoads and Sukhodolov, 2008). Helical flow cells are also often observed about confluences, however, the presence and characteristics of these helical cells at confluences remains controversial.

The confluence bed morphology can generally be related to the different hydrodynamics zones presented in Fig. 1 (Best, 1987, 1988). Common morphological features often observed about confluences include: a scour hole normally orientated along the region of maximum velocity where both flows begin to converge; avalanche faces at the mouth of each tributary; sediment deposition within the stagnation zone; and bars formed within possible flow separation zones or mid-stream in downstream channel (Szupiany et al., 2009). Another morphological feature sometimes observed at a confluence is a bed discordance (i.e. one tributary bed is deeper than the other), which can be formed through differences in channel discharges and bed geology (Gaudet and Roy, 1995). More generally, the patterns of erosion and deposition within the CHZ reflect the spatial variations in bed shear stress (Rhoads et al., 2009). Ultimately, the bed shear stress and sediment transport can be related to the localized turbulent fluctuations in flow velocity generated through the interaction of the flow with both vertical and horizontal variations in channel bathymetry, causing the flow to accelerate or decelerate (Best and Rhoads, 2008).

The paper presents some key results from two field surveys (FS–CNS1 and FS–CNS2) conducted about the confluence of the Negro and Solimões Rivers, in the Amazon basin, which is one of the largest confluences on Earth. The goals of this paper are: (1) to gain a comprehensive characterization of the basic hydrodynamics parameters about the confluence as well as of those affecting sediments transport, (2) to compare the basic hydrodynamics features with those commonly observed in previous confluence studies, and (3) to highlight some differences between low and relatively high-flow conditions about the transfer of momentum from the Solimões to the Negro side of the Amazon Channel.

2. Field site and instrumentation

The confluence of the Negro and Solimões Rivers is located near Manaus, in northern Brazil, where these rivers merge to form the Amazon River approximately 1600 km upstream from its mouth on the Atlantic Ocean. This confluence is famous for the meeting of the black and white waters of the two rivers, which may be visually observed not mixing for more than 50 to 100 km downstream. The distinct waters of these two rivers are related to the locations of the two catchments within the Amazon Basin described above.

As part of the CLIM–Amazon Project, which was a joint European and Brazilian Research Project funded by the EU about climate and sedimentary processes of the Amazon River Basin, two field surveys were conducted about that confluence in both low (October 2014, FS–CNS1 survey) and relatively high-flow conditions (April/May 2015, FS–CNS2 survey) (Gualtieri et al., 2015, 2018; this issue; Trevethan et al., 2015a, 2015b, 2016). In these field campaigns, acoustic Doppler velocity profiling (ADCP) and high-resolution seismic methods, such as echo-sounding and sub-bottom profiling, were used as well as water sampling for the measurement of several water chemistry parameters (temperature, conductivity, pH, turbidity, dissolved oxygen, oxygen isotopes) and suspended