SUSTAINABLE DEVELOPMENT AND FLOOD RISK – REDUCING UNCERTAINTY (BRISTOL BROADMEAD DEVELOPMENT CASE STUDY)

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This paper deals with the reduction of uncertainty in fluvial flood risk mapping. The ideas and opinions expressed are those of the author and not Symonds Group.

INTRODUCTION

In the UK national planning guidance on Development and Flood Risk is now given in Planning Policy Guidance Note 25 (DTLR, July 2001)[1], which replaces Circular 30/92 (DOE, 1992). Amongst other things the guidance in PPG25 states "Policies in redevelopment plans should outline the consideration which will be given to flood issues, recognising the uncertainties that are inherent in the prediction of flooding and that flood risk is expected to increase as a result of climate change". It goes on to state that "Planning authorities should apply the precautionary principle to the issue of flood risk, using a risk-based search sequence to avoid such risk where possible and managing it elsewhere". One of the more innovative and indeed controversial elements of the guidance note is the recognition that those wishing to undertake development that may impact flood risk and urban or surface water drainage must bear some of the cost in determining, quantifying and managing the risk resulting from such development. Indeed it goes as far as saying "Developers should fund the provision and maintenance of flood defences that are required because of the redevelopment".

The Environment Agency of England and Wales is charged with advising planning authorities on the application of PPG25 which in part it discharges through the creation and publication of maps which indicate areas considered to be at risk from flooding. This national dataset is and by necessity remains indicative, the intention being that refinement of the understanding of flood risk be considered more closely at a local level through the planning process. The methods used to derive these indicative maps are based on well understood and standard techniques and are applied through a national specification [2]. However, in considering flood risk at a local level and in particular in circumstances where the assumptions inherent in these techniques are exceeded there is a need to reduce the uncertainties associated with estimation of flood water levels and flood extents. This is particularly the case in urban environments where the predominance of culverted watercourses, extensive development on the natural flood plain and the interaction of urban drainage systems warrant close scrutiny of the techniques used to determine flood risk.

This paper describes a series of innovative approaches, which have been adopted to reduce the uncertainty associated with the previously identified flood risk at a location in the centre of the City of Bristol, England.

FLOOD MAPPING IN ENGLAND AND WALES

In England and Wales The Environment Agency has the lead role in providing advice on flood issues at a strategic level and in relation to planning applications. Under Section 105 of the Water Resources Act 1991[3], the Agency has a duty to survey matters relating to flooding, including the identification of areas where flood defence problems are likely. Department of the Environment Circular 30/92 "Development and Flood Risk" (MAFF circular FD1/92)[4], and latterly Planning Policy Guidance Note 25: Development and Flood Risk, provide guidance for all responsible authorities on the use of the maps produced by the Environment Agency in discharging this duty.

In 1994 the Environment Agency's predecessor the National Rivers Authority initiated a £25m programme of floodplain mapping across England and Wales to meet the requirements of the Department of the Environment's Circular 30/92 and Welsh offices Circular 68/92. Projects were established to deliver work for development hotspots identified and agreed in a Technical Protocol with the Local Government Association (LGA). In order to provide more precise information a national programme was adopted by the Environment Agency in 1996 to prepare maps for these priority areas. Following the 1998 Easter floods and government pressure all modelling studies and records of flood events were combined to produce one flood outline. This included work carried out as part of the hotspot studies and was supplemented using data from historical records, local knowledge and a study carried out by the Institute of Hydrology (Report IoH 130)[5]. The combined flood outline was used to produce an indicative flood plain map. These maps were issued to all planning authorities in England and Wales during 1999 and were published on the Internet in November 2000. By March 2003 studies at 821 "hotspot" locations across England and Wales had been completed and the IFM is updated annually as new information becomes available.

It is important to note that the IFM was produced as a flood awareness tool, not for making site-specific decisions. Despite this and the fact that PPG25 states explicitly that "such assessments do not absolve local planning authorities and developers from making their own assessments of risk when proposing sites for development …" there is mounting evidence that the IFM is not always applied with the purpose to which it was created in mind. The IFM is increasingly used by financial institutions, the insurance industry, in flood warning and emergency planning to supplement their business. Consequently there is a need to be sure of the quality of the information being presented. Indeed the guidelines require local planning authorities to be aware of the realistic limits to accuracy and precision in all predictions of flood events and apply these in determining development proposals.

The methods used to determine flood water levels and flood extents, which underpin the IFM, are well considered and the techniques that must be applied when undertaking hydrological and hydraulic modelling assessments are carefully specified [2]. However amongst those specialists who undertake the modelling assessments and work with the outputs there is clear understanding that the techniques applied are by necessity fit for purpose. "Fitness for Purpose" in this context is that the quality and reliability of the mapping data meets the needs of a flood awareness tool only.

If when considering proposals for development and through the application of the planning guidance it is determined that a more detailed flood risk assessment is warranted the appropriateness of the IFM and the underpinning modelling is called into question. This is of particular relevance in urban areas where it must be asked; do the model outputs appropriately reflect the flood flow mechanisms, which have often been complicated by the impact of urban development on overland flow routes and the interaction with urban drainage systems? Has it been possible to calibrate and verify the model in situations where there is often a lack of hydrometric data, particularly associated with stormwater drainage systems and culverted watercourses? Has the basis of model development been clearly stated and have the limitations in accuracy (spatially and temporally) been tested and demonstrated not to be sensitive to the selection of influential parameters? In conclusion is the level of accuracy sufficient to satisfy those who are responsible for considering the impact of flood risk during urban redevelopment for example?

The problems facing inspectors and assessors when considering flood risk often, particularly in urban areas, relate to the uncertainty over the predictions in flood flows and water levels. Considered alongside other uncertainties such as the potential impact of global climate change it can be seen that non-experts are increasingly uncomfortable with decision making in such circumstances [6]. Consequently specialists involved in determining flood risk are incumbent to identify concerns and uncertainties in the hydrological and hydraulic models used and wherever possible reduce these uncertainties to aid decision making.

BRISTOL BROADMEAD CASE STUDY

The city of Bristol has long suffered from flooding. There are records of significant flood events of the River Frome in the city of Bristol dating back to the 1700's [7]. Many significant floods have occurred in the 20th century with documented events occurring in 1926, 1935, 1936, 1937, 1960, 1974, 1980, 1982, 1999 and 2000. Flooding in Bristol is not restricted to fluvial flooding. Tidal flooding, deficiencies in surface water drainage systems, and fluvial flooding from the River Avon exacerbates the situation. The focus of this study remains fluvial flooding from the River Frome.

Upstream of Bristol the Frome catchment is dendritic and drains a number of rural and semi-rural sub-catchments. Within the city urban drainage facilities serving the Bristol Area – the Frome culvert system and the Northern Stormwater Interceptor Tunnel - contribute to the management of flood flows in the catchment. The catchment and study area include significant areas of urbanisation, notably Bristol and in recent years there has been extensive development in the lower catchment. Various alleviation measures such as the Tubb's Bottom Reservoir and the Northern Storm Water Intercept (NSWI) have been implemented because of this development and seek to control the magnitude of peak flood flows in the lower reaches of the Frome. Due to the characteristics of the lower urban reaches and the importance of controlling flows through urban Bristol much previous work has been done on the catchment and river flows of the River Frome. However flood risk remains a concern and common flood affected areas include Eastville, St Paul's and Broadmead. Figure 1 shows in diagrammatic form the lower Frome and River Avon hydraulic system below Tubb's Bottom Reservoir and in relation to the city centre.

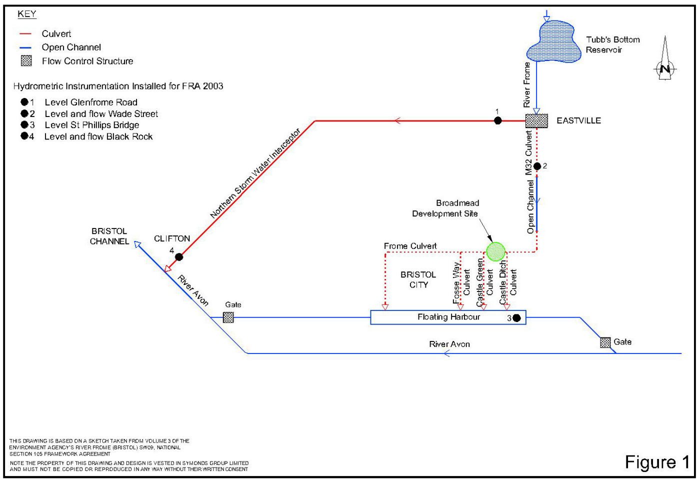

Figure 1

In 2002 the Environment Agency completed a study to prepare Indicative flood risk mapping as part of the Agency's commitments noted above. In addition to mapping a length of approximately 46.9km a baseline unsteady ISIS hydraulic model was created and provided design flood return period levels and flows at each mapping river cross-section location.

To create the model and provide best value for money existing hydraulic models and survey information were utilised. The hydraulic model was split into two distinct reaches at Frenchay Weir to optimise run times and as a result of the clients nodal licence limit. A total of 56 inflow hydrographs enter the models, 40 in the model upstream of Frenchay and 16 into the downstream Frenchay model. The downstream boundary condition for the upstream Frenchay model is the rating curve for the Frenchay Gauging station.

Five downstream boundary conditions were used in the downstream Frenchay model since the river Frome culvert system discharges into the Bristol Floating harbour at a number of locations (Frome Culvert, Castle Ditch Culvert, Fosse Way Culvert, and Castle Green Tunnel). At these discharge points head time boundaries with a constant water level of 6.6mAOD were used for the duration of the flood [(8)]. The fifth downstream boundary condition used was a head time boundary representing tidal levels in the River Avon at the NSWI tunnel's discharge location.

The NSWI is part of a scheme instigated in the 1960s to provide flood relief from the Frome to the city centre. The scheme is managed at the Eastville Intake structure, where gates are controlled to divert a proportion of flood flows into the NSWI and away from the Frome as it passes through the city. The arrangement is shown diagrammatically in Figure 2.on the next page. The outfall structure is tide flapped and subjected to the full range of a spring tide. When the tide flaps close during a rising tide, it is believed that the tunnel can discharge a portion of the flow in a tide locked situation[(9)], the remaining flow being reflected back up through the tunnel as a flood wave. The head time boundary used was based on tidal level data measured at Avonmouth with the assumption that the water gradient or the difference between Avonmouth and the NSWI discharge location water levels was negligible. The outlet of the NSWI to the River Avon is a complex hydraulic structure that has significant influence on the flow capacity of the upstream tunnel. Assumptions on the hydraulic performance of the structure were made and it was modelled as an orifice unit with tide flaps. A flow abstraction unit was used to simulate discharge during tide locking since the outfall is believed to be able to discharge a portion of flow in these circumstances; this portion is estimated to be 60%[(9)] a maximum

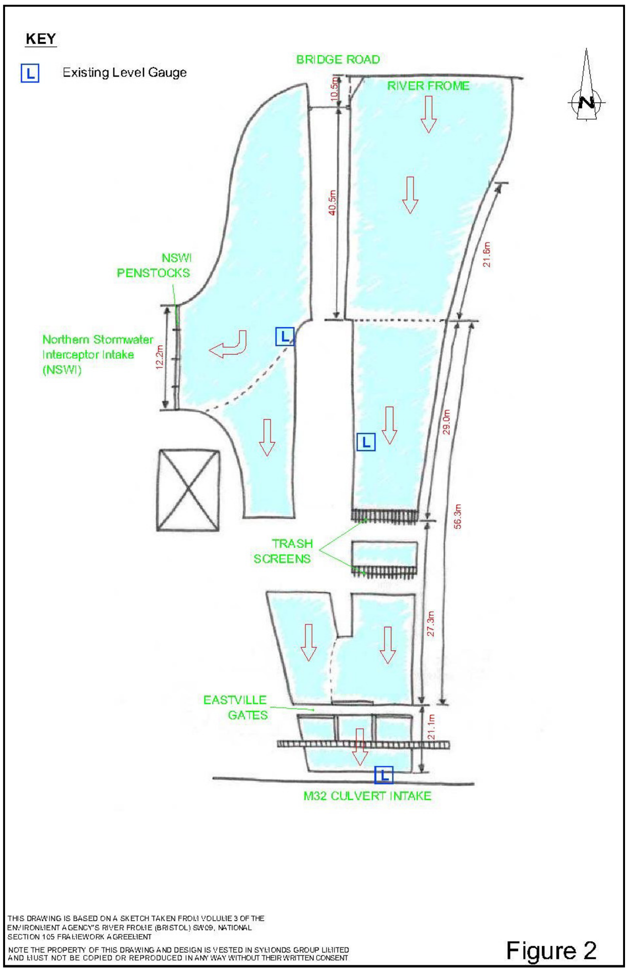

Figure 2

abstraction of 50% was used in the hydraulic modelling. The NSWI intake at Eastville, which consists of four automated vertical sluice gates, was simulated in the model using vertical sluice gate control options. Once all four gates are opened the water level is self determined.

A number of assumptions were made during the construction of the model which although acceptable for the production of indicative flood risk mapping, were highlighted in the supporting documentation. Flood return period water levels were produced for the 100, 50, 20, 10, 5 and 2-year events and flood mapping produced in accordance with the Environment Agency specification [(2)].

BROADMEAD DEVELOPMENT

In August 2002, the Environment Agency was consulted on a planning application submitted to the Planning Authority relating to the redevelopment for mixed retail, office, residential, public open space and access alterations to the highway network at land bounded by Newfoundland Street, Penn Street, Houlton Street, Wellington Road, Castlemead and Bond Street Bristol, principally the area known as Broadmead. In part because of the results of the IFM study, the Environment Agency advised that the redevelopment area was affected by extreme fluvial flows in the River Frome and tidal events from the River Avon.

Symonds Group was commissioned by the Bristol Alliance (the development proposers) to undertake a Flood Risk Assessment (FRA) for the urban redevelopment proposal. The flood risk assessment was undertaken in accordance with the guidance given in planning Policy Guidance Note 25 – PPG25 (DTLR, July 2001). Much of the FRA utilised the work that Symonds had previously undertaken on behalf of the Environment Agency. The FRA recognised that the fluvial flood risk was very much dependent on the operation of the control structure at Eastville and the performance of the culverted sections within the study area. The assessment recognised the assumptions made in the previous modelling exercise and consequently the limitations of the results. Importantly it was acknowledged that in order to reduce the level of uncertainty there was a need to collect additional flow and level data to better understand the influential flow mechanisms at the control structures. There was also a recognition that the currency of survey information, the availability of topographic information through the urban area and crucially the assumptions made at the downstream boundaries added to the uncertainty of the modelled flood risk. As a consequence of the flood risk assessment in October 2002 the Environment Agency advised on conditions that should be attached to the outline permission. Of note the conditions included for the need for a more detailed flood risk assessment to be completed which should incorporate further data to refine the existing hydraulic model. The key issue being that sensitivity testing of the existing model at Eastville revealed that small changes in flow magnitudes generated large fluctuations in water level, which was exacerbated by the significant influence of tidal levels in the Avon on water levels at Eastville – hence the high level of uncertainty associated with flood risk in the lower Frome.
Bristol City Alliance therefore appointed Symonds to undertake a variety of works to reduce the uncertainties associated with flood risk in the development area so that the reserved matters of the planning application could be met. Broadly speaking these works have been:

- Installation of flow and level measurement at key locations.
- Data collection over a winter period to more clearly understand the operation of flood defence structures in the system and provide calibration information
- Collection of additional topographic datasets to characterise the urban area
- Collection of additional datasets with which to model the interaction of surface flows and sub-surface drainage systems.
- Detailed computational modelling to more clearly define the flood risk resulting from overland flows, surface and sub-surface flow interactions and the operation of the culverted sections of watercourse.

DATA COLLECTION

The ISIS model made use of river survey data from existing models that are over 10 years old. Information on the Frome culvert system was originally collected by WS Atkins in the early 1980s [(10)]. Although some new information was collected during the construction of the ISIS model the first step of the detailed flood risk assessment was to quality assure topographic information through an independent check survey. Previously many of the drainage and culvert systems throughout the lower model were either excluded from the model or based on uncertain information. Of particular concern was the absence of information with which to classify terrain in the heavily urbanised areas.

To support the new hydraulic modelling and to provide more detailed information of the urban topography it was decided to use LiDAR (Light Distance and Ranging) information provided by the Environment Agency. The LiDAR dataset made it is possible to characterise the large urban area of the study where traditional surveying techniques would have been cost prohibitive. This is particularly important in instances where the built environment exerts significant influence on the progression of the flood hydrograph and consequently propagation of flood levels. The information collected by airborne sensors can produce high resolution and accurate height information with ground resolutions of 1-2m and height accuracies of 15-25cm. From this information a Digital Terrain Model (DTM) was constructed. Figure 3 is an example of the DTM created to support the new study…

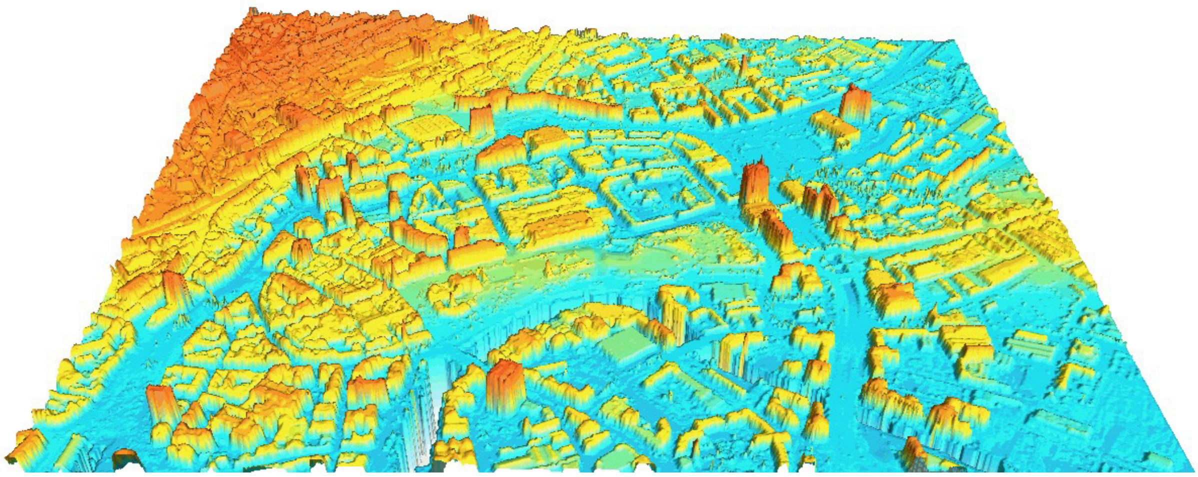

Figure 3: Digital Terrain Model of the Lower Frome centred on the proposed redevelopment area. N.B. The course of the River Frome is culverted throughout the area covered by the image).

This was supplemented and checked against survey datasets collected by traditional methods. Comparisons with manhole cover levels obtained from Wessex Water and with the Ordnance Survey's Master Map Landline dataset were also made to quality assure the DTM.

Details of major subsurface drainage systems including routes, chamber depths, cross-section details and manhole details were also obtained from Wessex Water. These were digitised and geo-referenced to be included as 1-dimensional (1D) elements in the subsequent hydraulic modelling.

In the original ISIS hydraulic model assumptions had to be made at the boundaries of the hydraulic model with little or no supporting data for corroboration. The constant level set in the floating harbour was based on operational information at sluice gates connecting it to the River Avon. Sensitivity testing found the model was sensitive to the head boundaries with increased boundaries reducing the hydraulic gradient and hence potential to discharge floodwaters into the harbour. Consequently there was an increase in flooding in the Eastville to St Paul's reach of the Frome i.e. the proposed development area. Additional sensitivity tests were undertaken to investigate tide locking of the NSWI outfall. Variations in the abstraction percentage (simulating the continued discharge of the NSWI during tide locking), the opening of the NSWI penstock gates threshold and the timing of the River Avon spring tide were also tested. Perhaps not surprisingly, significant deviations from the baseline ISIS model were found when the timing of the spring tide was altered and the efficiency of the NSWI outfall varied. It was concluded that changes in flow had a profound influence on flooding in the lower Frome. The lack of hydrometric information to test the modelling assumptions was therefore a concern for the detailed FRA also. It was particularly important in the detailed FRM to have available hydrometric data for calibration purposes also. Although calibration was possible for a limited number of events in the upper catchment ISIS model, downstream of Frenchay Weir there was no data available for this to occur - yet this is where the greatest implications for flood risk are found. In view of the influential significance of the flood defence structures and the lack of calibration in the lower ISIS model the detailed FRA put in place a programme to collect additional data. This data would test the NSWI tunnel's ability to discharge flows to the Avon during extreme events and provide further confidence in the new computational hydraulic model through calibration. Table 1 summarises the location, purpose and instrumentation deployed to collect this additional information.

Table 1 - Summary details of hydrometric measurement installed as part of the detailed flood risk assessment

National Grid Reference (Site name)	Location	Installation purpose	Instrumentation
ST 563 741 (Black Rock)	Discharge point of the NSWI to the river Avon.	To determine the efficiency of discharge from the NSWI during tide locking.	Two Doppler ultrasonic flow meters with integral pressure level sensors
ST 597 736 (Wade Street.)	Immediately upstream of the entrance to the river Frome Culvert in the vicinity of the proposed development	To determine flood flows entering the river Frome culvert system and to confirm the estimated flows passing through the Eastville complex. To provide information for model calibration.	A multi-path time-of-flight ultrasonic flow gauge. 3 paths set in an in line configuration. Level measurement via pressure sensor and upward looking ultrasonic level device.
ST 594 729 (St Phillips Bridge)	Within the floating harbour	To determine water level for model downstream boundary and to provide information for model calibration.	An air-vented pressure sensor set within a stilling chamber.
ST 603 749 (Glenfrome Road)	Within the NSWI just downstream of the control gates within the Eastville flood defence complex	To determine head difference (with the Black Rock installation) in the NSWI and provide information for model calibration.	Two air-vented pressure sensors set in conduits within the NSWI.

The aims of the regime were to collect information over one winter season in a robust and yet cost effective way. Figure 1 includes the locations at which the instrumentation was installed. Use has also been made of level data measured for the operation of the flood defence structures in the Eastville compound by the Environment Agency. Although not routinely archived a procedure was set up so that the data was recorded for the purposes of the flood risk assessment. The structures within the Eastville compound, which are non-standard, would not provide an easy method from which to derive flow from level. It was therefore decided to measure flow directly within the NSWI as detailed in Table 1. Consequently two Doppler ultrasonic devices were installed within the NSWI. The site chosen was determined by ease of access to the culvert. It was fortunate that the access chamber just upstream of the culvert's discharge point at Black Rock enabled the measurement of both fluvial flows from the NSWI and tidal flows resulting from insurgence past the gravity gates during a high tide. At each installation data is continuously logged at 15-minute intervals, collected, quality controlled and archived. The installations have been installed and the data is collected in line with the relevant British and International Standards [11,12].

The hydrometric installations were designed, specified, procured and installed as part of the flood risk assessment, the costs being met by the redevelopment proposer. Data collection began during September 2003 with the intention that data will be collected for a complete winter season. Figure 4 shows an example of flow and level data that has been collected at the Black Rock site.

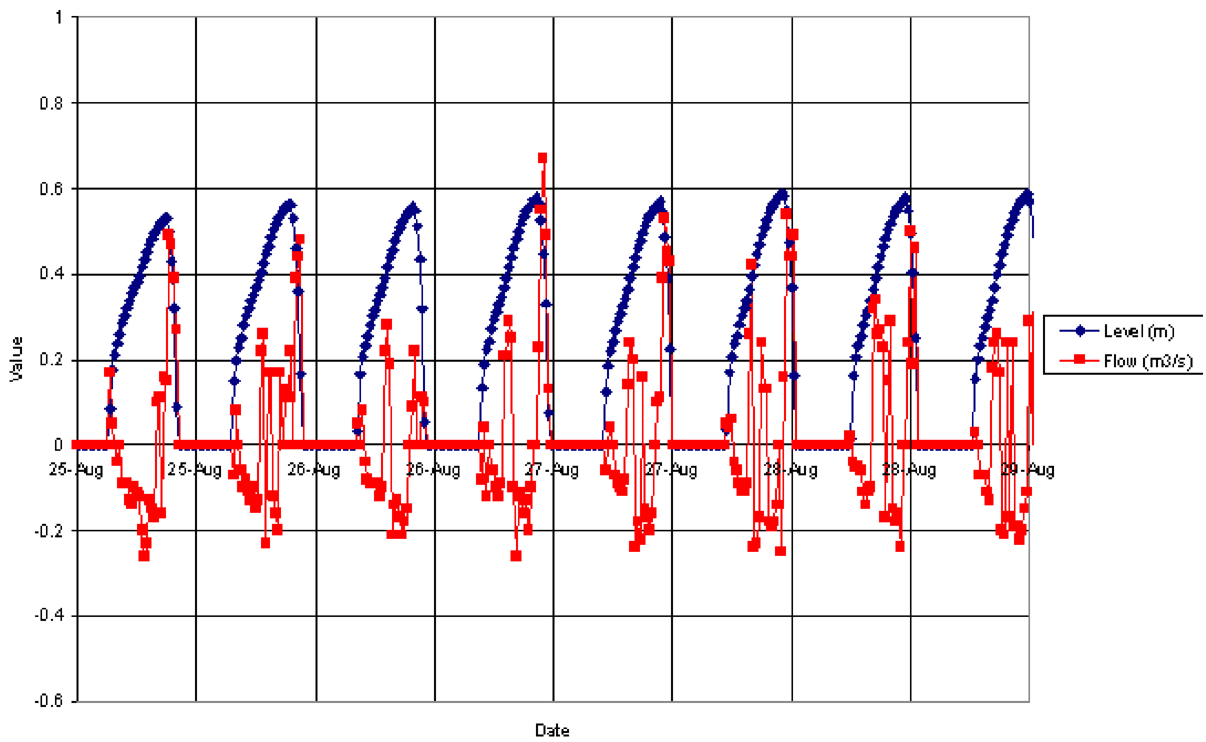

Figure 4: Example flow and level data within the NSWI captured over a four day period. (N.B. information is from one of two Doppler ultrasonics deployed and so represents a proportion of the total flow)

HYDRAULIC MODELLING

The indicative flood maps (IFM) were constructed using a traditional dot-to-dot method. This involved the calculation of offsets determined directly within the ISIS hydraulic model where the modelled water surface intersects ground level beyond the channel bank and plotting these points on a scale map. The points are then joined together by hand using available topographic information (5m interval contours) and engineering judgement to decide what happens between cross sections. The interconnecting plotted lines are then digitised within ArcView to produce the flood outlines. Where the flood level exceeds the elevation of the original cross section the cross sections are extended using landline contour data. This results in a less accurate method of determining the ground elevation at the point of intersection and was found to be particularly constraining in urban areas. Where there are levees or complex flood flow paths, engineering judgement is required to assess the flow in the creation of the IFM. In urban areas ground levels typically vary greatly over small distances and the built environment, channel walls, buildings, road and hard surfaces etc heavily influence the topography creating particular difficulties. So as to provide some ground truth to the flood plain maps derived, flood incident reports and anecdotal evidence illustrating the extent of inundation during recent floods were also considered. It was not possible to prepare flood risk mapping for the lower reaches of the culverted sections of the River Frome leading into the Floating Harbour. It was accepted that the flooding in this area would require more detailed consideration of the interaction of the watercourse, stormwater sewers and other urban drainage systems, together with an assessment of overland flow paths downstream of the entrance to the Frome culvert. Once channel capacity was exceeded by the 100-year event at this and other points no assessment was made of the flow paths outside of the watercourse. The impact of this on the detailed FRA was considered paramount since inundation of the proposed development area may result.

One of the key weaknesses of the S105 study undertaken therefore was the inability to hydraulically model out of bank flood flows through the lower reaches of the River Frome, where the characteristics of the built environment dominate flood risk. The interaction between channelled flood flows, over land flows and sub-surface drainage was also of key concern and not accounted for in the ISIS modelling exercise. It is particularly challenging therefore to derive flood flow and level estimates for urban and suburban areas as they typically show the following characteristics:

- Complex flow routes and levels through the built environment
- The presence of discrete lengths of flood defences
- Interaction between surface water systems and river flows and
- Heavily engineered channels and loss of functional flood plain.

The study area is characterised by many of these features as is shown in Figure 5.

Figure 5: Open channel section of River Frome (downstream of the M32 culvert and immediately upstream of the Frome culvert) illustrating key features of an urban watercourse)

The benefits of 2D modelling of flood risk are noticeably realised in the urban environment where there are demands that estimates are made of the flood hazard and the consequences in addition to flood extent. In this regard it is not only the frequency of flooding that is influential but also the depth, duration, velocity and extent.

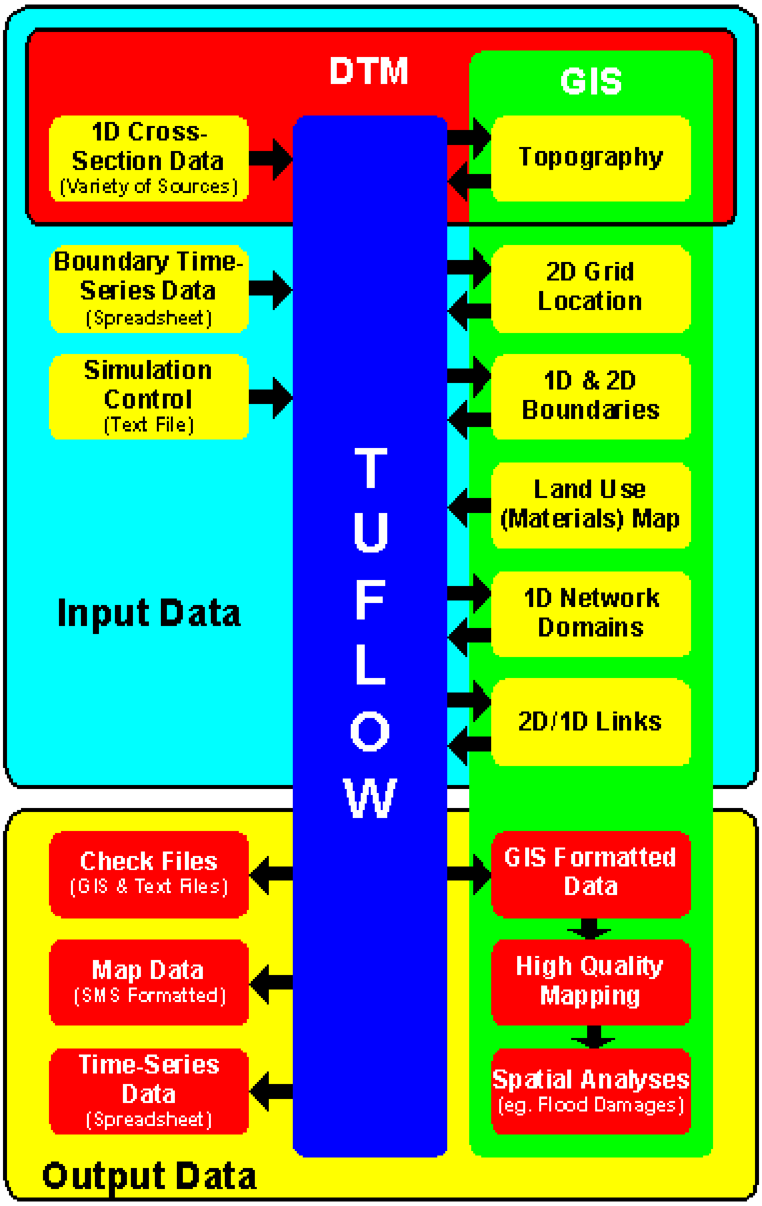

Figure 6: TuFlow input and output structure (reproduced with permission of WBM Oceanics Australia).

Fully hydrodynamic 2D models are capable of furnishing greater information on these parameters and can deliver the required strategic information. The benefits that will be accrued through the use of 2D fully hydrodynamic models in the urban environment can be summarised thus:

- The improved analysis of flood plain (out of bank) flows via better definition of physical situations and hence improved accuracy and confidence in results
- The improved identification and representation of surface water reflected flooding
- The improved prediction of flood hazards i.e. depths of flow velocities and durations and
- The improved representation of fluvial/tidal interaction.

For the purposes of the detailed flood risk assessment it was therefore decided to construct a full two dimensional hydro-dynamic model to overcome these limitations.

The modelling package chosen was TuFlow. TuFlow (Two-dimensional Unsteady Flow) solves the full two-dimensional dε ace flow. It also incorporates the full functionality of the ESTRY one-dimensional (1D) network solving the full (1D) free surface flow equations. The initial development of TuFlow was carried out as a joint research and development project between WBM Oceanics Australia and the University of Queensland in 1990. The project successfully developed a 2D/1D dynamically linked modelling system and latterly incorporated improvements in modelling hydraulic structures, advancing 1D/2D linking and using GIS for data management. TuFlow is specifically orientated towards establishing flow patterns in coastal waters, estuaries, rivers, flood plains and urban areas where the flow patterns are essentially 2D in nature and cannot, or would be awkward to represent using a 1D network model. A powerful feature of TuFlow is its ability to dynamically link to 1D networks. The user sets up a model as a combination of 1D network domains linked to 2D domains.

The TuFlow and ESTRY computational engines utilise GIS and other software for the creation, manipulation and viewing of data. Principally these are a GIS (e.g. MapInfo); 3D surface modelling software running inside the GIS (e.g. Vertical Mapper) for the creation and interrogation of a DTM and for creating 3D surfaces of water levels, depths and hazards; SMS (Surface Modelling System) for the viewing of results and creation of flow animations; and a text editor and spreadsheet software for data manipulation. The blend of these readily available tools provides a powerful, economical combination of software for hydraulic modelling.

Figure 6 illustrates the data input and output structure required to create a TuFlow model. Text files are used for controlling simulations and simulation parameters, whilst the bulk of the data input is in GIS formats. A GIS system is used to set up, modify, thematically map and manage the data. The required datasets include the digital terrain model, a materials layer in which hydraulic roughness is determined, breaklines or lines of elevation that may impact flow paths in the 2D domain (e.g. flood defence structures) and 1D elements such as open channel or sub-surface drainage networks.the actual operational efficiency of the flood defence structure and as a consequence the shape and size of the hydrograph entering the 2D domain.

Outputs of water level, depth, flow direction and velocities were obtained from the 2D model for a number of scenarios. Figure 7 shows modelled water depths from the baseline 1 in 100 year flow (plus 20% for sensitivity) model for the study area. Subsequently the baseline model was amended to include the topography of the proposed redevelopment.

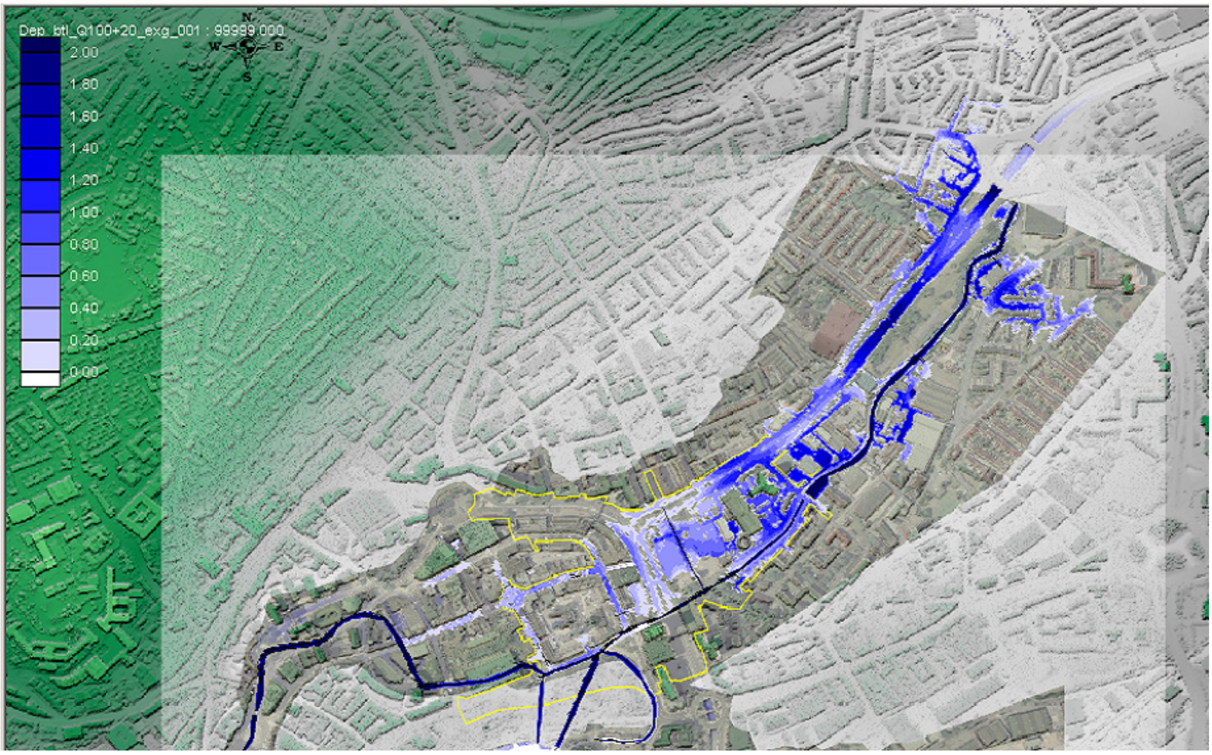

Figure 7: Example output from 2D hydrodynamic model. Depth (m) resulting from 100 year return period flood (plus 20% for sensitivity) throughout the study area.

Outputs of water level, depth, flow direction and velocities were obtained from the 2D model for a number of scenarios. Figure 7 shows modelled water depths from the baseline 1 in 100 year flow (plus 20% for sensitivity) model for the study area. Subsequently the baseline model was amended to include the topography of the proposed redevelopment. Figure 8 shows a comparison of the modelled water levels before and post development for the same event.

From these results it was possible to demonstrate not only the baseline conditions in terms of flood extent, flow routes and velocities but also the consequence of the proposed development. As part of the flood risk assessment ongoing studies are investigating mitigation methods through the incorporation of additional storage, culverted and surface flow routes and building thresholds and floor levels.

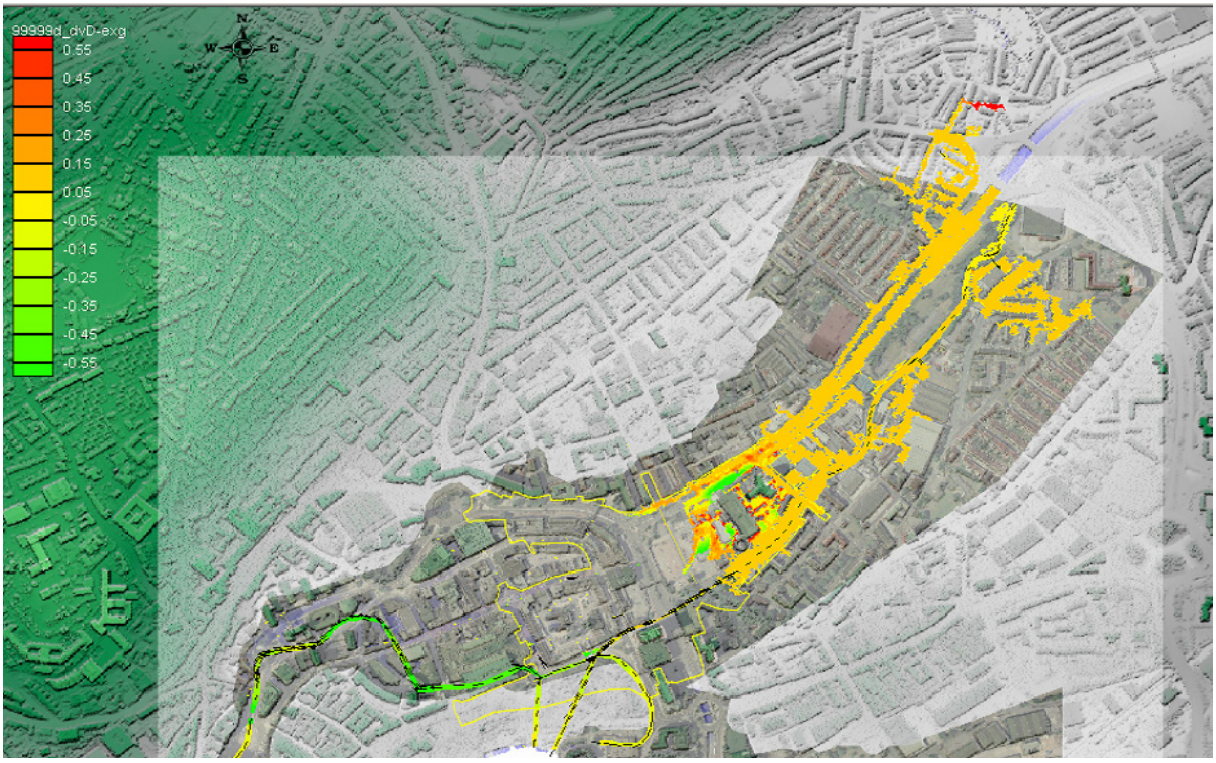

Figure 8: Example output from 2D hydrodynamic model. Difference in depth (m) before and after proposed development for 100 year return period flood (plus 20% for sensitivity)

CONCLUSIONS

A number of drivers are changing the needs for flood plain mapping and flood risk assessment [(12)]. The publication of PPG25 in July 2001 led to a major change in the way local planning authorities (LPAs) consider flood risk as part of the Town and Country Planning process. Additionally other organisations (financial planning services and insurance bodies) are increasingly using flood risk information. There is therefore a fundamental need to recognise the limitations and uncertainties of the (mapped) data that is available to such organisations and where required there must be amendment and improvement of the techniques which underpin these studies. The planning system now offers opportunity to realise these objectives.

In the built environment in particular it is essential that the model and techniques adopted for the study are fit for purpose. The model selected must accurately reflect the flow/flood mechanisms; be calibrated and verified wherever possible and must demonstrate that it is not sensitive to the selection of influential parameters.

In conclusion it is incumbent upon specialists in the field of flood risk and flood mapping to identify concerns and uncertainties in the hydrological and hydraulic models used. Whenever required these uncertainties must be reduced through the application of the most appropriate techniques available together with the collection of good quality hydrometric and supporting information. In doing so considerable assistance will have been given to those required to make decisions where flood risk is an issue.

REFERENCES

(1) OFFICE OF THE DEPUTY PRIME MINISTER, Planning Policy Guidance Note 25 – Development and Flood Risk, July 2001, HMSO, London.

(2) ENVIRONMENT AGENCY, Natcon 257 Specification for Section 105 Flood Risk Mapping Version 4.0, February 2003, Internal Document.

(3) WATER RESOURCES ACT 1991, Part IV General Functions With Respect To Flood Defence, 1991, HMSO, London.

(4) DEPARTMENT OF THE ENVIRONMENT, Circular 30/92 – Development and Flood Risk, 1992, HMSO, London

(5) INSTITUTE OF HYDROLOGY REPORT NO. 130, Flood Risk Map For England And Wales, October 1996, CEH Wallingford, Wallingford, Oxfordshire, England.

(6) DALE, AJG, PAPER TO CIWEM RIVERS AND COASTAL GROUP MEETING, Development and Flood Risk – A Precautionary Future, January 2003.

(7) BRITISH HYDROLOGICAL SOCIETY, Chronology of British Hydrological Events, http://www.dundee.ac.uk/geography/cbhe/

(8) W.S. ATKINS AND PARTNERS, Bristol and Floating Harbour Preliminary Findings, November 1993

(9) CITY AND COUNTY OF BRISTOL, The Northern Stormwater Interceptor, 1962

(10) W.S. ATKINS AND PARTNERS, Interim Report, Evaluation of the River Frome (Bristol) Culvert System, 1982

(11) ISO/TS 15769:2000, Hydrometric Determination - Liquid flow in open channels and partly filled pipes – Guidelines for the application of Doppler-based flow measurements, International Organisation for Standardisation, Geneva

(12) BS 3680 Part 3E (ISO6416) 1992, Measurement of Liquid Flow in open Channels – Measurement of Discharge by the ultrasonic (acoustic) method, International Organisation for Standardisation, Geneva

BIBLIOGRAPHY

ENVIRONMENT AGENCY, Flood Mapping Strategy, July 2003, Internal Document.

ENVIRONMENT AGENCY, NatCon 257 National Section 105 Framework Agreement River Frome (Bristol) SW09 Final Report August 2002.