A CASE STUDY OF INTERACTIONS BETWEEN FLOOD FLOW AND BUILDINGS IN AN URBAN ENVIRONMENT: GARDENS POINT DURING THE 12-13 JANUARY 2011 FLOOD OF THE BRISBANE RIVER (AUSTRALIA)

H. Chanson[1] and R. Brown[2]

[1]University of Queensland, School of Civil Engineering, Brisbane QLD 4072, Australia, h.chanson@uq.edu.au
[2]Queensland University of Technology, Science and Engineering Faculty, School of Chemistry, Physics and Mechanical Engineering, Brisbane QLD 4000, Australia, richard.brown@qut.edu.au

Abstract: Flood flows in inundated urban environment constitute a natural hazard. During the 12-13 January 2011 flood of the Brisbane River, detailed water elevation, velocity and suspended sediment data were recorded in an inundated street at the peak of the flood. The field observations highlighted a number of unusual flow interactions with the urban surroundings. These included some slow fluctuations in water elevations and velocity with distinctive periods between 50 and 100 s caused by some local topographic effect (choking), superposed with some fast turbulent fluctuations. The suspended sediment data highlighted some significant suspended sediment loads in the inundated zone.

Keywords: Floods, urban environment, inundated building, turbulence, sediment load, Brisbane River, January 2011, field investigations, instrumentation.

INTRODUCTION

Flood flows in urban environment constitute a hazard to both populations and infrastructure. A number of deadly catastrophes included the inundations of Vaison-la-Romaine and Nîmes (France) in the 1990s, the flooding of New Orleans (USA) in 2005, and the floods in Queensland (Australia) in 2010-2011. Some studies considered the storage effect of urban areas (Solo-Gabriele and Perkins 1997, Velickovic et al. 2011), and the flow redistribution in flooded streets (Bates et al. 2004, Werner et al. 2005). A limited number of studies looked at the impact of floods on structures and buildings (Thieken et al. 2005) and the potential impact on pedestrians (Asai et al. 2010).

Detailed water elevation, velocity and suspended sediment load data were recorded with high temporal and spatial resolutions in an inundated street on 12-13 January 2011 during a major flood of the Brisbane River (Australia). The results included the simultaneous measurements of turbulent velocities, suspended sediment concentration (SSC) and suspended sediment flux at high frequency for nearly 30 h about the peak of the flood. It is the aim of the present work to present an innovative characterisation of turbulence and sediment flux in the inundated urban environment.

FIELD INVESTIGATION AND INSTRUMENTATION

Located along the Brisbane River, the central business district (CBD) of the City of Brisbane is about 25 km upstream of the river mouth and the catchment area is 13,500 km^2. Following some heavy rainfall in the catchment during early January 2011, the Brisbane River water level rose rapidly on 11 and 12 January 2011 (Chanson 2011). The city of Brisbane was flooded from 11 to 14 January with the flood waters peaking early morning 13 January 2011 in the city. At the peak of the flood, the estimate river discharge was in excess of 9,000 m^3/s in the city reach (Malone, T. 2011, *Pers. Comm*) and the local friction slope was about 1×10^{-4} (Brown et al. 2011).

Some turbulent velocity measurements were performed along Gardens Point Road between 12 and 14 January 2011 (Fig. 1). The site was located between Gardens Point Road and the ground floor car park of C Block building of QUT Gardens Point campus. Figure 2 shows a photograph taken during the flood. Figure 3 details the ground floor car park of C Block building and Figure 4 shows a cross-sectional survey looking downstream. Further details and photographs were reported by Brown et al. (2011).

The free surface elevations were recorded manually using a measuring tape with reference to landmarks which were surveyed after the flood in relation to the Australian Height Datum (AHD). The turbulent velocities were measured with a Sontek™ microADV (16 MHz, serial A843F) equipped with a 3D side-looking head. During five data series, the acoustic Doppler velocimeter (ADV) was sampled continuously at 50 Hz, each series lasting between 10 min to 4 h. The ADV unit was equipped with a pressure sensor which was underwater and gave water elevation data during the first two data series only. All the ADV data underwent a thorough post-processing procedure to eliminate any erroneous or corrupted data from the data sets to be analysed (Brown et al. 2011).

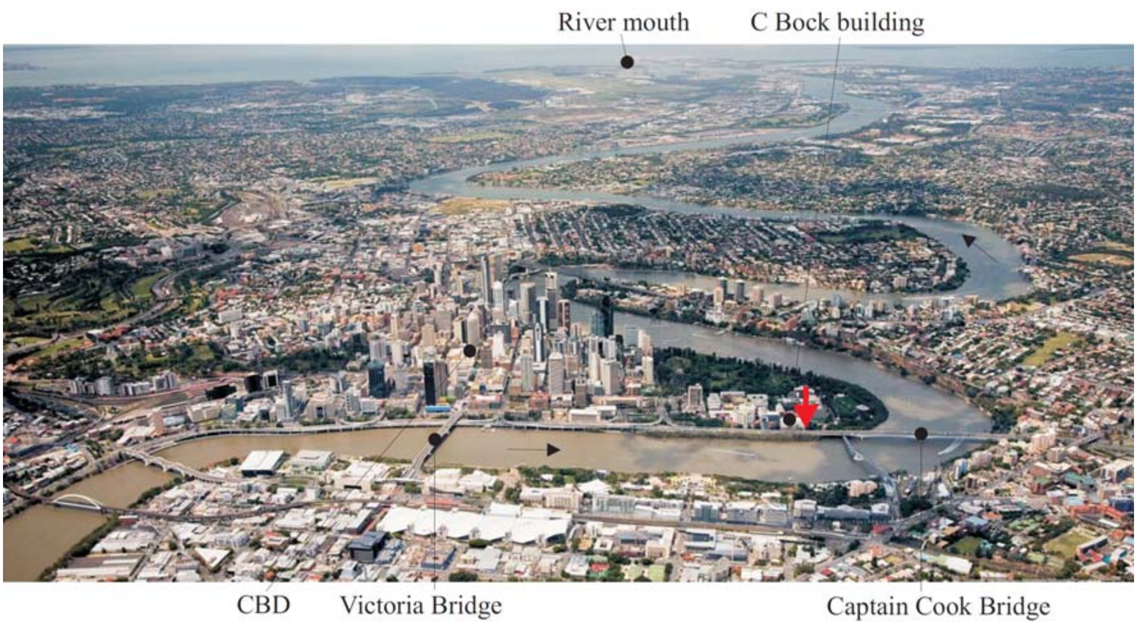

Fig. 1 - Brisbane River meandering around Central Business District in 2007 (Courtesy of the University of Queensland). Red arrow points to the sampling site 25 km upstream of river mouth, Black arrows show the river flow direction

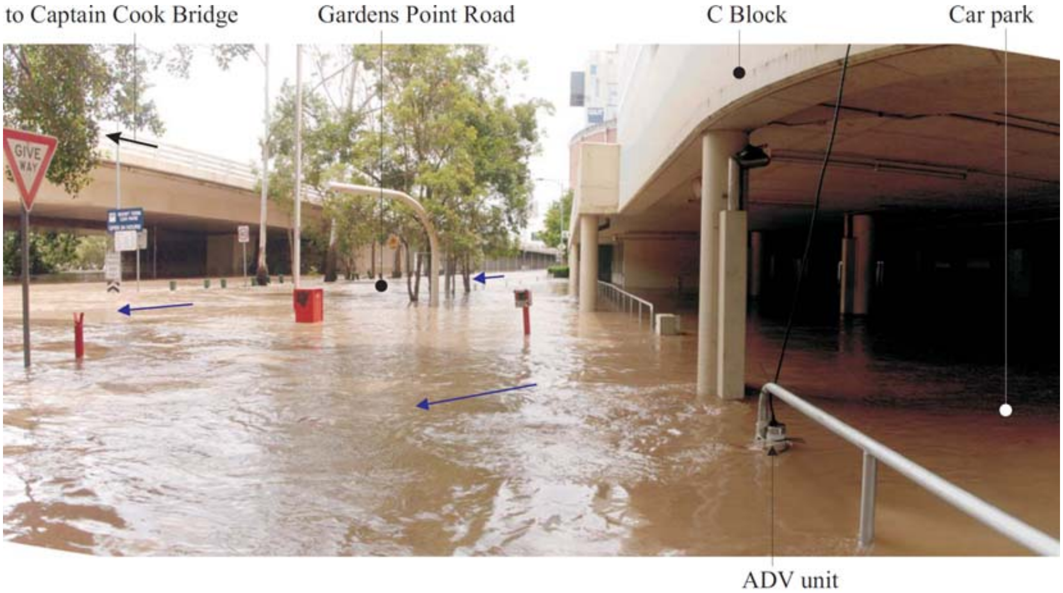

Fig. 2 - Gardens Point Road during the flood on 13 January 2011 at 11:40 looking upstream. Blue arrows show the main flow directions

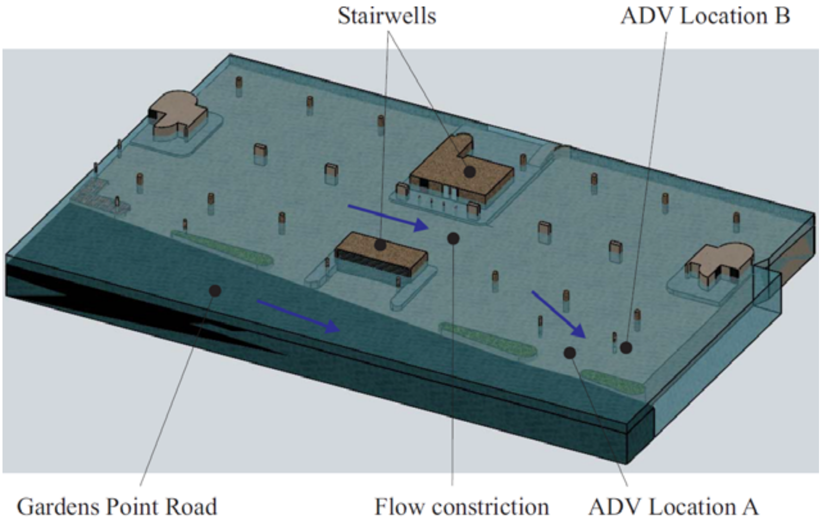

Fig. 3 - CAD sketch of the inundated Gardens Point Road and C Block car park. Blue arrows show the main flow directions.

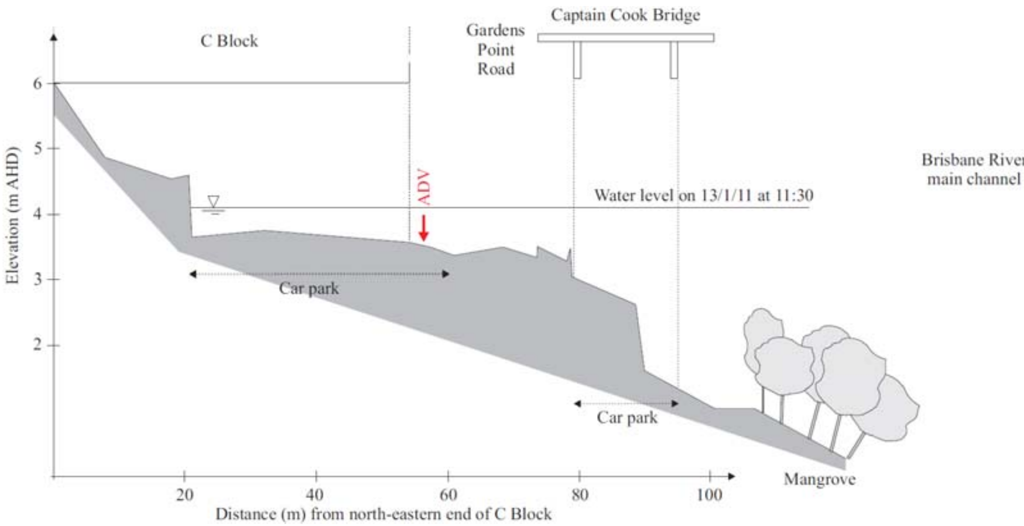

Fig. 4 - Dimensioned transect of the flooded Gardens Point Road and surroundings looking downstream

Some sediment material was collected on 13 and 14 January 2011 along Gardens Point Road. The soil samples consisted of fine mud ($d_{50} \approx 26$ μm). The calibration of the ADV unit in terms of suspended sediment concentration (SSC) was accomplished by measuring the signal amplitude of known, artificially produced concentrations of material obtained from the bed material sample, diluted in tap water and thoroughly mixed. All the experiments were conducted with the same microADV (serial A843F) using the same settings as for the field observations.

Some slow fluctuations in terms of both water elevations and velocity components were observed with periods between 50 and 100 s. A triple decomposition of the instantaneous velocity data was performed. The technique was previously applied to periodic turbulent flows and riverine flows with large coherent structures (Hussain and Reynolds 1972, Yossef and de Vriend 2011). Herein the instantaneous velocity time-series may be represented as a superposition of:

$$V = \langle V \rangle + [V] + v \tag{1}$$

where V is the instantaneous velocity, <V> the mean velocity contribution, [V] the slow fluctuating component of the velocity and v corresponding to the turbulent motion. <V> was selected as the low-pass filtered data with a cut-off frequency of 1/500 s^{-1}. The slow fluctuating component [V] was the band-passed signal with upper and lower cut-off frequencies set at 1/3 s^{-1} and 1/500 s^{-1} respectively. The turbulent component v was the high-pass filtered data with a cut-off frequency of 0.33 Hz (1/3 s^{-1}). All the statistical properties of turbulent velocity components were calculated over a 500 s interval (25,000 data samples). The same triple decomposition was applied to the water depth and suspended sediment data.

BASIC FLOW PATTERNS

During the rising stage of the Brisbane River flood, the river swelled and inundated Gardens Point Road (Fig. 2). The flood plain included some car parks located beneath Captain Cook Bridge, Gardens Point Road and car parks beneath a number of buildings (Fig. 3 & 4). Visual observations indicated some form of preferential flow path along Gardens Point Road where the free-surface flow was subcritical. During the flood, the authors went in the waters and a key feature was the slow fluctuations of water level and the water surges observed with periods of about one minute. These slow fluctuations were associated with changes in water elevations of up to 0.1 to 0.2 m.

The water elevations were recorded manually on three occasions (Fig. 5, filled squares) and using the ADV pressure sensor during the first data series. The corresponding water depth ranged from 0.9 m down to 0.25 m. The observations are reported in Figure 5. Both the manual observations and water level fluctuations showed some trends that were close to the Brisbane River water level record at the City Gauge located 1.55 km downstream. The pressure data highlighted some large fluctuations of the water level around its mean trend (black thick line, Fig. 5). Some simple calculations show that the dominant period was close to the first mode of natural sloshing resonance linked with the C Block building length (Brown et al. 2010). While the flow at the sampling location was subcritical, it is believed that the flow constriction created by the concrete stairwells induced some choking (Fig. 3). The gap between stairwells was 10 m compared to the car park width of 33.6 m. Based upon the water depth and velocity data, the application of the Bernoulli principle shows that the constricted flow could reach transcritical flow conditions, hence choking. When the flow in the stairwell contraction would choke, the energy losses in the contraction could become substantially larger than the rate of energy loss of the main flow, and the inundation flow would redirect around the stairwells to achieve a minimum energy path. The pattern would yield some flow instabilities in the surroundings of stairwells which could be amplified when their period was close to the natural sloshing period of the building car park.

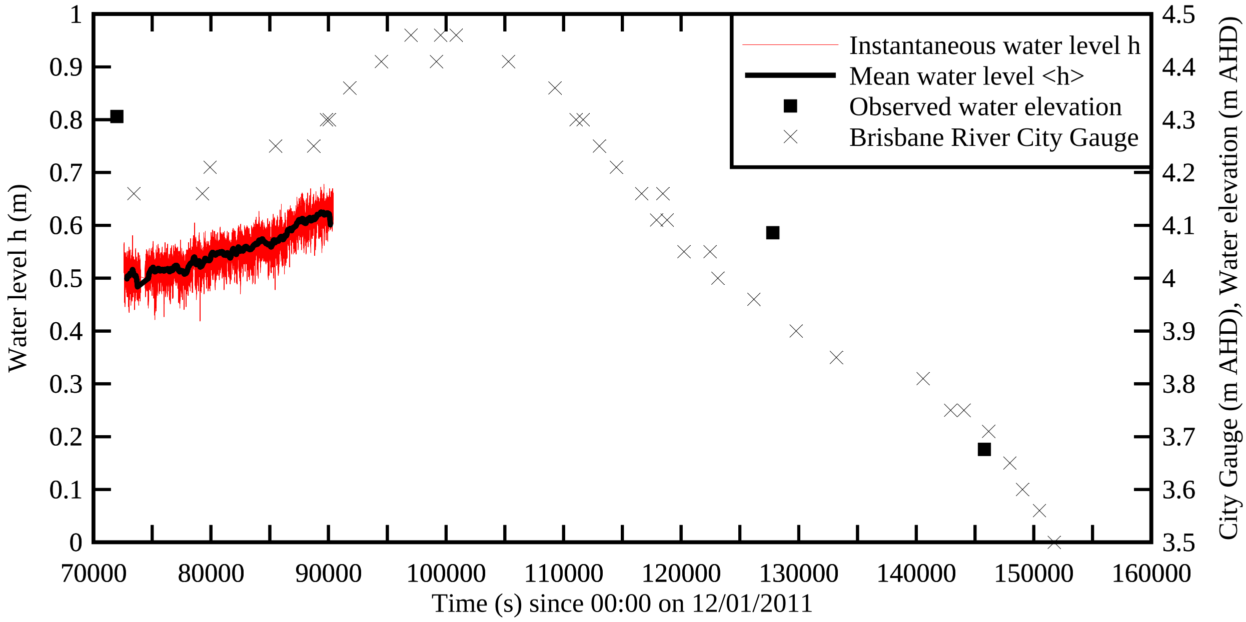

Fig. 5 - Instantaneous and mean water levels. Comparison with City Gauge data and observed water elevation

TURBULENT VELOCITY AND SUSPENDED SEDIMENT LOAD DATA

Figure 6 presents the time variations of instantaneous longitudinal velocity during the study and the data are compared with water elevations of the Brisbane River at the City Gauge. All the velocity data illustrated some large fluctuations around a mean trend throughout the study period. The magnitude of longitudinal velocity was about 0.5 m/s, except during the last data set (t > 150,000 s). For comparison, the longitudinal velocity in the main channel of the Brisbane River was estimated to be between 3.5 and 4.5 m/s at the peak of the flood (T. Malone 2011, *Person. Comm.*). During the last data set, the water level dropped rapidly from 0.26 m down to less than 0.10 m when the ADV unit came to be out of the water. All velocity data showed a very slow motion implying that the flow was disconnected from the main river channel.

A cross-correlation analysis was performed between the water level and velocity data for the first part of the study. Typical results are presented in Figure 7. They showed a strong negative correlation between the water elevation and longitudinal velocity, although with some time lag. That is, a rise/decrease in water depth was associated with a deceleration/acceleration of the flow with some delay of about 9 s (Fig. 7). The exact cause of the delay remains unknown.

The time-variations of suspended sediment concentration (SSC) are presented in Figure 8. The SSC data showed a general trend with an increase in mean concentration from about 6 kg/m^3 to more than 20 kg/m^3 during the entire study period (Fig. 8). The trend might be linked with the change in ADV sampling volume elevation. However, during the last data series in shallow waters, it is likely that the data trend reflected an increase in SSC prior to mud deposition on the concrete invert.

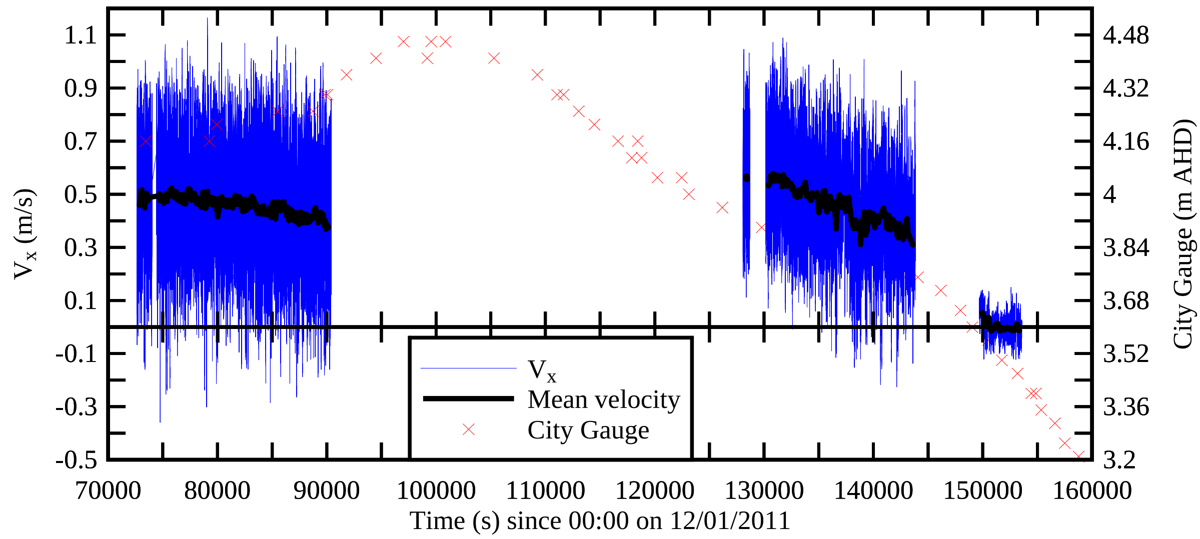

Fig. 6 - Time variations of the longitudinal velocity V_x along Gardens Point Road during the January 2011 flood - Comparison with the Brisbane River City Gauge data

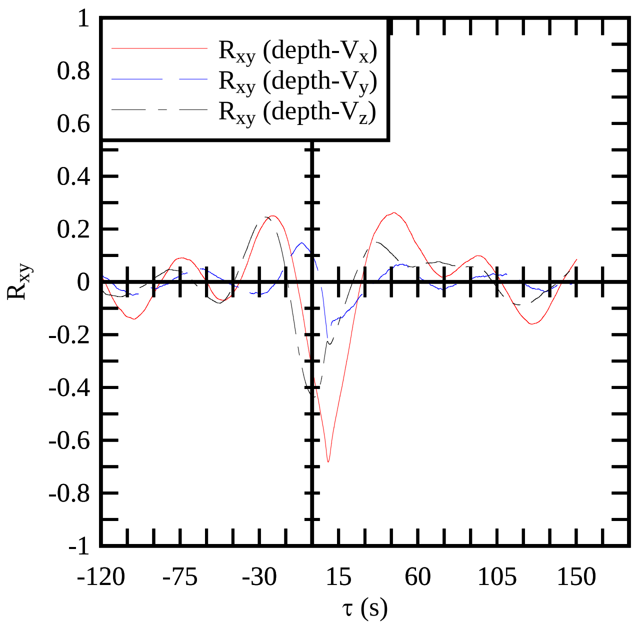

Fig. 7 - Cross-correlation functions between instantaneous water level and velocity component for 74,000 < t < 89,000 s

The longitudinal suspended sediment flux data $q_s = SSC \times V_x$ showed some substantial sediment flux values: the mean sediment flux ranged from 10 to 35 tonnes per hour per unit cross-section area. The results highlighted some large fluctuations in suspended sediment flux per unit area.
It is noteworthy that a statistical analysis suggested that most fluctuations in SSC were relatively rapid with periods less than 3 s. The results implied some differences in time scales between turbulent velocity and SSC fluctuations. The finding might suggest that the velocity fluctuations were linked with local effects and features of the urban environment, while the suspended sediment concentration and flux were affected predominantly by the upstream catchment runoff characteristics including the sediment wash load.

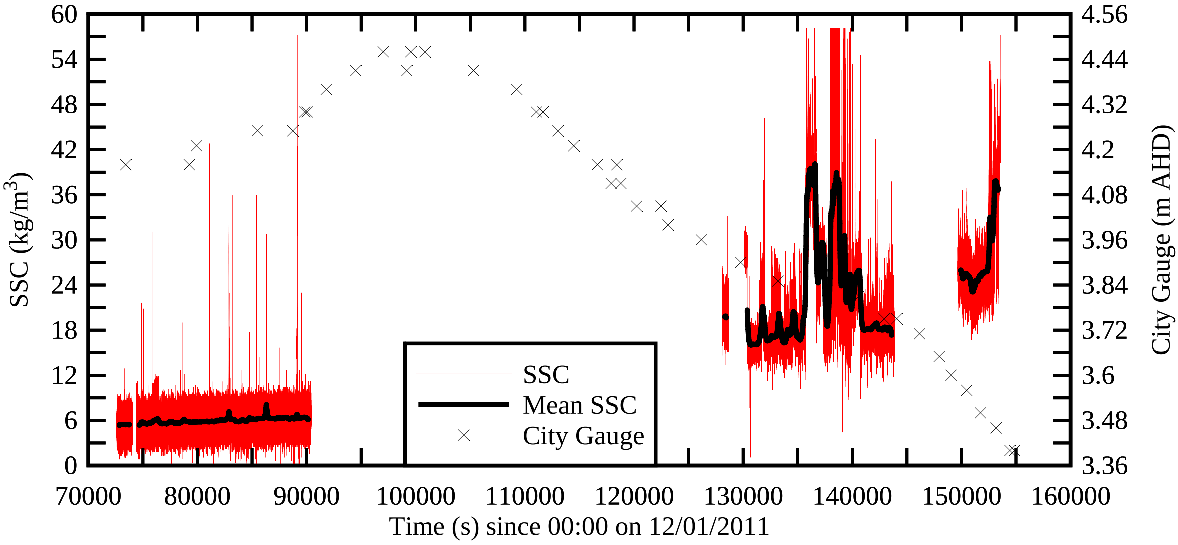

Fig. 8 - Time variations of suspended sediment concentration SSC along Gardens Point Road on 12-13 January 2011

CONCLUSION

On 12-14 January 2011 during the flood of the Brisbane River, a field investigation was performed in an inundated urban setting. The velocity components were collected at relatively high frequency using acoustic Doppler velocimetry. The suspended sediment concentration was deduced from the acoustic backscatter data based upon detailed calibration tests, thus providing the simultaneous measurements of suspended sediment flux in the sampling volume with the same temporal resolution. The field observations highlighted a number of unusual flow interactions with the urban surroundings. These included some slow fluctuations in water elevations and velocity with distinctive periods between 50 and 100 s caused by some local topographic effect (choking), superposed with some fast turbulent fluctuations. The velocity data were analysed using a triple decomposition. The suspended sediment data highlighted some significant suspended sediment loads.
The field deployment was conducted in very challenging conditions. These included the preparation and installation of equipments when most services were shut down and many city streets were under water, during a period when nearly 150,000 people were affected by the flood in Brisbane.

ACKNOWLEDGMENTS

The authors thank all people who participated to the field study, as well as those who assisted. They acknowledge the financial support of QUT Faculty of Built Environment and Engineering through a special project grant and of the Australian Research Council (Grant DP120100481).

REFERENCES

Asai, Y., Ishigaki, T., Baba, Y., and Toda, K. (2010). Safety Analysis of Evacuation Routes Considering Elderly Persons during Underground Flooding. *J. of Hydroscience and Hydraulic Eng.*, JSCE, Vol. 28, No. 2, pp. 15-21.

Bates, P.D., Horritt, M.S., Aronica, G., and Beve, K. (2004). Bayesian Updating of Flood Inundation Likelihoods Conditioned on Flood Extent Data. *Hydrological Processes*, Vol. 18, No. 17, pp. 3347-3370.

Brown, R., Chanson, H., McIntosh, D., and Madhani, J. (2011). Turbulent Velocity and Suspended Sediment Concentration Measurements in an Urban Environment of the Brisbane River Flood Plain at Gardens Point on 12-13 January 2011. *Hydraulic Model Report No. CH83/11*, School of Civil Engineering, The University of Queensland, Brisbane, Australia, 120 pages.

Chanson, H. (2011). The 2010-2011 Floods in Queensland (Australia): Observations, First Comments and Personal Experience. *J. La Houille Blanche*, No. 1, pp. 5-11.

Hussain, A.K.M.F., and Reynolds, W.C. (1972). The Mechanics of on Organized Wave in Turbulent Shear Flow. Part 2: Experimental Results. *J. of Fluid Mech.*, Vol. 54, Part 2, pp. 241-261.

Solo-Gabriele, H.M., and Perkins, F.E. (1997). Streamflow and Suspended Sediment Transport in an Urban Environment. *J. Hyd. Eng.*, ASCE, Vol. 123, No. 9, pp. 807-811

Thieken, A.H., Muller, M., Kreibich, H., and Merz, B. (2005). Flood Damage and Influencing Factors: New Insights from the August 2002 Flood in Germany. *Water Res. Res.*, AGU, Vol. 41, No. 12, Paper W12430 (DOI: 10.1029/2005WR004177).

Velickovic, M., Soares-Frazao, S., and Zech, Y. (2011). Porosity Model of Flow through an Idealised Urban District. Influence of City Alignment and of Transient Flow Character. *Proc. 34th IAHR World Congress*, Brisbane, Australia, 26 June-1 July, Engineers Australia Publication, Eric Valentine, Colin Apelt, James Ball, Hubert Chanson, Ron Cox, Rob Ettema, George Kuczera, Martin Lambert, Bruce Melville and Jane Sargison Editors, pp. 3823-3830.

Werner, M.G.F., Hunter, N.M., and Bates, P.D. (2005). Identifiability of Distributed Floodplain Roughness Values in Flood Extent Estimation. *J. of Hydrology*, Vol. 314, No. 1-4, pp. 139-157.

Yossef, M.F.M., and Vriend, H.J. de (2011). Flow Details near River Groynes: Experimental Investigation. *J. Hyd. Eng.*, ASCE, Vol. 137, No. 5, pp. 504-516.