TÍTULO: Hydrodynamics and mixing at river confluences: on the influence of buoyancy and tides.

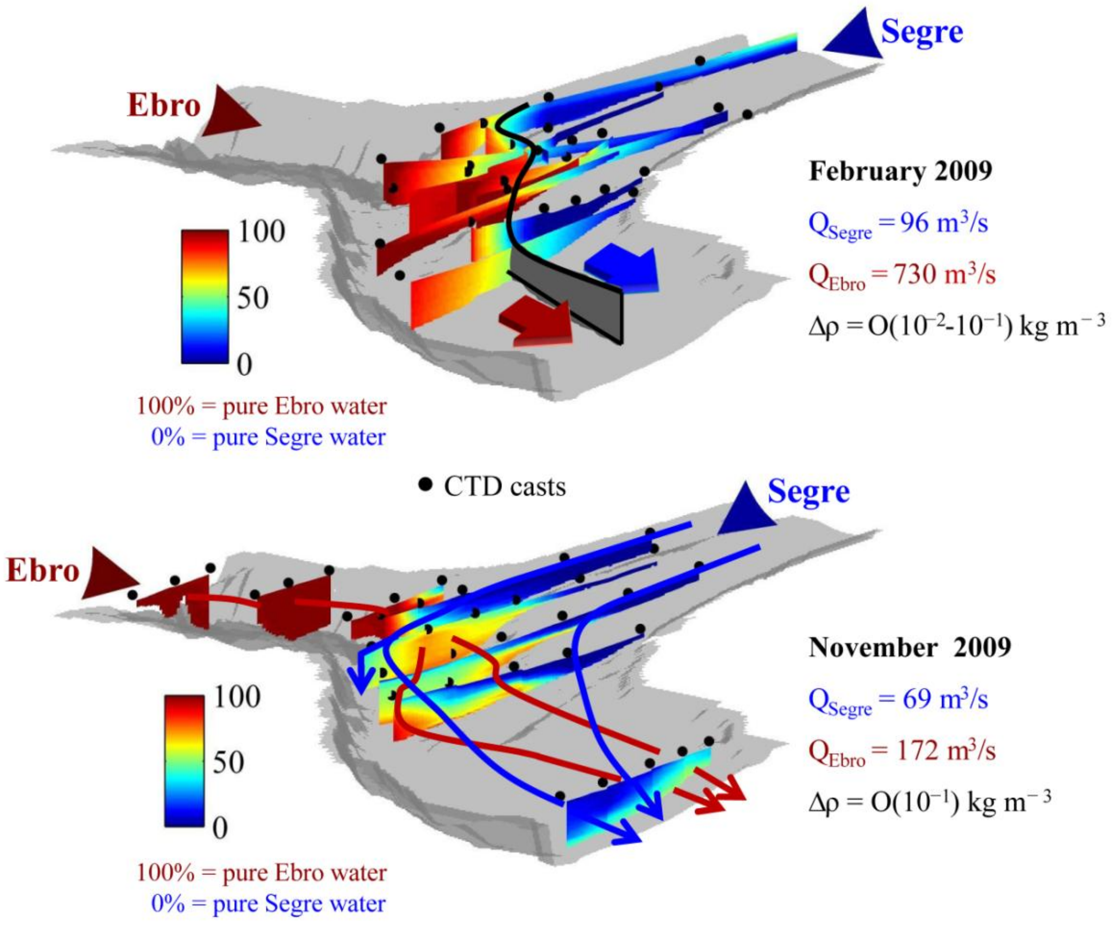
Doctoranda: Cintia Luz Ramón Casañas

Director: Francisco Rueda Valdivia

Fecha y lugar de la defensa: 10 de Marzo de 2016, Instituto del Agua.

Departamento: Ingeniería Civil, Universidad de Granada

Correo electrónico: crcasanas@ugr.es



Abstract

River confluences are critical points in river networks where strong physical and chemical gradients develop, resulting in a wide range of distinctive environmental conditions (habitats) for biological growth. Large variations in water temperatures, organic matter, nutrients, for example, and in general, in water chemistry have been reported to occur at these sites. As a consequence of their high spatial and temporal heterogeneity of habitats and resources, river confluences behave as biological hotspots, where the number of species appears to increase very significantly in comparison with other river reaches. The effects of river confluences persist downstream, therefore, affecting biological communities and ecological processes at scales of river reaches and channel networks. The spatial extent of the reaches downstream of river junctions where heterogeneous habitat conditions persist, largely depends on the rate at which mixing between the mainstream and tributary waters occurs. The literature on mixing in river confluences is extensive, but still, our understanding of flow and mixing dynamics in these sites is far from complete. In particular, the effect of density contrast between the confluent streams on mixing has traditionally been neglected, which has been justified by differences in the inertia of the confluent flows being much higher than density differences. However, as the scale of the confluent channels increases, the probability of draining different geological terrains also increases which results in an increasing potential for significant differences in density.

In this work, we present results of a series of field experiments carried out in a confluence in Northern Spain where the presence of density contrasts is important for both the spatial arrangement of the rivers once at the confluence and river mixing. The confluence presents seasonal variations in the river density contrast, which ranges from O (10^{-2}) kg m^{-3} in winter to O (1) kg m^{-3} during summer. Depending on the river density contrast the confluent rivers flow side by side or one on top of the other. Through the use of three-dimensional numerical experiments, we illustrate that, despite being negligible from a dynamic point of view, the weak density contrasts observed in winter are able to distort the mixing layer between the rivers. This distortion changes the contact area available for mixing, and ultimately affects mixing rates. Numerical experiments are also presented for the strong density contrasts observed in summer, when the confluence is vertically stratified. We assess the factors controlling the

location of the plunging zone and mixing rates. In particular, we focus on the interaction between inertial and buoyancy forces, the effect of wind forcing and the unsteady nature of the hydraulic forcing. It is shown that the steady-state location of the plunge zone is controlled by an inertia-buoyancy balance, which accounts for the relative magnitude of the buoyancy forcing associated with river density differences, and the magnitudes of both the main-stream and the tributary inertia. This has important consequences for river mixing since mixing rates increase as the plunging occurs at the confluence due to a combination of large mixing-interface surfaces and high diffusivities. Wind forcing, depending on its velocity and direction is able to affect mixing rates at this confluence through (1) altering the buoyancy-inertia equilibrium, (2) altering the patter of secondary circulation within the confluence and/or (3) increasing shear at the confluence. This work further shows that there is a time lag between a change in the equilibrium conditions of the inflows and the system response (movement of the plunge point) to this change.

River junctions where water may follow two or more alternative pathways (diffluences) are also critical points in river networks where aquatic migratory species select different migration routes. This is the case, for example, of the juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin River Delta. This work also presents preliminary results on a reach of the Sacramento River where juveniles may remain in the main Sacramento River or select other two migration routes that lead to the interior of the delta, where salmon survival is known to decrease. This river reach is affected by the tides, with flow reversal occurring during flood tides; and the entrances to the two migration routes that lead to the interior of the delta are located at the outside of a river bend, where secondary circulation is known to occur. Our results are consistent with previous studies that show that during the flood tide almost all the flow, and thus, all the salmon, are directed to the interior of the delta through these two migration routes. This work also suggests that, during ebb tides, fish entrainment rates into the interior of the delta are higher than those expected by flow entrainment alone due to the preference of salmon for migrating near surface (first four meters of the water column in the Sacramento River), together with the effect of secondary circulation that pushes the surface-biased salmon towards the outside of the bend where the entrance of these two migration routes are located.

CV

(March 2016)

Ph.D. Earth Sciences, Universidad de Granada, 2016

M.S. Environmental Management of Aquatic Systems, Universidad de Cantabria, 2011

Degree in Environmental Sciences, Universidad de Granada, 2009

Publications

Submitted:

Ramón, C. L., J. Prats and F.J. Rueda, The influence of flow inertia, buoyancy, wind, and flow unsteadiness on mixing at the asymmetrical confluence of two large rivers, under review in Journal of Hydrology.

Catalá, T. S., I. Reche, **C.L. Ramón**, Á. López-Sanzc, E. Calvo, X. A. Álvarez-Salgado, Chromophoric signatures of long-lived microbial by-products in the dark ocean, under review in Geophysical Research letters.

Published:

Ramón, C.L., J. Prats, F. Rueda (2015), Simulation of turbulent flows in river confluences and meandering channels with a Cartesian 3D free surface hydrodynamic model, *International Journal of Computational Methods*, 12(6), 1550035, doi:10.1142/S0219876215500358

Acosta, M., M. Anguita , F. J. Fernández-Baldomero, **C. L. Ramón**, S. G. Schladow and F. J. Rueda (2015), Evaluation of a nested-grid implementation for 3D finite-difference semi-implicit hydrodynamic models, *Environmental Modelling and Software*, 64:241-262, doi:10.1016/j.envsoft.2014.10.015

Ramón, C.L., A. Cortés, F. J. Rueda (2015), Inflow-outflow boundary conditions along arbitrary directions in Cartesian lake models, *Computers & Geosciences*, 74: 87-96, doi:10.1016/j.cageo.2014.10.002.

Ramón, C.L., J. Armengol, J. Dolz, J. Prats and F.J. Rueda (2014), Mixing dynamics at the confluence of two large rivers undergoing weak density variations, *Journal of Geophysical Research – Oceans*, 119, doi:10.1002/2013JC009488.

Ramón, C.L., A.B. Hoyer, J. Armengol, J. Dolz and F.J. Rueda (2013), Mixing and circulation at the confluence of two rivers entering a meandering reservoir, *Water Resour. Res.*, 49: 1-17, doi:10.1002/wrcr.20131.

Scientific Meetings

February 22-27, 2015. Granada (Spain)	2015 ASLO Aquatic Sciences Meeting: Global and regional perspectives – North meets South	*Spatial distribution of inflowing rivers and mechanisms inducing mixing at the confluence of two large rivers subject to vertical stratification* (Poster). <u>Authors</u>: Ramón, C, Dolz, J, Armengol, J and Rueda, F
June 27-July 1, 2011. Girona (Spain)	7th Symposium for European Freshwater Sciences	*Circulation and mixing at the confluence of two rivers entering a meandering reservoir* (Poster). <u>Authors</u>: Ramón, C, Dolz, J, Armengol, J and Rueda, F
June 13-17, 2011. Granada (Spain)	2nd IWA Symposium on Lake and Reservoir Management: Sustainable Approaches to enhance Water Quality	*Circulation and mixing at the confluence of two rivers entering a meandering reservoir* (Poster). <u>Authors</u>: Ramón, C, Dolz, J, Armengol, J and Rueda, F

Grants and International Research Stays

2011-2016: PhD grant from the Spanish Government: *Programa Estatal de Promoción del Talento y su Empleabilidad. Subprograma de Formación de Profesorado Universitario (FPU).*

September 4-December 22, 2013. International research stay: United States Geological Survey (USGS), Sacramento, CA, USA. <u>Supervisor</u>: Jon Burau.

May 17-August 17, 2014. International research stay: University of Illinois in Champaign Urbana, Department of Geography and GIScience, Champaign, IL, USA. Funded by the Spanish Government *(Ayudas para estancias breves en otros centros españoles y extranjeros*, BOE-A-2014-2814). <u>Supervisor</u>: Bruce Rhoads