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AN INTEGRATED AND NOVEL APPROACH TO ESTIMATING THE CONVEYANCE CAPACITY OF THE RIVER BLACKWATER

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ABSTRACT

This paper presents a number of complex issues associated with the methodology and preliminary analysis of velocity and discharge measurements using various techniques applied to the River Blackwater, UK. An ADCP deployment procedure was adapted in order to take into account the difficulties of using such equipment in small rivers. The velocity profile in the middle of main channel has been measured using both ADCP and ADV, and averaged over a time scale of 800 s and 300 s respectively, to obtain a stable value. A discrepancy of approximately 6.8% was observed in the mean streamwise velocity between both measurements. A good agreement between surface velocity measurements using PIV and ADCP in cross-sections located in straight and meandering reaches of the river was observed. Finally, several numerical models have been benchmarked against a physical scale model of the river.

Keywords: acoustic techniques; comparative studies; flow measurements; rivers

1. INTRODUCTION

This paper presents the initial findings of a three year research project whose overarching aim is to examine the feasibility of using novel, image-based systems in order to obtain a reliable estimation of the discharge within a 300 m reach of a two-stage, double meandering channel of the River Blackwater, Hampshire, UK. To that end, a series of full-scale experiments has been undertaken in which various aspects of the flow have been recorded using a variety of measuring techniques: Particle Image Velocimetry (PIV), Digital Photogrammetry (DP), Acoustic Doppler Current Profiler (ADCP) and Acoustic Doppler Velocimeter (ADV). The data obtained from each of these measuring techniques have been combined in order to gain an insight into the 3-D nature of the flow during flood and non-flood conditions. In addition to the full-scale measurements, the project is also using data previously collected from a series of physical modelling experiments (1:5 scale) undertaken at the former UK Flood Channel Facility (Lambert and Sellin, 1996).

The full-scale and physical measurements are being complemented by an extensive numerical modelling campaign. This aspect of the project uses a variety numerical models of various dimensions to quantify these turbulent structures and ultimately to lead to an improvement in flood flow prediction. Three 3-D models (Delft3D, Phoenics and Telemac) and a quasi 2-D model (SKM) are to be used to simulate the flow and ultimately it is envisaged that the results obtained from at least one of these models will be used in conjunction with the measurements of the water surface in order to obtain an estimation of the conveyance of this particular stretch of the River Blackwater.

The project is still at its early stages and the results presented below are of a preliminary nature, but still sufficiently accurate to enable appropriate conclusions to be drawn. Section 2 of the paper contains a brief description of the 300 m reach of concern, while section 3 discusses a variety of issues relating to full-scale measurements. Section 4 presents a selected analysis of the data obtained to date, while section 5 presents initial results from the numerical modelling. Finally, section 6 presents a summary of the results obtained to date.

2. SITE DESCRIPTION

The full-scale experimental site is a 300 m reach of River Blackwater, Hampshire, UK which was altered and re-engineered as a double meandering two-stage channel (Figure 1) due to a major road construction nearby. The one-in-a-hundred year flood design capacity of the channel was 4.3 m^3/s, and the bank full capacity of the main channel was 1.5 m^3/s. The catchment area is approximately 35 km^2 and the hydrological response is considered as "flashy" as the upstream reach is dominated by an urban area. The catchment geology mainly consists of Bracklesham Beds Sandstone, overlain by patches of Barton Sands (Clarke et al., 2007).

The channel has been specifically designed to flood, with past records indicating that on average at least two events can be expected to occur each year. This channel has been extensively studied at a large model scale (1:5) (Lambert and Sellin, 1996) and as such an extensive database exists which enables comparisons with the full-scale data and initial calibrations of the numerical models. A plan view of the channel is shown in Figure 1 and illustrates the measurement locations which have been adopted for the current study. The measured cross-sections typically have a width of 4 m to 6 m. One of the benefits (and complexities) of undertaking full-scale work, is the ability to measure and comprehend the changes in surface roughness that occur over time (Figure 2). Such changes in vegetation have been shown to alter the bank full value of Manning's *n* from ~0.05 to ~0.25 (Sellin and van Beesten, 2004).

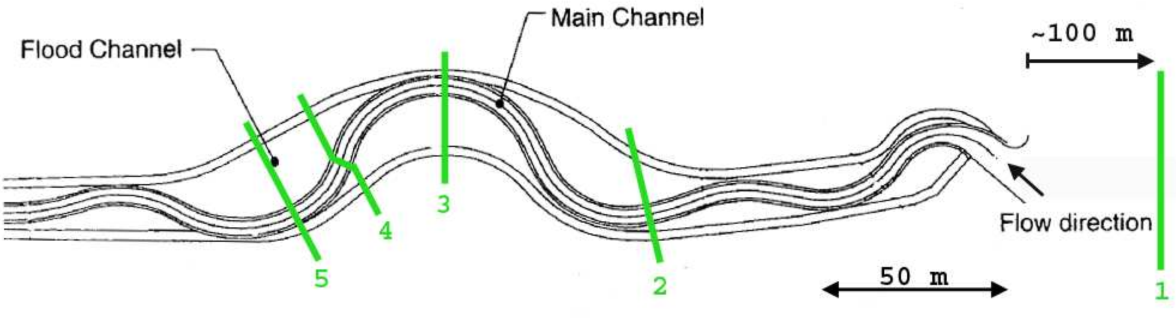

Figure 1. Plan view of the channel and model (adapted from Sellin and van Beesten, 2002)

Figure 2. A view of sections 4 and 5: (a) June 2007, (b) March 2007

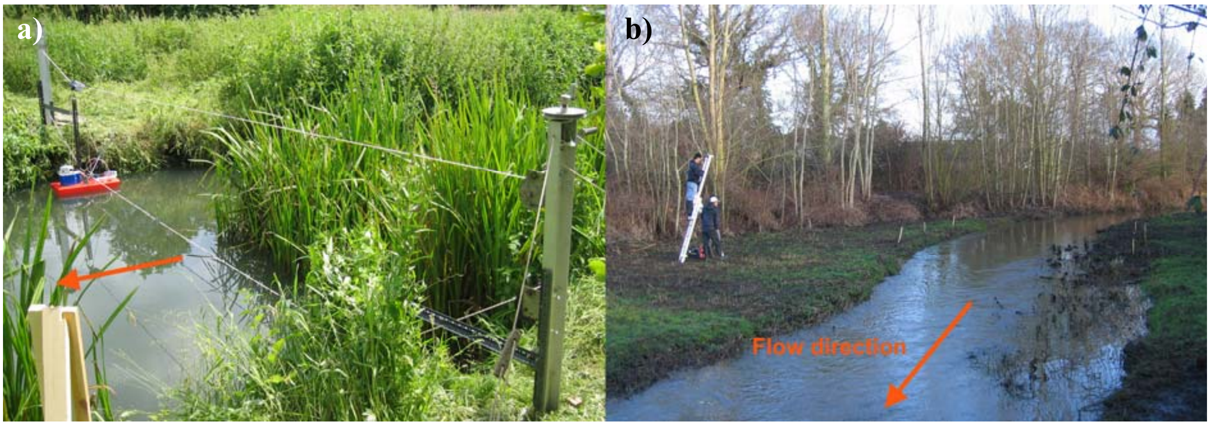

Figure 3. (a) ADCP measurement at section 2, June 2007, (b) PIV measurement at section 4, January 2008

3. DATA COLLECTION

At the beginning of the project (2007), ground levels and bathymetry of the study reach were collected using total stations. It is planned that an additional survey will be carried out at the end of the project to monitor changes of the levels and bathymetry during the course of the project. Comparison of the 2007 and 2002 original survey data shows that ground level changes are less than 0.1 m in more than 90% of the surveyed area. However, depositions of approximately 0.2 m have been observed in a large number of regions between riverbank and floodplain. The comparison above is only for ground level as bathymetry was not obtained during the 2002 survey. In order to obtain a rapid evaluation of the water surface slope, staff-gauges have been installed and levelled at several locations along the study reach.

Discharge and velocity data in the main channel have been measured using a four beams-pulse-to-pulse coherent acoustic Doppler current profiler (RD Instrument-ADCP Streampro). The ADCP has four transducers aligned in a Janus configuration which enable the collection of 3-D velocity data. The ADCP has been equipped with a 3-axis digital compass which provides heading data, for velocity vector transformation into other coordinate systems, and tilt data for further data quality assessment. In order to obtain reliable velocity statistics, two types of data collections, transverse (moving-vessel) and vertical (fixed-vessel) have been performed in the studied cross-sections. The transverse measurements are used to obtain instantaneous velocity and discharge data while vertical measurements are performed to obtain depth and time-averaged velocity profiles at various locations along a cross-section.

The data obtained from the transverse measurements effectively ensure that the velocity data are represented on a spatially distributed grid along the cross-sections. Since the ADCP allows only a total of 20 depth cells, the bin size during the transverse measurements was set to 0.05 m to ensure that all of the depth is covered in the measurements. The width of the cells in the same ensemble varies with respect to the transverse speed of the transverse measurement, i.e. the speed at which the ADCP catamaran traverses the river. However, in order to minimise such variations, on each occasion the ADCP was pulled across at a slow but constant speed (~0.1 m/s) which also minimised the possibility of air entrainment beneath the catamaran, which would result in loss of ensemble data. Furthermore such speeds enabled a reasonable grid resolution to be obtained. The transverse path of the ADCP was guided by a pre-tensioned rope across the channel to ensure that ADCP travels along a reasonably straight and consistent line (Figure 3a). This setup helped to ensure that the ADCP started and stopped its transverse at the same reference point during each run. In addition, Figure 3a also illustrates that the ends of the rope used to traverse the ADCP catamaran is connected to a rope via two rigid plastic limbs equipped with pulleys. The rigid limbs and the tensioned rope restrict the changes of bearing of the catamaran. The ADCP being used in the current work computes Doppler shift from 48 samples each second. However, the velocity of the ADCP catamaran used for each Doppler shift computation is recorded only six times per second (RD Instruments, personal communication). Thus, any rapid changes of the ADCP bearing and velocity add errors to the measurements. However, using the system outlined above keeps such errors to a minimum. Finally, a hinge installed in the connection between the limbs and ADCP catamaran allows the ADCP catamaran to rotate along its pitch axis, ensuring that ADCP position is relatively horizontal all the time.

Unfortunately the ADCP is not suitable for measuring the flow when the depth is small (typically less than 0.4 m in the studied reach) or where a significant amount of vegetation is present. Hence, in order to measure flows on the floodplain an ADV (Nortek 10 MHz Velocimeter) which samples every 0.04 s has been used during flood conditions. During the commissioning stage of the project, the ADV was used to measure the velocity at a selected number of points in the main channel in order to compare with data obtained from the ADCP. This comparison is discussed in section 4.

A high resolution camcorder (Sony DCR-TRV22 High8 Handycam) has been used to record the movement of seeded particles on the water surface. After a number of trial runs it was found that *biodegradable packing chips* represented a suitable seeding material. The data obtained from this camera were then being processed using PIV algorithm (Fujita et al. 1998) to obtain 2D velocity vector on the water surface. Permanent dGPS coordinated calibration markers were established on the edge of the floodplain banks in the scanned area, so that the inclined video image may be ortho-corrected to an appropriate horizontal datum using the post-processing software.

Finally, dynamic water surface elevations of the PIV-measured have been recorded using a pair of high resolution camera (Nikon D-80). The data obtained from the cameras enable a Digital Elevation Model (DEM) of the water surface to be derived by Digital Photogrammetry.

4. PRELIMINARY RESULTS AND DISCUSSION

At the time of writing a significant flood event has not occurred in the reach under consideration. However, sufficient data has been obtained in order to provide confidence in the approach adopted and to undertake preliminary benchmarking of the numerical models. In this section the ADCP data is compared to ADV and PIV data during a winter period (December 2007 and January 2008), when the growth of vegetation on the main channel was at a minimum.

As illustrated in Figures 2a and 3a, vegetation can be pronounced in the main channel of the River Blackwater (and other small rivers) during summer months. The left part of the main channel of cross-section 2 was covered by weeds on June 2007 (Figure 3a). In order to obtained reliable measurements, these weeds were physically removed. Four transverse measurements having discharge values within a 2.2% discrepancy to their mean discharge were interpolated to a fine grid (10 data points × 50 data points) over the width and depth of the cross-section using the Inverse Distance Weighting (IDW) method (Figure 4). In order to minimise the effect of random errors which may occur in the collection of the data, further averaging is required in order to obtain the finer detail of secondary flow cells (Szupiany et al., 2007). Bottom profiles of the transverse measurements have also been averaged using the IDW method and used as a reference for removing 6% data above river bed, the region where *sidelobe interference* might occur.

The averaging result shows that streamwise velocity is relatively high on the right part of the main channel while it decreases and changes direction on the left part of the main channel (Figure 4a). Two counter-rotating secondary flow cells having a maximum transverse velocity of 0.10 m/s (Figure 4b) can be seen on the right part of the main channel. The length of the velocity vectors help to indicate the magnitude of the secondary flow cells at these cross-sections. The secondary flow pattern in the left part of the main channel is less clear than the right-hand side. Streamwise velocity flowing to the opposite direction on the left part of the main channel may be caused by dense vegetation in this region. The *bottom track* of the individual transverse measurement was examined in order to examine if there was evidence of a *moving bed* but no such phenomenon was observed.

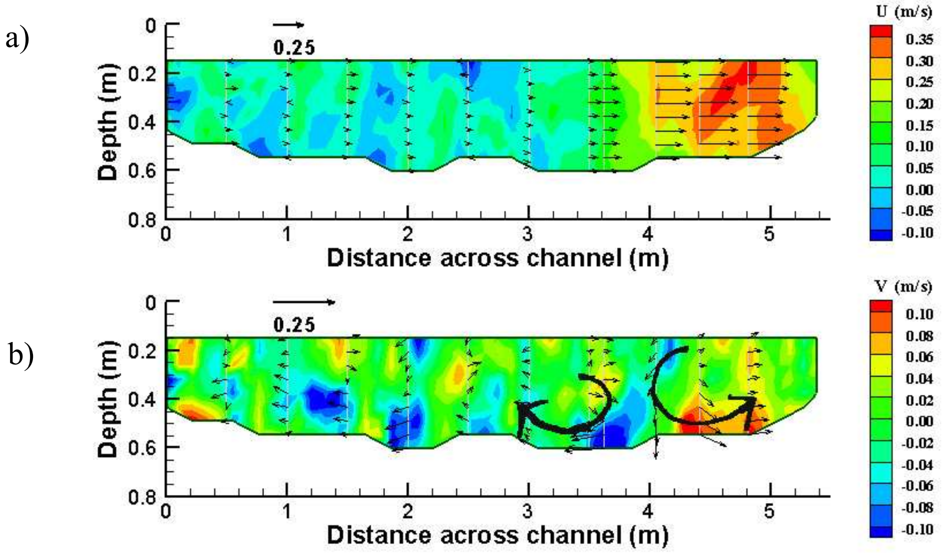

Figure 4. Velocity at section 2 (looking downstream): (a) streamwise velocity contour and vector, (b) lateral velocity contour and secondary flow velocity vector

Comparison of ADCP and PIV measurements

Velocity profiles were measured using ADCP and PIV at cross-sections 2 and 5 during a five-hour bankfull event in January 2008. ADCP data at 0.16 m below the surface is used in this comparison as flow data above that level could not be measured due to equipment limitations, e.g. blanking distance. Instantaneous velocity data from four ADCP transverse measurements and 300 s averaged ADCP velocity data at five vertical locations are presented along with 80 s averaged PIV data. Figure 5 shows the PIV velocity data along the ADCP paths at cross-sections 2 and 5, whereas Figure 6 shows the comparison of PIV surface velocity data and ADCP velocity data at 0.16 m below surface at cross-section 2 and 5. PIV velocity distribution has a tendency to decrease in the middle of the channel (Figure 5a & b) while some negative vectors are observed on the edges of the channel (Figure 5b). Both phenomena give an indication of a transverse shear layer and possibly suggest the existence of planform vortices, rotating anti-clockwise on the left part and clockwise on the right part of the main channel. Indication of the planform vortices is not observed on the ADCP data, which may be due to the ADCP boat reducing the extent of surface vortices in the location of measurements.

In general, the streamwise velocity measured by ADCP at the surface is larger than the streamwise velocity measured by the PIV in most part of the cross-sections. However, these differences are small and may be caused by a reduction in the discharge since both sets of measurements occurred at different times. The PIV measurements were undertaken approximately one hour after the ADCP measurement during which time the discharge was observed to decrease by approximately 10%. The relationship between PIV surface velocity and ADCP discharge will be further examined when more data become available.

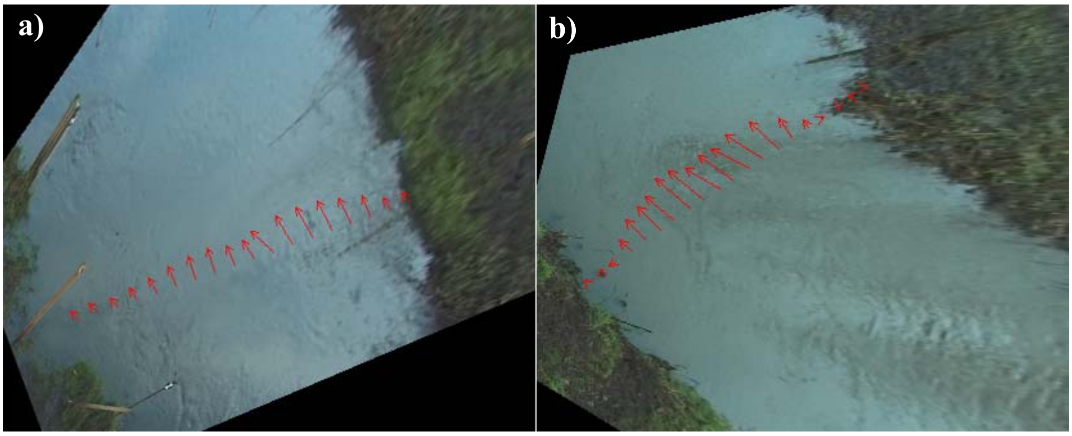

Figure 5. PIV velocity magnitude at cross-section 2 (a) and 5 (b)

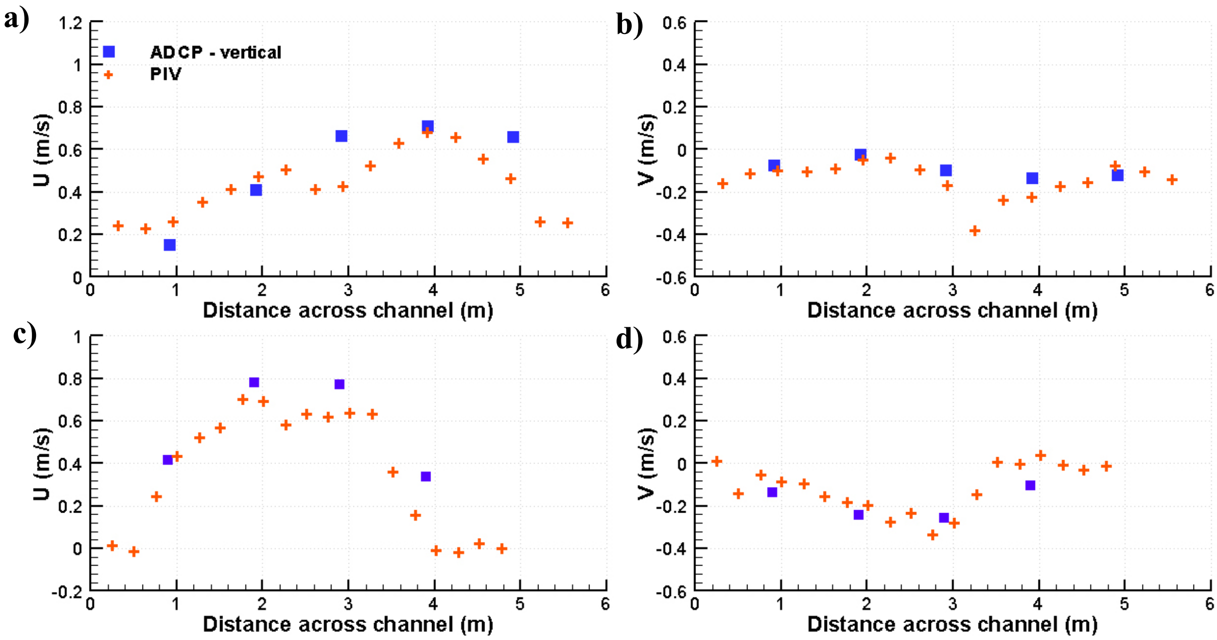

Figure 6. ADCP and PIV velocity magnitude at section 2 ((a) and (b)) and at section 5 ((c) and (d))

Comparison of ADCP and ADV measurements

Both the ADCP and ADV have been used to measure velocity in a location near the thalweg of cross-section 5 (see Figure 1) in December 2007. The ADCP measurements were conducted twice, before and after ADV measurements in order to monitor any changes in discharge. The measurements campaign lasted for 100 minutes. During this time, velocity data were collected using ADCP and ADV for 800 s and 300 s respectively (see Figure 7a). Analysis of previous measurements indicates that 200 s and 40 s data sampling are required by the ADCP and ADV respectively to obtain stable mean velocity and standard deviation. The results of the ADCP data indicated that on this occasion the discharge increased by 13 % during the measurement period from 0.775 m^3/s to 0.873 m^3/s. Hence, an increase in streamwise velocity between the first ADCP transverse, the ADV measurements and the second ADCP transverse can be observed (see Figure 7b). Figure 7b indicates that the maximum discrepancy in streamwise velocity between the first and second ADCP vertical measurements compared to the ADV measurements were approximately 10% and 7% respectively.

The depth-integrated streamwise velocity measured by ADCP underestimates the ADV measurement by 6.8% and overestimates by 5.1% for the first and second vertical respectively. These values are similar to those obtained by others in shallow rivers and laboratory experiments (Stone & Hotchkiss 2007, Nystrom et. al., 2007).

Similar trends are observed on the lateral (Figure 7c) and vertical (Figure 7d) velocity measurements although as expected the differences are less pronounced. In Figure 7c a positive value of velocity indicates a clockwise rotation of the flow, i.e. at the water surface the maximum velocity is of the order of 0.15 m/s resulting in an anticlockwise rotation. The lateral velocity component can be observed to be a function of depth, whereas the vertical velocity component appears to be depth invariant over the measured range.

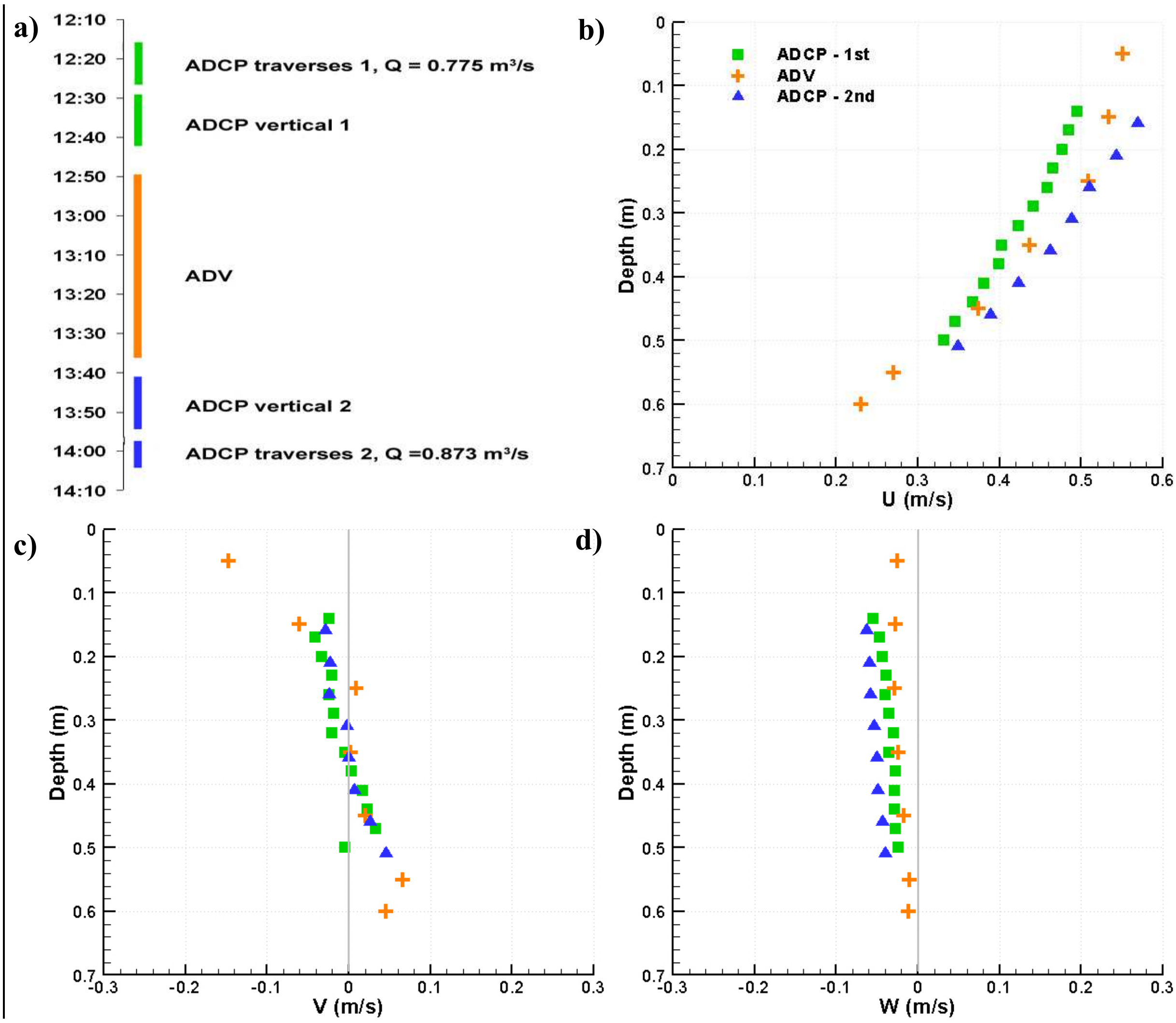

Figure 7. Comparison of ADV and ADCP data: (a) time allocation of measurements, (b) streamwise velocity, (c) lateral velocity, (d) vertical velocity

5. NUMERICAL MODELLING OF RIVER BLACKWATER

Initial numerical modelling of the physical model of the River Blackwater has been undertaken using Delft3D, Telemac and SKM and benchmarked against the measurement data obtained at laboratory scale by Lambert and Sellin (1996) (Figure 7). Simulations were performed for cross-sections 3 and 5, at water depth and discharge of 0.187 m. The main channel and floodplains were artificially roughened using gravel with a d_{50} of 8 mm . The experimental results together with initial modelling results are shown in Figure 8. While there is still a significant amount of work to be undertaken with respect to the development of the numerical models the initial results are encouraging. SKM appears to be capable of predicting the depth-averaged streamwise velocity across the main channel and floodplains reasonably well. Both Telemac and Delft 3D are capable of predicting the aforementioned distribution in the main channel to a reasonable degree. All three models predict the maximum value of the lateral distribution of the depth averaged streamwise velocity reasonably well. However, it must be stressed at this stage that such simulations have been undertaken using a variety of sweeping assumptions and have yet to redefined, i.e. it is expected that with a little effort a closer agreement between the physical data and the numerical simulations could be obtained.

Numerical simulation of the full-scale river for the data presented in section 4 using the models is currently ongoing. These simulation models will enable the internal flow structures based on velocity, water surface and vortex distributions to be reconstructed and enable physical insights to be made.

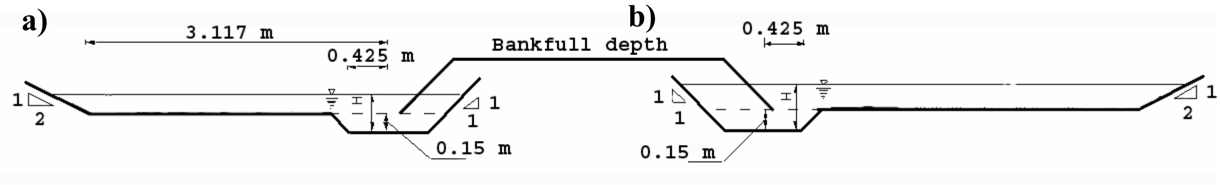

Figure 7. Geometry of the small-scale model at (a) section 3 and (b) section 5

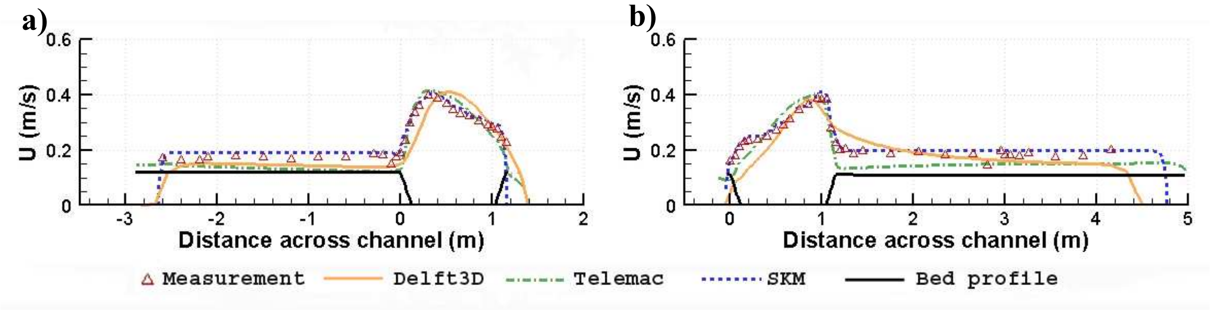

Figure 8. Measured and simulated streamwise velocity at: (a) section 3, (b) section 5

6. CONCLUSIONS

Various measurement techniques (PIV, DP, ADCP and ADV) have been used to record and examine complex turbulence flow in a two-stage channel. Numerical models of various dimensions have been benchmarked against large scale physical model of River Blackwater. The following conclusions could be drawn from this study:

a. Minimising the ADCP movements during vertical measurement is important since, due to the small width of the channel, any slight movement may result in a relatively large error with respect to the boat position. An adaptation has been made on the ADCP to improve this situation.
b. The existence of vegetation in the main channel adds further complexities to the secondary flow pattern and streamwise velocity distribution, both of which are difficult to explain.
c. Discrepancies of 19% and 10% were observed on the mean streamwise velocity measured by ADCP and PIV, with PIV appears to mostly under-measure the ADCP data, although it is suspected that this is related to changes in the discharge.
d. ADCP data have been benchmarked against ADV data, and good agreement in terms of mean velocity and a similar trend of both velocity distributions was observed. The discrepancy of mean streamwise velocity between both measurements is within the range observed by others (Stone and Hotchkiss, 2007, Nystrom et al., 2007).

Further analysis on measurement data and full-scale modelling of the River Blackwater are currently ongoing. More measurements campaigns will be carried out until the end of the project (2009) with a view to obtaining more data (especially flood data) that will lead to more understanding on the conveyance in compound channel.

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REFERENCES

Clarke, A., Hughes, T., Hensler, A., Jenkin, P. (2007), River Blackwater flood study: Final flood mapping report, Peter Brett Associates, Reading.

Fujita, .I, Muste, M. and Kruger, A. (1998), Large-scale Particle Image Velocimetry for Flow Analysis in Hydraulic Engineering Applications, Journal of Hydraulic Research, IAHR Vol.36, No.3, 397-414.

Lambert, M. F and Sellin, R. H. J. (1996), Velocity distribution in a large-scale model of a doubly meandering compound channel. Proc. Instn Civ. Engrs Wat., Marit. & Energy, 118.

Le Coz, J., Gilles, P., Magali, J., Andre, P. (2007), Mean vertical velocity profiles from ADCP river discharge measurement datasets, Proceedings 32nd Congress of International Association of Hydraulic Engineering and Research (CD-ROM).

Marsden, R. (2005), StreamPro ADCP performance characteristics, Proceedings of the IEEE/OES Eight working conference on current measurement technology.

Muste, M., Yu, K. and Spasojevic, M. (2004). Practical aspects of ADCP data use for quantification of mean river flow characteristics; Part I: Moving-vessel measurements, Flow Measurement and Instrumentation, 15(1), 1-16.

Muste, M., Yu, K. Pratt, T and Abraham, D. (2004). Practical aspects of ADCP data use for quantification of mean river flow characteristics; Part II: Fixed-vessel measurements, Flow Measurement and Instrumentation, 15(1), 17-28.

Nystrom, E.A., Rehmann, C.R., and Oberg, K.A. (2007), Evaluation of mean velocity and turbulence measurements with ADCPs, Journal of Hydraulic Engineering, pp. 1310-1318.

Sellin, R.H.J. and van Beesten, D.P. (2004), Conveyance of a managed vegetated two-stage river channel, Proc. Institution of Civil Engineers, Journal of Water Management, Vol. 157, WM1, 21-44.

Sellin, R.H.J. and van Beesten, D.P. (2002), Berm vegetation and its effect on flow resistance in a two-stage river channel: an analysis of field data, Proc. The International Conference on Fluvial Hydraulics, Belgium, pp.319 - 326.

Sellin, R.H.J., C.A.M.E. Wilson, C.A.M.E., and Naish, C. (2001), Model and prototype results for a sinuous two-stage river-channel design CIWEM, The Journal volume 15/ No 3.

Stone, M.C. and Hotchkiss, R.H. (2007), Evaluating velocity measurement techniques in shallow streams, Journal of Hydraulic Research Vol. 45, No. 6, pp. 752 – 762.

Szupiany, R.N., Amsler, M.L., Best, J.L., Parsons, D.R. (2007), Comparison of fixed- and moving-vessel flow measurements with an aDP in a large river, Journal of Hydraulic Engineering, pp. 1299-1309.