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# Secondary currents: Measurement and analysis

GASTÓN A. PRIEGO-HERNÁNDEZ
*División Académica de Ciencias Básicas, Universidad Juárez Autónoma de Tabasco,*
*carretera Cunduacán-Jalpa de Méndez, km 1, Col. La Esmeralda, 86690 Cunduacán,*
*Tabasco, México*

FABIÁN RIVERA-TREJO
*División Académica de Ingeniería y Arquitectura, Universidad Juárez Autónoma de Tabasco,*
*carretera Cunduacán-Jalpa de Méndez, km 1, Col. La Esmeralda, 86690 Cunduacán,*
*Tabasco, México*
Corresponding author; email: jgfabianrivera@gmail.com

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## RESUMEN

La dinámica de fluidos tiene como propósito entender el movimiento de líquidos y gases por medio de funciones que describen la distribución de velocidades. Algunos fenómenos naturales que presentan estas funciones son los huracanes, los cuales son generados por las diferencias de presión; los ciclones, cuya fuente primaria de energía es el gradiente horizontal de temperatura, y los remolinos, que están ligados al gradiente de presión hidrostático. En el caso particular de los remolinos, éstos generan velocidades secundarias, las cuales son flujos que se forman por la existencia de fuerzas desiguales entre el gradiente de presión hidrostático y las fuerzas centrífugas, o debido a esfuerzos cortantes tal como sucede en la unión de dos o más flujos. Este fenómeno también se observa en tornados, donde la fuerza centrífuga es mayor en la parte superior y luego va disminuyendo hacia el fondo, mientras que en los ríos se detecta particularmente en curvas y uniones (confluencias). Entender cómo se desarrollan estas velocidades secundarias es de interés, debido a que el comportamiento de los flujos está en función de la magnitud de dichas velocidades, de modo que su caracterización es fundamental. El objetivo de este estudio fue estimar las velocidades secundarias en la unión de dos ríos, a partir de mediciones de campo realizadas con medidores acústicos Doppler. Un segundo objetivo fue graficar las velocidades secundarias y, en consecuencia, apreciar las líneas de corriente y los mecanismos de rotación de flujo. Estos mecanismos están relacionados con los procesos de erosión y sedimentación, por lo que su entendimiento ayudará a pronosticar cambios morfológicos en los ríos.

## ABSTRACT

Fluid dynamics has the purpose of understanding the movement of liquids and gases by functions that describe the distribution of velocities. Some natural phenomena that present these functions are hurricanes, generated by pressure differences; cyclones, developed by the horizontal temperature gradient; and eddies, associated with a hydrostatic pressure gradient. In the particular case of eddies, they generate the so-called secondary velocities, which are flows formed by the presence of unequal forces between a hydrostatic pressure gradient and centrifugal forces, or by shear stresses at the joining of two flows. In addition, this phenomenon is observed in tornados, where the centrifugal force is greater in the upper layer and decreases towards the bottom, whereas the pressure gradient moves from a high to a low pressure; while in rivers it is detected particularly in bends or joins. Understanding the development of secondary currents is important for the reason that flow behavior is a function of the magnitude of these currents; hence their characterization is fundamental. The objective of this study was to obtain the secondary velocities developed as an effect of the union of two water currents, based on data acquired from Doppler acoustic recorders. A second objective was to draw the secondary velocities and to show the rotation flow effect, a kind of results that are difficult to obtain in any other way. The flow mechanisms are related with erosion and sedimentation processes; therefore, understanding them might help to evaluate and predict morphological changes in rivers.

**Keywords:** Flow structure, ADCP, velocity field.

## 1. Introduction

Unequal forces generate velocity components on a direction transverse to the flow, which produces a circulation named secondary current. This flow, coupled with the longitudinal movement, causes a helical flow that forms or models the section into the curves (Perkins, 1970). Furthermore, it is stated that it is not possible to reach an adequate description of the flow in curves or shallow water from one-dimensional models and even from classical two-dimensional models, such as the Saint-Venant equations, due to the essentially three-dimensional nature of the flow (Weber, 2007). Given these facts, a better understanding of hydrodynamics presented in curves and junctions, characterized mainly by the secondary flow, is necessary. The velocity on these areas is not uniformly distributed (Odgaard, 1982); rather, it is logarithmic due to the flow resistance produced by the bottom when turning on the same radius.

Hydrometric windlasses are used in traditional measurements of currents in channels (Priego *et al*., 2012); however, these are only able to measure the magnitude of the velocity vector in the main flow direction. In recent years, in order to experimentally characterize the velocity field and flow discharge in river environments, acoustic Doppler current profilers (ADCP) have been developed. However, its use in Mexico is still incipient, mainly due to lack of knowledge about its use and capabilities. In most of the documented cases, its use in Mexico is limited for flow measurement purposes, which results in high costs since these devices are expensive and require skilled personnel for its operation. These devices base their functioning on sound, in order to measure the particles suspended in water and obtain velocity compounds of the flow in three directions. From this kind of data and applying the Rozovskii development (1957), it is possible to estimate the secondary currents through the following equation:

$$\frac{v^2}{r} = gS_r + \frac{1}{\rho}\frac{\partial \tau_r}{\partial z} = 0 \tag{1}$$

where $v$ is the velocity, $\rho$ is the water density, $r$ the curvature radius, $S_r$ the cross slope, $\tau_r$ the transverse shear force, and $g$ the acceleration of gravity. The first term in Eq. (1) is the centrifugal acceleration, the second is related to the slope of water on a transverse surface, and the third is the turbulent shear force.

Rozovskii (1957) and Kikkawa *et al*. (1976) indicated that the magnitude of the secondary flow is directly related to the water depth for the curvature's radius and the vertical profiles of transverse velocity, which vary significantly with the flow resistance of the bottom. However, secondary currents in the confluences are characterized by complex hydrodynamic conditions and which knowledge is essential for the development of a general theory; however, at present few field data are available (Best, 1987; Bridge, 1993; Weerakoon *et al*., 1991). Some conceptual models, based on experimental work (Lane *et al*., 1998; Roberts, 2004; Song *et al*., 2012) indicated that the hydrodynamic characteristics of the confluences include an area of stagnant flow upstream, which generates a shear layer or section (abrupt change on direction of velocities) between the junction of the two flows. The surface of this convergence generates a helical cell on each side of the shear layer, and flow separation occurs immediately downstream of the confluence (Mosley, 1976; Best, 1987).

Rozovskii (1957) and Bathurst *et al*. (1977) used electromagnetic flow meters in determining the transverse and longitudinal components of the velocity vector. Other authors such as Rhoads and Kenworthy (1995) proposed to identify separately the contributions of the uneven flow and the helical motion for the velocity field of cross currents; as a first approximation, primary and secondary velocities were calculated, and the components of the cross currents were determined.

Primary ($v_p$) and secondary ($v_s$) velocities, defined by Bathurst *et al*. (1977) were the components of the resulting velocity ($v_r$) at some depth on the flow column (Fig. 1), which was oriented in a direction