Chandler, J. H.; Wackrow, R.; Sun, X.; Shiono, K.; Rameshwaran, P.. 2008 Measuring a dynamic and flooding river surface by close range digital photogrammetry. In: *Silk Road for Information from Imagery, Beijing, 3-11 July 2008*. International Society for Photogrammetry and Remote Sensing, 211-216.

MEASURING A DYNAMIC AND FLOODING RIVER SURFACE BY CLOSE RANGE DIGITAL PHOTOGRAMMETRY

J.H. Chandler[a] R. Wackrow[a], X. Sun[a], K. Shiono[a] and P. Rameshwaran[b]

[a] Dept. Civil and Building Engineering, Loughborough University, LE11 3TU, UK - J.H.Chandler@lboro.ac.uk
[b] Centre for Ecology & Hydrology, Wallingford, OX10 8BB, UK - ponr@ceh.ac.uk

KEYWORDS: Close Range Photogrammetry, Digital Surface Models, Digital Photogrammetry, Feature Extraction, Hydrology, Floods, Point Cloud

ABSTRACT:

Current state of the art computational fluid dynamics (CFD) and in particular, river flow modelling, require accurate estimation of the "free surface" in order to accurately predict the three dimensional flow field along a river. Such models are increasingly important for management of river basins and mitigation of river floods as the incidence of extreme rainfall events increases, causing widespread flooding, disruption and loss of life. To increase the accuracy of such flow models, it has become necessary to calibrate model outputs using field data, demanding improved measurement of the flow field along rivers.A substantial and funded research project being conducted at Loughborough University is developing image based river measurement methods using a combination of Particle Image Velocimetry (PIV) and close range photogrammetry (CRP). This paper will report on the use of digital close range photogrammetry to measure the dynamic topographic water surface exhibited by real and flooding rivers.A pair of Nikon D80 (10 Mega-pixel) digital cameras have been purchased, each equipped with a variables zoom lens (f: 18-70mm). The two cameras have been synchronized using two cables connected via a single relay operated switch, tests demonstrating that the accuracy of synchronization is better than 100th of a second. The cameras are mounted on two standard camera tripods, providing convergent and stereoscopic coverage of the river reach, which is between 10 and 20m distant. In initial tests, conventional photogrammetric control was provided using temporary targeted points, coordinated using a Reflectorless Total Station. Subsequent work is being conducted on a semi-engineered river at Farnborough, in the UK, where fixed targets have been permanently installed and coordinated to be in position necessary for the two year duration of the project.Imagery is being processed using the Leica Photogrammetry System (LPS); commercial software which provides the ability to automatically extract digital elevation models. A key issue is the targeting of the water surface and a variety of seeding particles have been tested. Natural materials are clearly preferred, to avoid polluting the natural riverine environment. Leaves, sawdust, and wood chips have all demonstrated some localised success but suffer because of a basic lack of contrast in the imagery captured. It has always been recognized that white polystyrene chips used for packing and posting delicate objects would resolve such difficulties but are clearly undesirable from an environmental perspective. Fortunately, biodegradable packaging chips are now available and tests demonstrate that LPS can successfully generate DEMs representing the dynamic and flooding water surface. Such material degrades within a few days, less if subjected to the mechanical action associated with a flowing river.This presentation will outline the development and application of the methodology, focusing on the accuracies attainable. Specific tests were developed to assess accuracy using a fixed, horizontal survey staff located just above the water surface. Accuracies of 3mm were achieved using the Nikon cameras located 11m away, more than sufficient for the uncertainties associated with the flow modelling. Key issues to be discussed include: synchronization, seeding and significantly, the use of a convergent camera configuration to increase the accuracy of data generated still further. The approach will be used over the next two winter seasons and combined with PIV to parameterise water flow and develop the 3D computerised flow models further.

1. INTRODUCTION

River flooding is becoming an increasing concern to society, exacerbated by extreme rainfall events associated with global warming. This provides an opportunity for hydrologists seeking to understand how rivers flow with a source of potential research funding. Current state of the art computational fluid dynamics (CFD) and in particular, river flow modelling, require accurate estimation of the "free surface" in order to accurately predict the three dimensional flow field along a river. Such models are increasingly important for management of river basins and mitigation of river floods as the incidence of extreme rainfall events increases, causing widespread flooding, disruption and loss of life. To increase the accuracy of such flow models, it has become necessary to calibrate model outputs using field data, demanding improved measurement of the flow field along rivers.

A substantial and funded research project being conducted at Loughborough University is developing image based river measurement methods using a combination of Particle Image Velocimetry (PIV) and close range photogrammetry (CRP). This paper will report on the use of digital close range photogrammetry to measure the dynamic topographic water surface exhibited by real and flooding rivers.

2. WATER SURFACE MEASUREMENT- PAST WORK

Measuring water surface elevation is often perceived to be routine because the concept of "surface" is generally simplified to refer to a single point in space. Proprietary systems range from simple linear scale gauges fixed to the side of a river, and read manually, through to electronic based instruments which use piezometers or float and pulley systems, with data recorded and transmitted at user selectable frequencies (Campbell

Scientific, 2007). Attempts to measure the true water surface, which can only be derived from sampling points over a wider area at an instant, are more unusual.

Some novel work has been conducted and developed specifically for laboratory flumes. Muslow et al., (2006) reports on an optical triangulation method which incorporates a laser light sheet reflecting off the water surface and captured by a digital camera. Excellent accuracies are reported (0.03mm), which are achieved from a flowing water surface in real time. However, the system is restricted to laminar flows because any ripples in the water surface disturb the laser light sheet and degrade the accuracy of the method. The technique is not suitable for turbulent flows. Piepmeir and Waters (2004) review stereo based imaging systems for measuring water waves created in laboratory flumes. They note how various authors have "polluted" the water, utilizing specialized lighting to provide suitable texture that can be measured. This is a key problem for measuring surface of a material that is generally reflective and transparent. Their own solution involved texturising the water surface with a fine mist to minimize reflections. Unfortunately they provide no details upon how this is achieved. They do report on the use of the Digiclops software development kit (Point Grey Research, 2007) to generate xyz locations and then Matlab to generate surface plots.

Working in the more uncontrolled field environment is more challenging and photogrammetric based systems have been utilized at a range of scales. At the small scale, Lane et al., (2003) use scanned aerial photography at 1: 4500 scale to yield water level estimates to a precision of ±0.15m on a flooding river in northern England. They measured natural standing water features called "wrack lines", but although valuable for determining river elevation at a point, were insufficient in number to provide a true surface. Perhaps the most ambitious, although expensive example is that achieved by Yamazoki et al., (1998), who obtained synchronized imagery from two aircraft flying above the Ishikon River in Japan. The river was in spate following snowmelt, this provided natural texture suitable for automated DEM extraction. Accuracies of between 0.12 and 0.36m were achieved.

At close range, the oblique perspective has proved flexible for deriving water surface data using photogrammetry. Fraser and McGee (1995) used two synchronized large-format CRC-1 cameras to capture 71 floating targets during the filling of the Bay Springs Lock in Mississippi, USA. Accuracy of data derived was 2cm; achieved every eight seconds during the eight minutes, 26m lift cycle. Chandler et al., (1996) also used two synchronized analogue cameras in an oblique perspective. Two Hasselblad ELX cameras, modified to include a reseau plate, were used to measure the confluence of a pro-glacial meltwater channel, immediately downstream of the Upper Arolla glacier in Switzerland. They used 60 polystyrene fishing floats as marker points, constrained by six fishing lines. Images were scanned and off–the-shelf image processing software was used to measure the centroids of each target. A self-calibrating bundle adjustment was then used to derive xyz coordinates and consequent DEMs.

The review of past work suggested a solution based upon close range photogrammetry would provide a viable method to a capture dynamic water surface data. The experience of the first author using low-cost digital sensors for measurement (Chandler et al, 2007) also suggested several new opportunities. These included: flexibility, convenience and improved accuracy associated with a rigid sensor array. Also, a far higher image resolution than had been possible using a scanned analogue approach. Finally, increased flexibility of commercial photogrammetric software suggested that oblique imagery (Chandler et al., 2002) would be viable and practicable for non-photogrammetrists to process.

3. THE MEASURING SYSTEM

3.1 Imaging

A pair of Nikon D80 digital cameras, each equipped with a standard variable zoom lens (18-70mm), was purchased in October, 2006 for the project. These two 10 Mega-pixel sensors would be sufficiently robust for fieldwork, and costing just $US1,000, provided high resolution at a low price. River flow rates of up to 1m second were expected and so it would be important to attain image pairs that were synchronized to a high level of precision. Initial attempts to synchronize both cameras using a Nikon ML-N3 infrared remote control were unsuccessful. This device proved unreliable in the field environment, particularly because it was difficult to maintain the line of sight to both camera sensors. The solution involved purchase of two Nikon MC-DC1 remote cords which were then adapted and configured to work in conjunction with a small battery operated relay switch (Figure 1).

Figure 1. Camera synchronization- relay switch and cords

This produced the two electrical pulses necessary to activate both the camera exposure systems and trigger the shutter. This system also allows the potential of both single and continuous image acquisition rates, up to three frames per second, provided an identical manual exposure setting was used for both cameras. Tests involving acquisition of imagery of a digital stop-watch demonstrated that synchronization accuracy of 100th of a second was achieved.

Figure 2. Synchronised Nikon D80 cameras and video camera

3.2 Control

Differential GPS was used to establish the precise coordinates of twelve monumented stations, installed around the main fieldsite on the River Blackwater, near Farnham, UK. This particular reach of the river (230 x 60m) was selected because it had been the subject of previous river studies and consequently the river regime and flow characteristics were familiar. The differential GPS survey was linked to the Ordnance Survey National Grid coordinate system and provided a consistent control framework for subsequent use. For example, one early activity was to use two motorized total stations to capture a high-resolution digital ground model representing the whole floodplain, including the sub-surface riverbed. Subsequent CFD modeling would need water surface data at four specific locations along a single meandering section of the channel: 1st straight section, a crossover, the bend apex and a 2nd straight section.

The two cameras could be located on a low berm just above the normal river channel, and approximately 4-5m from the bank edge (Figure 2 and Figure 3 - 1st Straight Section). Early experiments utilized temporary control targets fixed in position on the floodplain and coordinated using a reflector-less Total Station. This demonstrated feasibility of the technique and allowed the identification of appropriate seeding material. However, the desire to capture image sequences during flooding conditions suggested that the installation of permanent targets on the floodplain would be more effective. These would serve as photo-control for both the CRP and PIV.

Steel "concrete reinforcing" bars of 1.5m in length were hammered 1m into the soil surface and proprietary targets attached using brackets and bolts. Additional wooden struts were added to provide additional rigidity (Figure 3). Four or five bars were introduced at each site with one or two targets attached to each bar. Use was made also of existing wooden posts (Figure 3 and Figure 4) that had been installed to mark the positions of the key cross sections for other monitoring work. The coordinates of each target was established using a reflector-less Total Station with measurements acquired from at least two survey control points. The stability of the points appears high, as suggested by low target residuals achieved during photogrammetric processing (Table 1). A repeat total station survey is planned at the end of the monitoring work to confirm and quantify potential deformation.

Figure 3. Nikon D80 image- used for measurement

Exterior orientation parameters

image ID	Xs	Ys	Zs	OMEGA	PHI	KAPPA
3	488026.1133	156019.1010	64.9044	57.9165	-56.2199	-28.1594
4	488026.6326	156017.4667	64.9345	61.6903	-48.8990	-22.8489

Interior orientation parameters of photos

image ID	f(mm)	xo(mm)	yo(mm)
3	23.0500	-0.1832	-0.1165
4	21.3500	-0.2711	-0.2612

The residuals of the control points

Point ID	rX	rY	rZ
21	0.0028	0.0007	0.0020
22	-0.0021	-0.0005	-0.0022
23	-0.0021	0.0011	-0.0043
24	0.0043	-0.0049	0.0100
25	-0.0034	0.0031	-0.0051
26	0.0004	0.0005	-0.0003

Table 1. Exterior/Interior orientation and residuals

3.3 Seeding

Accurate water surface measurement using CRP has previously relied upon the use of a well defined floating marks or "seeds", (Fraser and McGee, 1995; Chandler et al., 1996). One of the key challenges has been identifying an appropriate seed and finding an appropriate method of distribution. To avoid polluting the environment a variety of natural substances were considered and in some cases tested. Unfortunately, neither sawdust, wood chippings or dry leaves proved suitable. Such materials have failed in respect of either: availability, cost, size or buoyancy- all important criteria. Polystyrene packing chips appeared promising from a pure photogrammetric perspective, but were never tested because of obvious environmental concerns. Fortunately, the first author came across "biodegradable packing chips" which, consisting of starch, distintegrate within a few hours of coming into contact with water. Although slightly more expensive than their polystyrene counterparts, they provide good contrast with the river surface under a variety of lighting conditions (Figure 3 and Figure 4).

A final practical problem to resolve was to distribute the seeds evenly over the test area and at an appropriate density. The best solution established to-date is simple but effective, consisting of five plastic containers mounted on a survey staff. Each container is pre-filled with seeds and an assistant tilts and shakes the staff so that an appropriate density of chips is achieved, Figure 4.

Figure 4. Simple seed distribution

3.4 Photogrammetric processing

Use of small format digital cameras for spatial measurement has become increasingly routine since their introduction (Shortis and Beyer, 1996; Fraser, 1997; Chandler et al., 2005), particularly for vertical image configurations using commercial photogrammetric software. Key issues to address relate to stability of camera calibration and the oblique camera configuration.

The two D80s were calibrated in the laboratory using a test-field and self-calibrating bundle adjustment and methodology reported prior (Chandler et al., 2005, Wackrow et al., 2007). Both the zoom and focus setting of the two lenses was fixed at a focal length of approx. 24mm, using electrical tape and the auto-focus function was switched off. The stability of the recovered inner orientation parameters always needs to be considered but experience has demonstrated that the recovered lens model is generally stable (Wackrow et al., 2007). The focal length and principle point offset tends to be less stable but these primary parameters can also be less significant if the object field itself is planar and parallel to the focal plane. For higher accuracy work using a oblique imagery it is important to recover these parameters *in-situ*. For this reason, the methodology adopted in this project has been to utilize the laboratory calibrated lens model, but estimate principal point offset and focal length for each camera using measurements derived from the synchronized river image pairs (Figure 3).

All measurements have been carried out by a research assistant specializing in CFD and is not a trained photogrammetrist. Facilities provided by the Leica photogrammetry system (LPS) version 9.0 have been utilized, using the following workflow:

1. Image pair loaded into LPS, target and tie-points measured manually/semi-automatically and report file generated.
2. Report file reformatted to create four input files necessary to run GAP, an external self-calibrating bundle adjustment. GAP used to derive focal length and principal point offsets.
3. Recovered primary inner orientation parameters are re-introduced into LPS and final exterior orientation estimated and residuals assessed (Table 1).
4. Operator manually measures a set of tie points on one image, representing the base of each seed. Tiepoints are "transferred and measured" on the second image-automatically.
5. The LPS bundle adjustment ("Triangulation") is then re-estimated to derive XYZ coordinates representing the base of each of the seed points.
6. Data assessed and exported into Matlab for visualization (Figure 5) and subsequent processing.

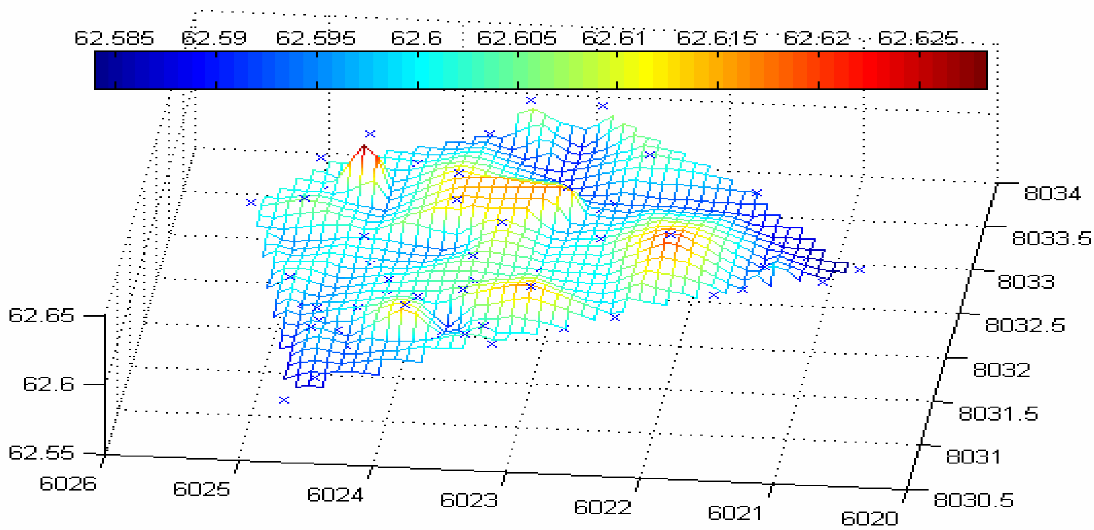

Figure 5. Visualisation of measured water surface (note vertical exaggeration)

4. DISCUSSION

4.1 Rotated control

The Leica photogrammetry suite (LPS) is primarily developed for processing vertical aerial photography, the predominant market. Using this package for processing terrestrial oblique imagery is less routine and additional difficulties have to be overcome. First, the "terrestrial" option of LPS was discounted. It was desirable to work in the same site coordinate system for all test areas, which had been established using differential GPS.

This led to two alternatives, both tested and which proved viable. The first involved using the original 3D photo-control coordinates directly in LPS, measuring photo-coordinates and processing using the triangulation software. Unfortunately, the mathematical model used to derive initial estimates for the exterior orientation in LPS is oversimplified. Although it is perfectly adequate for vertical aerial photography, it is unable to compute values for high-angle obliques and the bundle adjustment fails. This therefore requires the user to provide starting values and enter as "initial estimates"; simple for the three positional elements but more problematic for the three rotations.

The alternative processing solution involved using a 3D Similarity Transformation to rotate the control coordinates so that mean camera axes become vertical equivalents. This was achieved using a simple routine developed and explained in Chandler (1999). The advantage of this approach is that initial estimates of exterior orientation derived using LPS are then adequate and the bundle adjustment converges. The main disadvantage is that the water surface data derived subsequently is in the rotated coordinate system. An extra data processing stage is therefore required to transform the data back into the original system, using a reverse 3D Similarity Transformation (Chandler, 1999).

The approach that will be adopted in future surveys, will be to pre-estimate the initial exterior orientation parameters and bypass the oversimplified LPS algorithm. Over the next two years, the cameras will be positioned in similar locations for photo-acquisition during different river flood conditions. Now that the initial position and rotational elements have been derived, they should serve for future imagery.

Figure 6. Survey staff located close to water surface

4.2 Data accuracy

An independent check on the accuracy of data generated by photogrammetry is always desirable, but can occasionally be difficult to achieve. For this project independent accuracy assessments were derived by conducting a similar survey on a local river. The key element in this process was to derive elevation estimates for a series of points located on a survey staff secured just above the flowing water surface (Figure 6). These photogrammetrically acquired estimates could be then directly compared with measured known values and true accuracy determined and quantified. Figure 7 conveys graphically the discrepancies between photogrammetrically acquired coordinates and their positions measured using a reflectorless Total Station.

The overall root-mean-square error of the differences is 3mm, with a maximum differences of 5mm. These errors are fit for purpose of determining water surface elevation to an accuracy of ±5mm. The two cameras were positioned approximately 8m away from the staff and so the rms error of 3mm equates to 9µm on the image, approximately 1.4 pixel. It is hoped that these accuracies may be improved still further by adopting a convergent camera configuration which appears to resolve systematic errors arising from a slightly inaccurate lens model (Wackrow and Chandler, 2008a). A series of experiments investigating this possibility are reported in a related Congress paper (Wackrow and Chandler, 2008b).

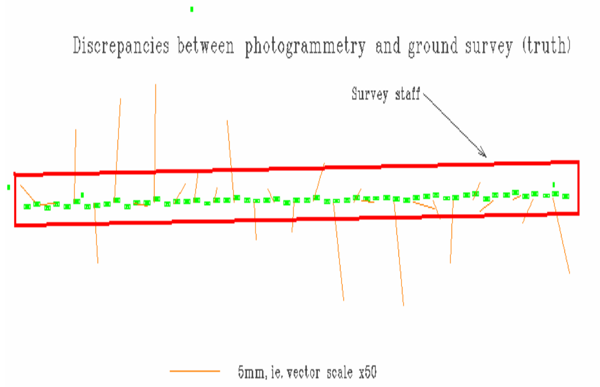

Figure.7

4.3 Use of water surface data in computational fluid dynamics (CFD)

Flow visualization and numerical simulation show a significant change of water surface level in the areas of cross-over reach and apex section in compound meandering channels, (Rameshwaran & Naden 2004; Shiono et al., 2008). A change of water level affects flow characteristics, such as boundary shear stress and flow resistance and elevations are required for the validation of computer model results. In the past, most of the three-dimensional CFD studies in river engineering have been performed with the planar fixed lid hypothesis for the treatment of the free surface. Use of a planar fixed lid treatment of the free surface may be inadequate for natural rivers where the free surface elevation varies substantially, particularly around vegetation and roughness elements and at bend apexes and cross-over regions. Rameshwaran and Naden (2004) shows that the free surface treatment for the spatial variation of the water surface in 3D CFD models are vital for the accurate prediction of bed shear stress. Accurate measurement of the water surface elevation using traditional and direct methods, without disturbing the flow, is extremely difficult and dangerous, particularly where free surface variation is especially complex.

5. CONCLUSION

This paper has described the development of a simple measurement system to measure the topography of a dynamic and flowing river surface. Use has been made of two consumer grade digital cameras, combined with commercial photogrammetric software, allowing the developed methodology to be robust, cost effective and usable by non-photogrammetrists. The approach will be used over the next two years and combined with 2D particle image velocimetry (PIV) to parameterise water flow and develop 3D computerised flow models further. Remaining challenges include comparing 3D PIV data derived using photogrammetric image sequences, with 2D video-based PIV. Also, to reconcile 'surface' flow velocities measured in the field with their 'depth-averaged' equivalents derived from the numerical flow models.

REFERENCES

Campbell Scientific, 2007. HydraCOM water monitoring, logging and telemetry. http://www.campbellsci.co.uk/ index.cfm?id=187 [accessed 15th December, 2007].

Chandler, J. H., Ashmore, P., Paola, C., Gooch. M. J. And Varkaris, F., 2002. Monitoring river channel change using terrestrial oblique digital imagery and automated digital photogrammetry. *Annals of the Association of American Geographers,* 92(4): 631-644.

Chandler, J. H., Fryer, J. G. and Jack, A., 2005. Metric capabilities of low-cost digital cameras for close range surface measurement. Photogrammetric Record, 20(109): 12-26.

Chandler, J.H., 1999. Effective application of automated digital photogrammetry for geomorphological research, *Earth Surface Processes and Landforms*, 24: 51-63.

Chandler, J.H., Bryan, P. and Fryer, J.G., 2007. The development and application of a simple methodology for recording rock art using consumer-grade digital cameras, *The Photogrammetric Record*, 22(117): 10-21.

Chandler, J.H., Lane, S.N. and Richards, K.S., 1996. The Determination of Water Surface Morphology at River Channel Conferences Using Automated Digital Photogrammetry and Their Consequent Use in Numerical Flow Modelling, *International Archives of Photogrammetry and Remote Sensing*, XXXI(B7), Kraus, K. and Waldhause, P. (Eds), ISPRS, XVIIIth Congess, Vienna, 1996, pp 99-104.

Fraser, C. and McGee, R.G., 1995. Dynamic measurement of undulating water surfaces in a lock fill. *Photogrammetric Engineering and Remote Sensing*, 61(1): 83-87.

Fraser, C.S., 1997. Digital camera self-calibration. ISPRS Journal of Photogrammetry and Remote Sensing, 52: 149-159.

Lane, S.N., James, T.D., Pritchard, H. and Saunders, M. 2003. Photogrammetric and laser altimetric reconstruction of water levels for extreme flood event analysis . *The Photogrammetric Record* 18 (104): 293–307.

Muslow, C., Schulze, M. and Westfeld, P., 2006. An optical triangulation method for height measurements on instationary water surfaces. *International Archives of Photogrammetry and Remote Sensing*, XXXVI(5), H-G. Maas (Ed), Dresden, 2006, pp 213-217.

Piepmeir, J.A. and Waters, J., 2004. Analysis of stereo vision based measurements of laboratory water waves. Geoscience and Remote Sensing Symposium, IGARSS '04. Proceedings. IEEE International Volume 5, 2004 pp 3588 – 3591.

Point Grey Research, 2007. Products and Services: Stereo Vision Products: Digiclops. http://www.ptgrey.com/products/ digiclops/index.asp [accessed 15th December, 2007].

Rameshwaran, P. and Naden, P.S. 2004. Three-dimensional modelling of free surface variation in a meandering channel. *Journal of Hydraulic Research*, 42(6): 603–615.

Shiono, K, Spooner, J., Chan, T., Rameshwaran, P. and Chander, J.C (2008), Flow characteristics in meandering channels with non-mobile and mobile beds for overbank flows, *Journal of Hydraulic Research. International Association for Hydraulic Engineering Research*, (in press).

Shortis, M. R. and Beyer, H.A., 1996. Sensor technology for digital photogrammetry and machine vision. Chapter 5 in Close Range Photogrammetry and Machine Vision, (Ed. K. B. Atkinson).Whittles Publishing, Caithness. 371 pages: 106-155.

Wakrow, R., and Chandler, J.H., 2008a. A convergent image configuration for DEM extraction that minimises the systematic effects caused by an inaccurate lens model. *Photogrammetric Record*, 23(121), 6–18.

Wackrow, R. and Chandler, J.H, 2008b. Minimizing systematic errors in DEMs caused by an inaccurate lens model. International archives of Photogrammetry and Remote Sensing. XXI(5) (in press).

Wackrow, R., Chandler, J.H., and Bryan, P., 2007. Geometric consistency and stability of consumer-grade digital cameras for accurate spatial measurement. *Photogrammetric Record,* 22(118): 121–134.

Yamazaki, F., Hatamoto,, M., Kondo, M., 1998. Utilization of synchronous shutter apparatus in the photographic measurement method of flood flows surfaces. *International archives of Photogrammetry and Remote Sensing*. XXXII(5), Chikatsu and Shimizu (Eds), Hakodate, pp 848-855.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by the Engineering and Physical Science Research Council grant: EP/E003915/1. In addition, collaborators based at the Centre for Ecology and Hydrology, the University of Birmingham and the Environment Agency.