Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Modelling overbank flow structures in doubly meandering channels

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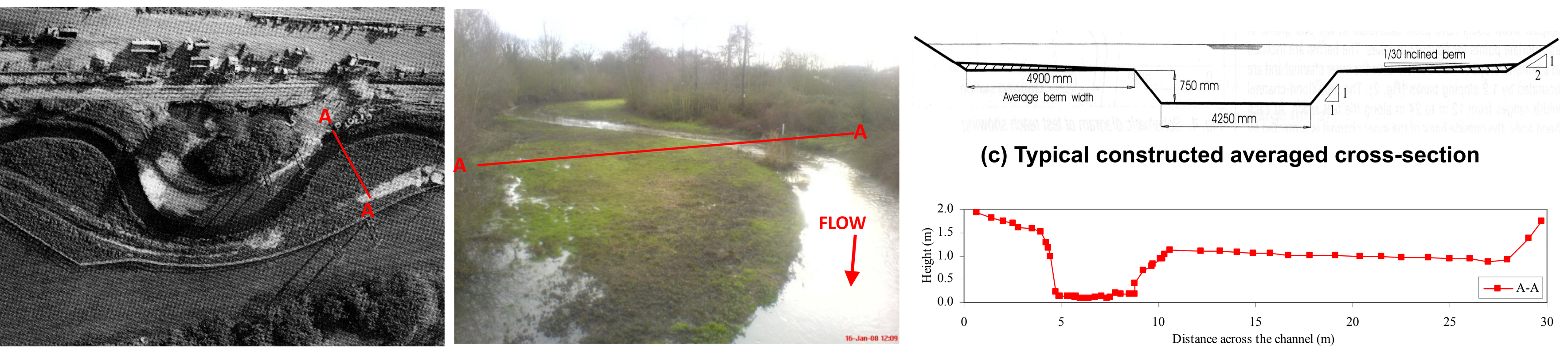
INTRODUCTION

Overbank flow in a meandering channel displays a complex coherent flow structure resulting from the interplay between the floodplain flow and the main channel flow. Modelling such coherent flow structures is of great importance for addressing river engineering and management issues. As a consequence of the construction of a major road bypass during 1993-94, a length of the River Blackwater near Farnborough, UK was reconstructed as a doubly meandering two-stage channel which was designed to provide a more environmentally sustainable basis for future river-channel restoration projects (Figure 1). A recent field survey shows that the main channel is no longer trapezoidal nor does the floodplain berm have an inclination of 1 in 30 towards the main channel as constructed (Figure 1). It is important to predict and understand the coherent flow structures in the river during floods in order to explain these topographical changes. The main aim of this research work is to predict and investigate the flow behaviour in the 1:5 scale physical model of the River Blackwater using a three-dimensional (3D) finite volume model in order to understand the flow phenomena occurring in the natural situation.

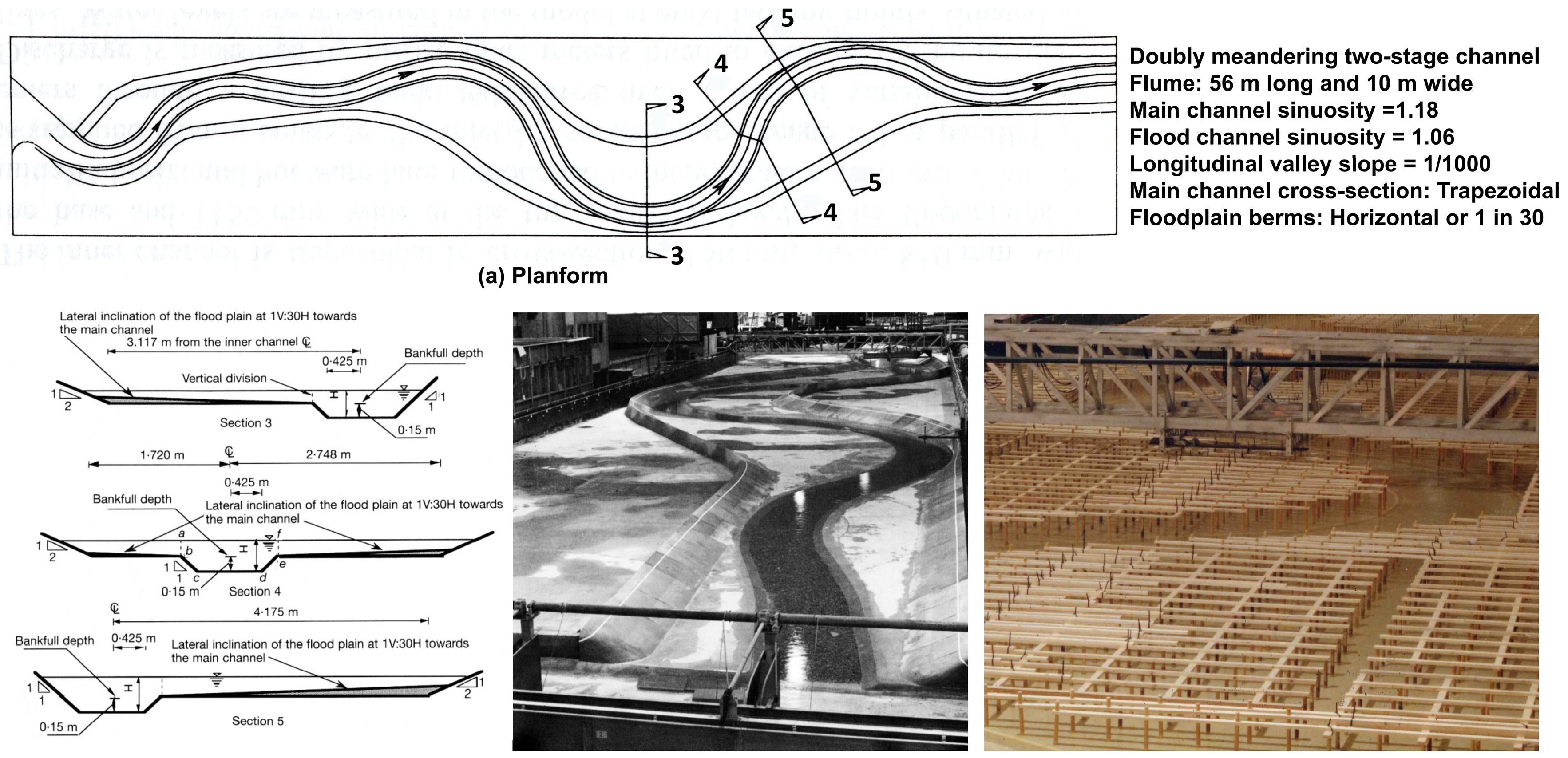


(a) Aerial view of the River Blackwater (b) Recent view of the River Blackwater (c) Typical constructed averaged cross-section (d) Recent surveyed cross-section A-A

Figure 1 River Blackwater

1:5 SCALE RIVER BLACKWATER MODEL

The undistorted 1:5 scale model of the River Blackwater was constructed in the 56 m long and 10 m wide UK Flood Channel Facility flume, as shown in Figure 2 (Lambert and Sellin, 1996). Experiments were carried out with different roughness conditions to represent the natural situation during floods (Figure 3). The roughened main channel and floodplain surfaces were obtained by placing a layer of gravel on the channel surfaces. The floodplains were either horizontal or at an inclination of 1 in 30 (Figure 2). The non-managed floodplain was represented in the physical model by vertical rods (diameter=25 mm) placed in a triangular array of 60 degrees. It was designed to have a density of 12 rods per m^2 with the spacing between rods about 300 mm.



(b) Cross-sections looking from downstream (c) 1:5 scale physical model (d) Roughened floodplain with rods

Figure 2 The River Blackwater 1:5 scale physical model

(a) Flooded channel (b) Managed floodplain (c) Non-managed floodplain

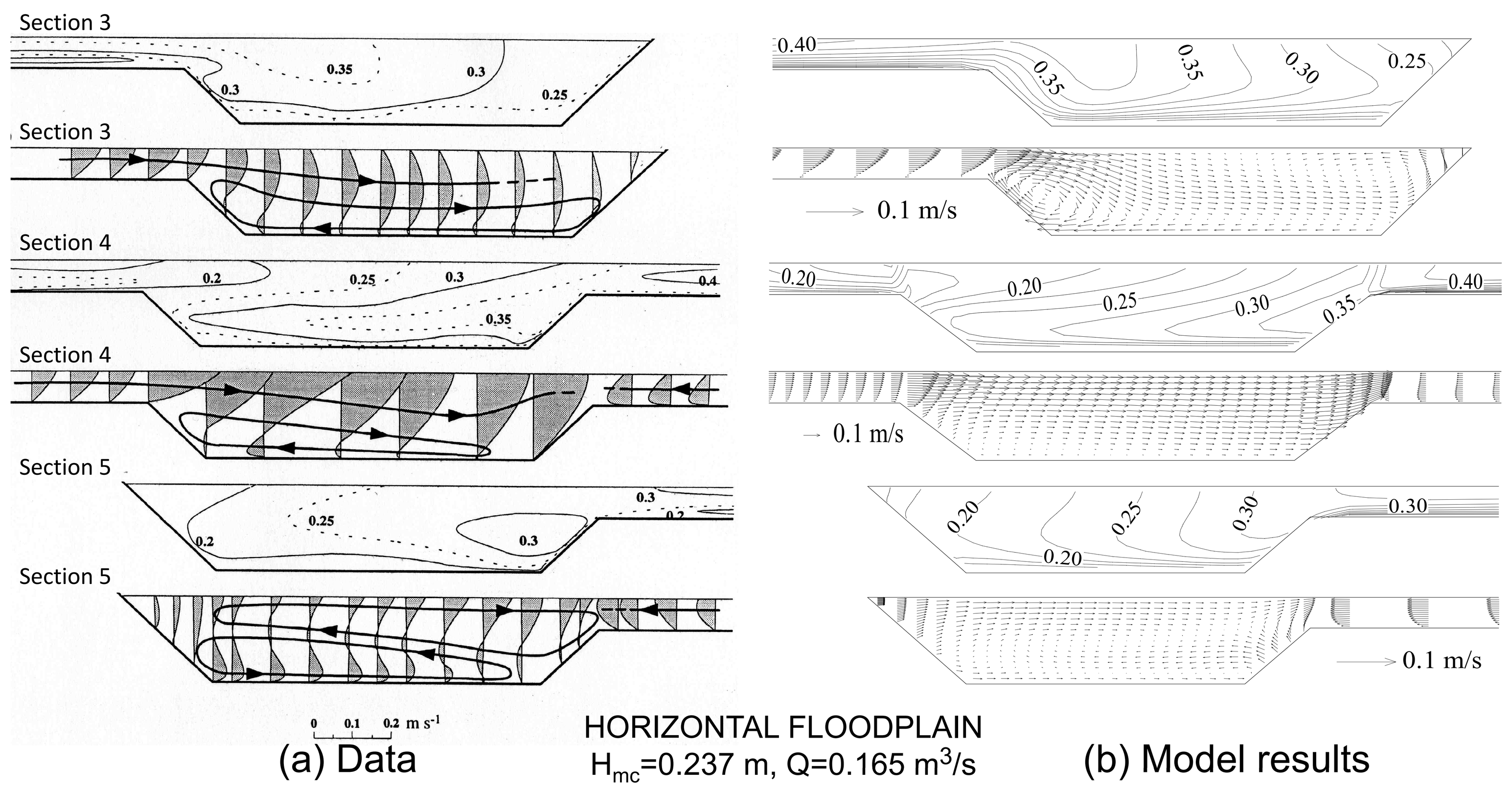
Figure 3 Flooding and floodplain management

MODEL EQUATIONS

In the non-vegetated floodplain cases, the flow fields are modelled using the Reynolds-averaged (i.e. time-averaged) continuity and Navier-Stokes equations (RANS). For the vegetated floodplain case, an alternative model, based on the double-averaging methodology (i.e. double-averaged continuity and Navier-Stokes equations - DANS), which includes drag terms, form-induced momentum fluxes, blockage (porosity) and turbulence effects due to individual roughness elements on the floodplain, is implemented (de Lemos, 2006; Nikora *et al.*, 2007; Rameshwaran and Naden, 2011).

MODEL RESULTS

The comparison plots in Figure 4 show that the model reproduces the main channel streamwise velocity distributions and secondary flow patterns reasonably well. Figures 5 and 6 show that floodplain inclination generally increases the bed shear stress magnitudes in the main channel as a result of the higher velocity. On the floodplain, bed shear stress magnitudes are higher (i.e. higher erosion region) where the main channel flow enters onto the floodplain berms in both cases without rods. For the inclined floodplain with rods, the bed shear stress magnitudes are considerably reduced on the floodplain compared to the other cases due to the slower velocity on floodplain. Figure 6 shows that in the inclined floodplain cases, the flow tends to follow the berm contours along the floodplain wall. Here the maximum water surface velocity regions are located on the inner side of the main channel and at the downstream side of floodplain berms as expected. In the horizontal floodplain case, where the floodplain flow enters the main channel and the main channel flow expels onto the floodplain can be clearly seen from the changes in velocity magnitude between the main channel and the floodplain. For the inclined floodplain with rods, the flow magnitudes are considerably reduced on the floodplain and conveyance is reduced due to blockage. In the horizontal floodplain case, the maximum velocity streamlines are situated in the right-hand floodplain bank region due to the expelling flow from the main channel from the previous bend. This behaviour is also reflected in the bed shear stress prediction. This behaviour is shown schematically in Figure 7.



(a) Data (b) Model results

Figure 4 Comparison of streamwise velocity and secondary flow field

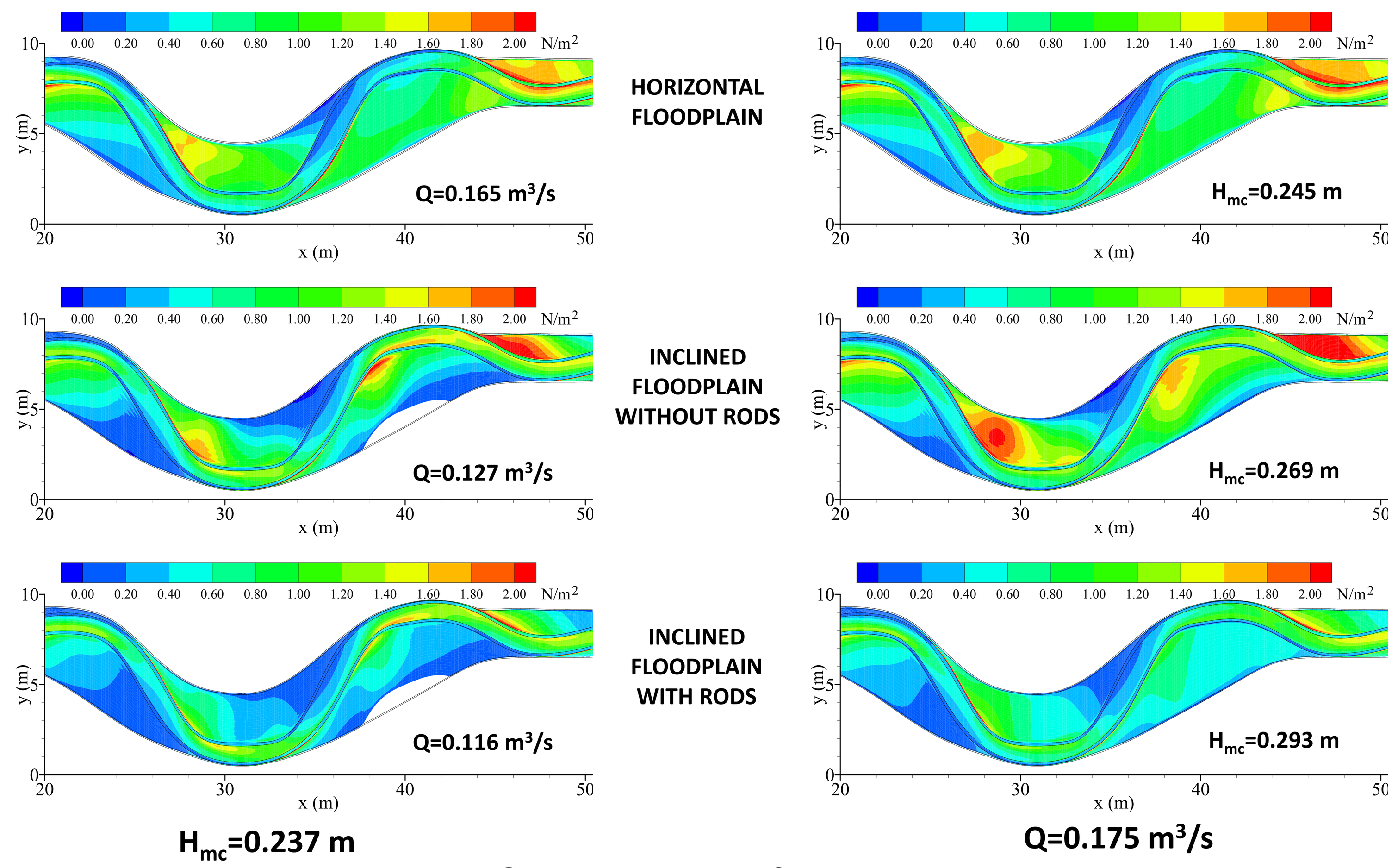


Figure 5 Comparison of bed shear stress

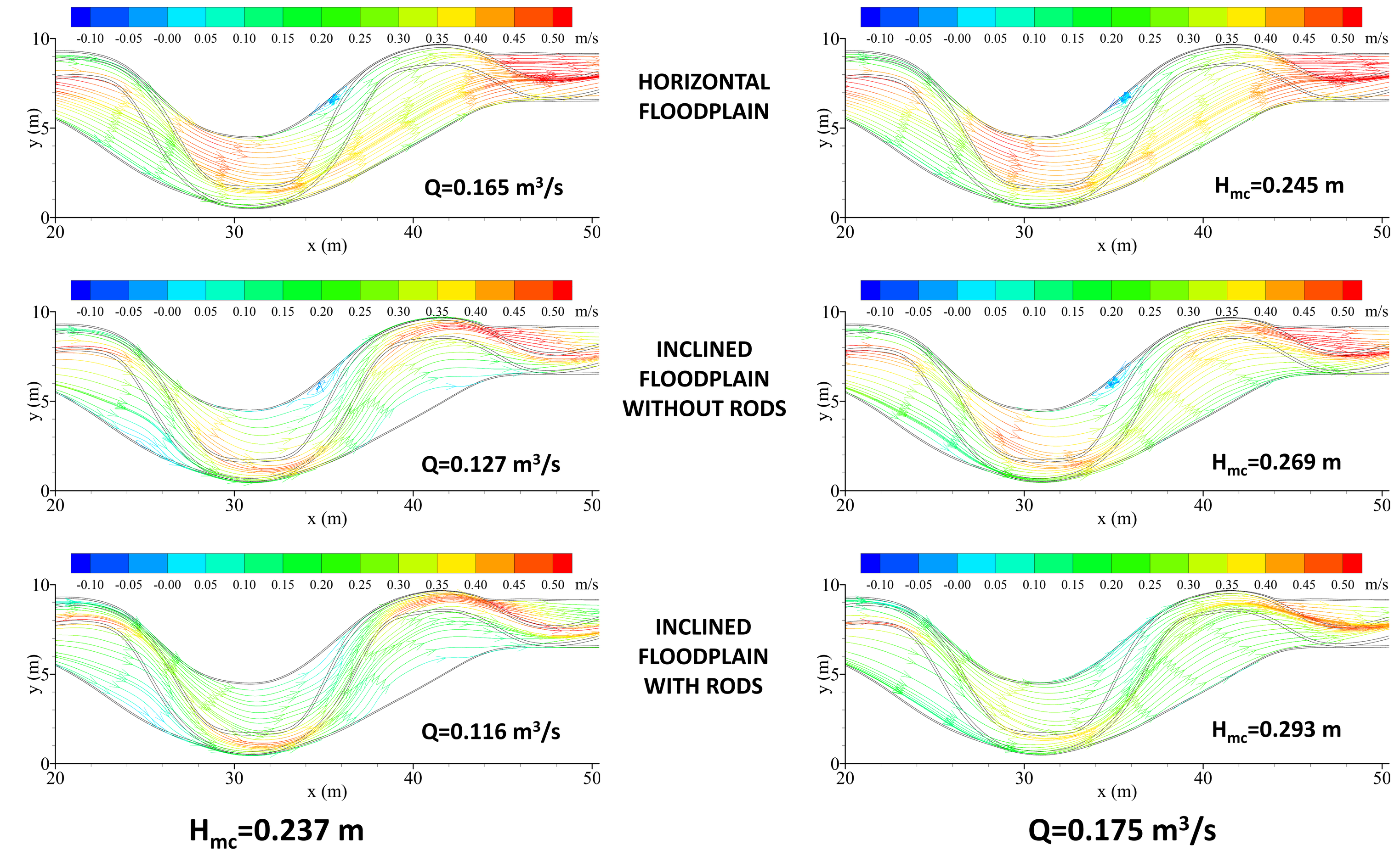


Figure 6 Comparison of flow patterns at water surface

CONCLUSIONS

The complex coherent flow structures modelled for the doubly meandering two-stage channel of the River Blackwater have been shown to vary with both floodplain topography and roughness. For highly managed floodplains (low roughness), the coherent flow behaviour may be used to explain recent topographic changes. With regard to future management, understanding the effect of vegetation on coherent flow structures is important for both flood risk and topographic change.

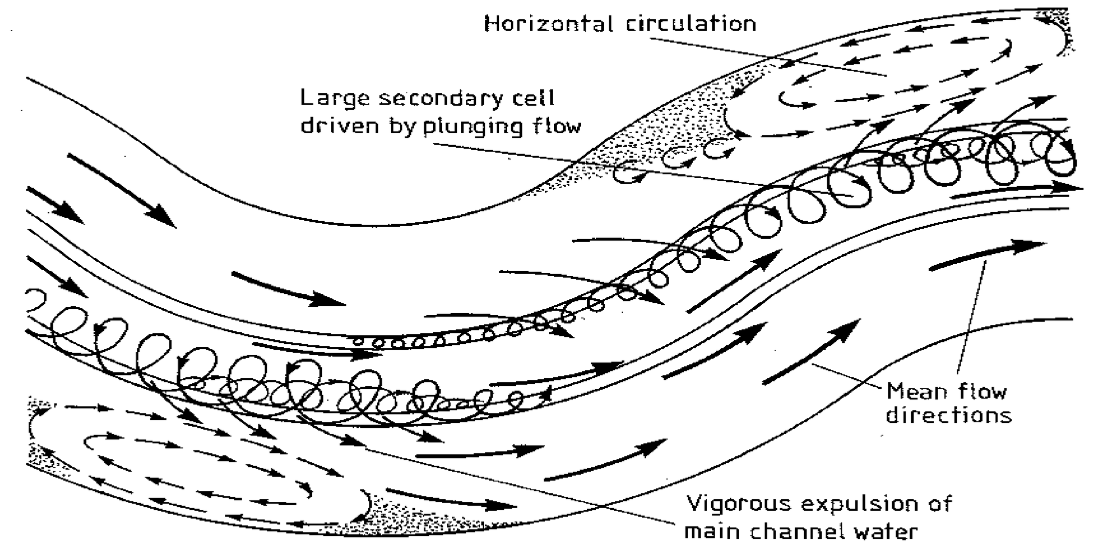


Figure 7 Coherent flow structures within a doubly meandering two-stage channel

REFERENCES

de Lemos, M. J. S. (2006) *Turbulence in porous media: Modeling and applications*, 335pp.
Lambert M.F. & Sellin R.H.J. (1996) *P I Civil Eng-water*, 118, 10-20.
Nikora, V., McEwan, I., McLean, S., Coleman, S., Pokrajac, D. & Walters, R. (2007) *J Hydraul Eng.*, 33, 873-883.
Rameshwaran, P., Naden, P. S. & Lawless, M. (2011) *Earth Surf. Proc. Land.*, 1350–1366.

WHY: Should we need to predict coherent flow structures behaviour and understand flow processes in rivers during floods?

BECAUSE: It is of great importance for predicting flood conveyance, the effect of floodplain management and topographic change.

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