SECONDARY CURRENTS AND FLOW VARIABILITY IN STRAIGHT OPEN CHANNELS: IMPLICATIONS FOR STREAM RESTORATION PROJECTS

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One of the major objectives when restoring a channelized stream is to induce variability in the flow patterns. The idea behind it is that geomorphological variability will induce hydrodynamic variability, which in turn will promote ecological diversity. If a restoration of a channelized stream is to be carried out focusing on the addition of variability in the flow patterns, it seems logical to start with the quantification of the "background" variability. The research presented herein has been motivated by the restoration of the West Fork of the North Branch of the Chicago River (WFNBCR) at Northbrook, an urban channelized stream of northeastern Illinois. The restoration of the fork included pool-riffle structures, which were designed based on the results of laboratory experiments. The laboratory experiments included different pool-riffle designs as well as a flat bed configuration (Rodríguez et al., 2003). This paper presents the results of the flat bed experiments, which correspond to the pre-restoration conditions (i.e. the degraded stream).

A tilting flume 12.20 m long, 0.91m wide and 0.6 m high was used for the experiments. 3D Velocities were measured using an Acoustic Doppler Velocimeter on one half of the channel cross section, every 5 cm and 1 cm in the transverse and vertical directions, respectively. Two flow conditions were tested, with discharges of 0.04 and 0.12 m^3/s. The low and high discharges resulted from converting to a 1/7 Froude scale the one-year and two-year return period floods for the WFNBCR at Northbrook, respectively.

The results show that both inner and outer velocity laws provide a good collapse of the measured streamwise velocities, confirming that the data corresponds to the equilibrium region. The shear stress distribution presents an oscillating pattern in agreement with Ikeda (1981). A simplified model for secondary circulation in straight channels (Ikeda, 1981) accurately predicts the observed recirculation patterns (Fig. 1), particularly in the regions away from the lateral walls. Secondary circulation cells scale with the cross-sectional flow depth, resulting in 6 cells for the low flow and 4 cells for the high flow. The cells stretch slightly in the spanwise direction so that the lateral distance between two consecutive cells is 1 to 1.5 times the flow depth h. The secondary flow affects the vertical transfer of momentum and thus the principal velocity distribution. Cores of high streamwise velocity are located in the downwelling zones between cells. Bed shear stress patterns are in total synchronicity with the 3D velocity distribution, with higher and lower values coinciding respectively with regions of flow downwelling and upwelling.

The picture is completed with the analysis of the turbulence data. Semi-empirical equations for 2D equilibrium layers (Nezu and Nakagawa, 1993) agree with observations of streamwise Reynolds stresses, eddy viscosity, and turbulence intensities. In addition, the simplified model for turbulence anisotropy used by Ikeda (1981) provides a good approximation to the measured data (Fig.2).

There is a substantial variability in the flow patterns, manifested in the form of streamwise velocities with cores up to 10% faster than the surrounding flow and secondary currents that are cellular and of the order of 5% of the mean streamwise velocity. Turbulence anisotropy at the bed and walls is the main mechanism for the generation of secondary currents. The secondary flow redistributes momentum, the downflows transporting high momentum fluid towards the bottom resulting in an increase in the bed shear stresses while the upflows transport momentum away from the bottom reducing the bed shear stresses. These variations in the bed shear stress are of the order of 20% of the cross sectional averaged value.

The present results are applicable to channelized urban streams, and constitute the baseline for further investigations on artificially-induced secondary currents and flow variability in stream restoration projects.

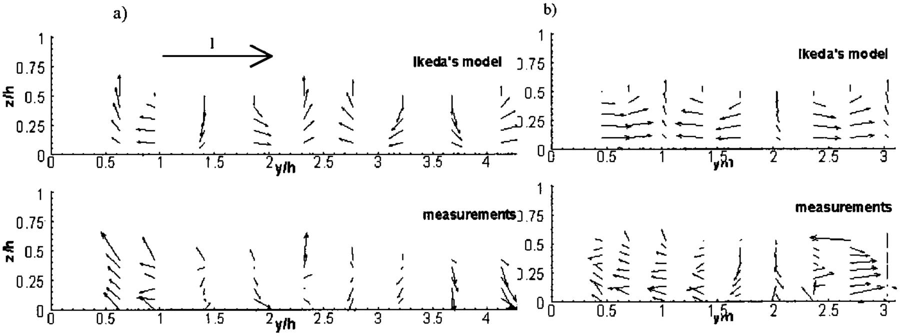

Fig. 4 Secondary currents divided by $<U_*>$: a) low flow, b) high flow.

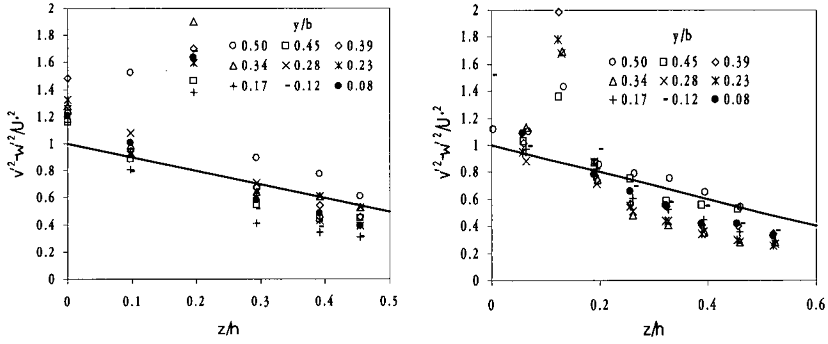

Fig. 10 Dimensionless turbulence anisotropy for: a) low flow, b) high flow.

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