FLOOD MODELLING THE COMPLEXITIES OF URBAN ENVIRONMENTS
MEETING THE CHALLENGE IN NEWCASTLE

Bill Syme
Associate, WBM Pty Ltd

David Gibbins
City Strategist – Integrated Flood Management, Newcastle City Council

Presenters: ***Bill Syme and David Gibbins***

Presenters' Profiles

Bill has over twenty years experience in computer modelling, mostly within the floodplain management fields. He is the primary author of the TUFLOW modelling software, which is now widely used within Australia and the UK for flood modelling. Bill's experience includes numerous flood investigations within Australia and overseas, including recent visits to the UK where the TUFLOW software has been selected for the Thames Embayments Inundation Study in London, and for modelling the London 2012 Olympic Site.

David holds a degree in Civil Engineering from the University of Newcastle and has worked in a diversity of roles with Newcastle Council. After the devastating flash flooding in Newcastle in 1988 he became part of a group seeking to find ways to manage these risks. He now heads the development of Council's integrated citywide flood management strategies. Hobby's include a recent attack on kayaking.

Postal Addresses

Bill Syme
C/O WBM Pty Ltd
PO Box 203
Spring Hill, Q, 4004
Australia

E-mail: wjsyme@wbmpl.com.au

David Gibbins
City Strategist Integrated Flood Management
Newcastle City Council
PO Box489
NEWCASTLE NSW 2300

E-mail: dgibbins@ncc.nsw.gov.au

Flood Modelling the Complexities of Urban Environments Meeting the Challenge in Newcastle

Bill Syme
Associate, WBM Pty Ltd

David Gibbins
City Strategist – Integrated Flood Management, Newcastle City Council

Abstract

Large urban catchments can present extraordinary challenges to both flood simulation software and modellers. A little more than a decade ago software and computing power was stretched "to the max" to confidently simulate comparatively simple riverine flood behaviours in floodplains. Today this level of complexity equates to just a small element in a remarkable mosaic of multilayered complexity which forms the Throsby, Cottage and CBD flood model in Newcastle. The community's and the development industry's expectations have increased to the point where models need to predict flood levels to the highest standard. Given the density of urbanisation, understanding the train of causes and affects is paramount. A major step towards this challenging goal was the development and calibration of a high-resolution computer flood model across the 42 sq km study area and some 19,000 flood affected properties. Recent advances have offered the opportunity to develop a confident and useable model. An unusually comprehensive historical data set for the 1988 and 1990 floods provided a solid base for validating the model's predictions. This paper presents the need for the approach adopted, the TUFLOW model developed and its rigorous calibration. Challenging and interesting aspects to the model's development and validation are discussed. The benefits of taking on a challenge and successfully applying recent advances in technology were realised.

Key Words: Technology Advances; Flood Modelling; Urban; Newcastle; TUFLOW

1 Introduction

The Throsby, Cottage and CBD catchments contain much of Newcastle's urban expansion since the mid 1800's. Creeks were realigned, covered and replaced by concrete channels and large box culverts. Wetlands and estuarine areas were filled. Flood behaviour was changed dramatically, and made far more difficult to model than in their natural state.

The Throsby and Cottage Creek catchments, and to a lesser extent the CBD, have an established history of flooding. The catchments are steep around their perimeter, but drain onto low-lying, flat areas, where it is difficult for floodwaters to escape. Some of the low-lying areas are subject to tidal and other ocean influences.

Beginning in the late 1800's in response to the flooding and health problems, the creeks have been heavily engineered into concrete lined stormwater channels, or replaced by underground pipes and box culverts. In a number of areas, the creek lines have become non-existent, with the pipes and culverts being relied upon to carry the floodwaters.

Roads also act as flow paths once the capacity of the channels and culverts is exceeded. A number of rail, road and other embankments exacerbate the flood problem by diverting and blocking floodwaters. Continued urbanisation has also increased the rate and quantity of runoff, further worsening the flood risk.

While the drainage engineering works have reduced the flood risk in some areas, problem areas remain and it is not unfeasible for floods to massively exceed the capacity of the channels and culverts. The potential for widespread flooding, risk to life-and-limb and damage to buildings and infrastructure is an on-going issue for Newcastle City Council.

These risks were amply demonstrated during the April 1988 and February 1990 flash floods. Simulations of more extreme floods reveal an even greater and wider level of risk.

2 Background

The coastal location and flashy nature of the catchments combine to give a susceptibility to intense but very localised flooding forced by thunderstorms over sections of the three catchments. Historically in the last twenty years this spawned a series of isolated and reactive small investigations across the study area in what were perceived to be localised 'hot spots'.

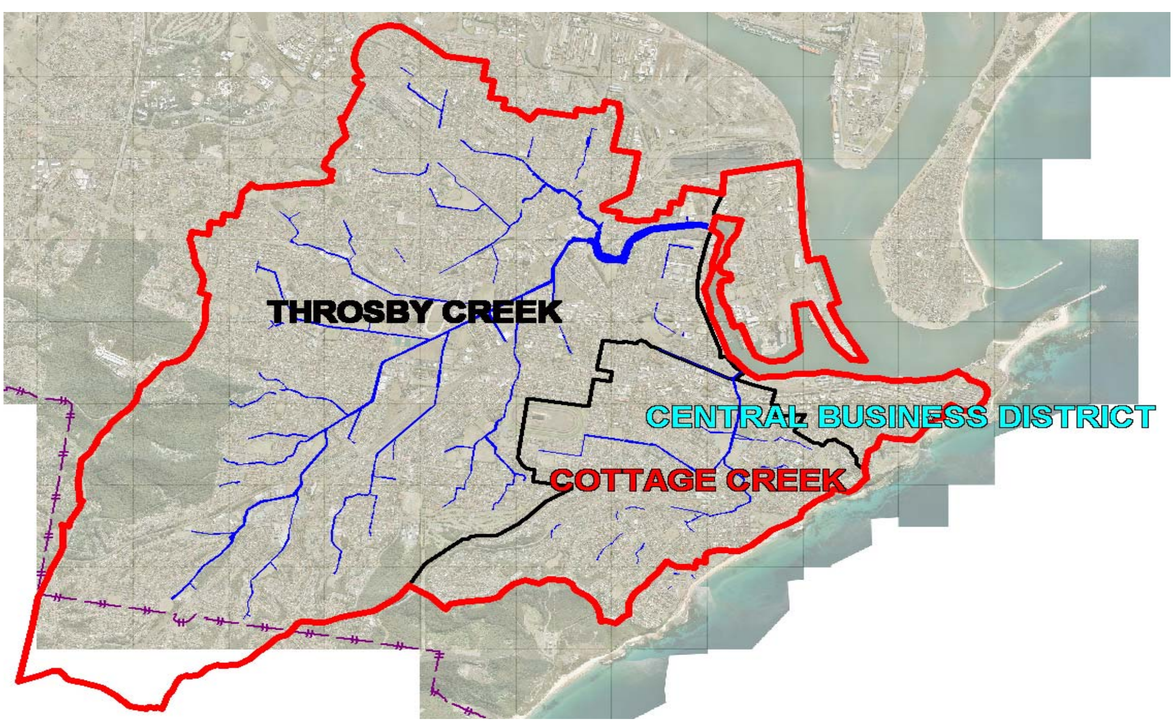
Research into available flood records from Newspapers since early European settlement gave a perspective that flooding in the three catchments was a much broader risk and a more strategic approach would be required.

In the late 1980's an attempt to derive a computer flood model by the Total Catchment Committee through the local Water Authority was launched. Maps were produced, but these had to be highly qualified and restricted in their application. While the attempt was genuine, time and resource constraints in addition to limitations of computer power, available software at the time and topographic data, resulted in flood information that was not confident enough to apply to individual properties.

The lack of a confident flood model translated into developments having floor levels set by Council staff after field inspections and an examination of broad-scale historic flood maps compared with the results of the above broad-scale flood model (where output was available in a useable form). This is a time consuming, frustrating and stressful method, contributing to a high turnover of Council staff.

3 Setting the Bar

The bar was raised and set when the Building Better Cities program initiated an inner city revitalisation program in the early 1990's. This major redevelopment that would take place over more than a decade was pivotal from a flood management-planning viewpoint.



Study Area

The redevelopment would skirt the majority of Newcastle Harbour frontage at the bottom of the three catchments of Throsby Creek, Cottage Creek and the CBD. The revitalisation authority (The Honeysuckle Development Corporation) and Council carried out a series of studies that defined floodways, set floor levels and found that the extreme flood events of the three catchments crossed over in the lower reaches.

The Honeysuckle studies were of necessity somewhat generalised and significant differences in design water levels (up to nearly one metre) were detected with a later flood study in Cottage Creek. This was an unsatisfactory position.

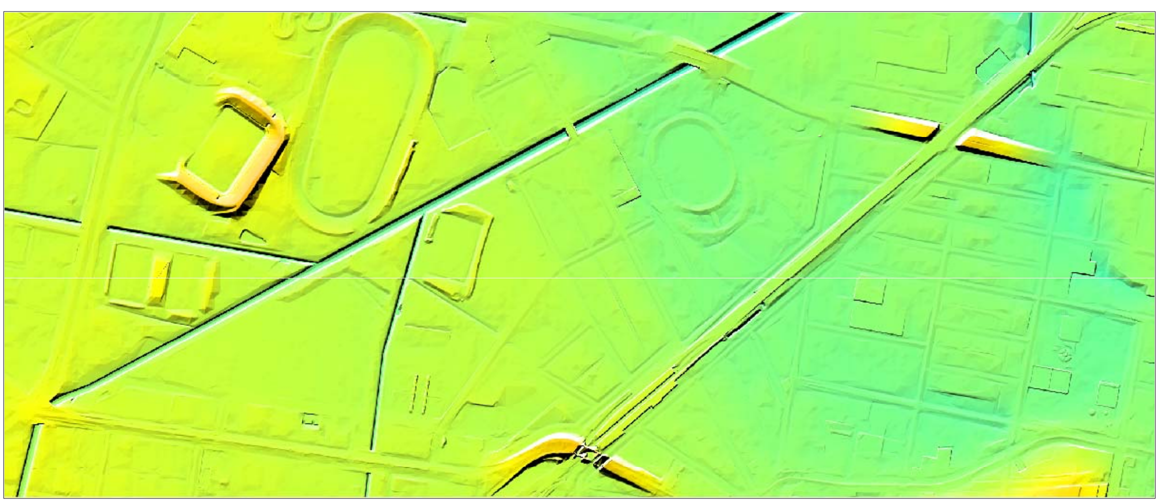
The need for an integrated flood study across all three catchments of the highest accuracy possible became apparent to the Committee in the new millennium. Useable results for thousands of individual properties (where levels could vary within individual properties) were required. There was significant questioning if such a study would be achievable over such a complex and large area. With some risk taking and enterprise the bar was set and the present study commissioned.

4 Defining the Flood Risk

The Throsby and Cottage Creek catchments, and the CBD Flood Study, is being carried out to meet the objectives described above, leading to a much improved and better understanding of the flood behaviour and the risk to the community. It is producing leading-edge computer based models that simulate the flooding processes of the whole catchment, and also the potential interaction between catchments in the low-lying areas, hence the combining of the three catchments into one study.

The study is being carried out in preparation for a Flood Risk Management Study that will investigate options and planning strategies for reducing the flood risk and minimising damage to buildings and infrastructure. It is noted that the Flood Risk Management Study will be simplified by the fact that for all practical purposes the catchments for the Study Area are in a single (Newcastle City) Local Government Area

The Study is being carried out through the Newcastle Flood Risk Management Committee with Grant assistance from the NSW Flood Program, which includes Commonwealth assistance.



The above image shows the DTM generated by the 12D software then converted to Vertical Mapper. The 12D DTM triangulation is a combination of photogrammetry and ground survey for the open channels. The final DTM is an excellent example of a good DTM for flood modelling and floodplain management. It does not have any of the data "noise" and vertical accuracy and triangulation issues associated with ALS data.

5 Topographic Data

Even before the commissioning of the Study, it was apparent that a high quality representation of the topographic and built environment would be a fundamental foundation to all efforts. Without such a representation no simulation of flood behaviours would be successful as the flow patterns were completely dependent on ground levels and the shape of the built environment. Even if flood surfaces could be derived without this detailed topographic information it not be possible to map the results and determine which properties were affected without such data.

Gathering this information is impractical by conventional land survey because of the sheer scale – there was about 25 square kilometres of detailed topography to be represented. After intensive investigation of options under expert guidance commissioned through the University of Newcastle, including the emerging technology of air borne laser scanning, it was decided to commission conventional but very low-level photogrammetry.

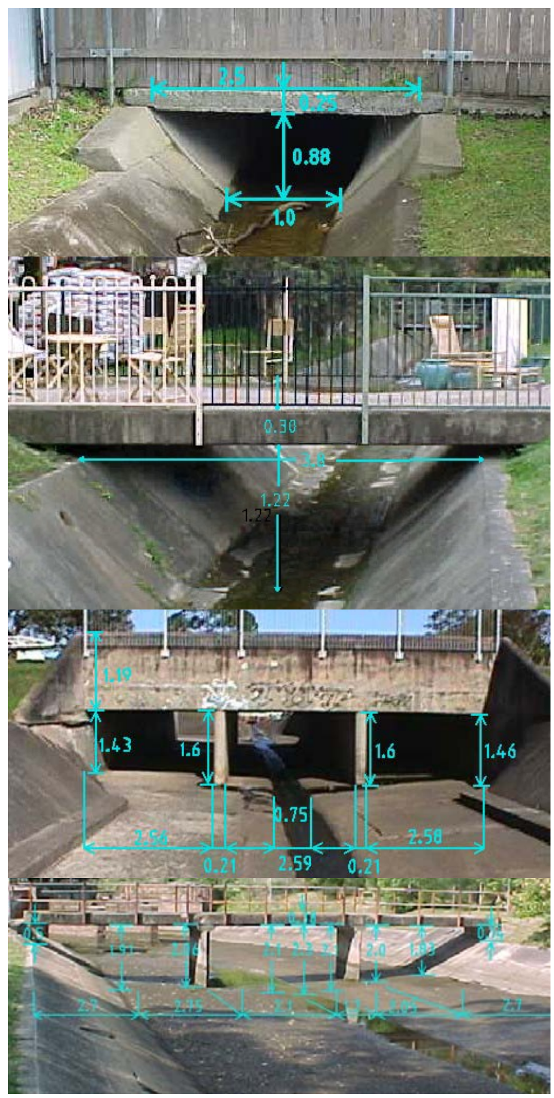
The photogrammetric vertical accuracy was independently assessed with thousands of ground truth random test points required to be within +/-0.1 metre (85% confidence). The final digital elevation model resulting in millions of triangular elements.

Of critical importance was the representation of the numerous concrete lined channels, which even in large events carry the bulk of the floodwaters. In endeavouring to minimise uncertainties, it was paramount that these critical flow paths were ground surveyed and 'cut in' to the overall DTM. Rather than carry out the conventional cross-section survey approach, the channels were surveyed as 3D breaklines along their banks, sides, low drainage sections, etc. This approach provided a more cost effective and accurate approach, and greater ease when cutting into the photogrammetric DTM.

This work was completed before the present flood study was commissioned. (The photogrammetry was carried out by QASCO P/L, and the building of the DEM by WBM P/L with independent assessment and guidance carried out the University if Newcastle (Fryer 2001). The University of Newcastle review commented that one reason for the success of the DEM was the ever-present human control of the derivation and data processing, rather than being an automated process.

In addition to the DTM, NCC collected the following topographic data:

- Bathymetric (depth) surveys of tidal areas were also stamped into the DTM;
- Surveys of hundreds of stormwater channel crossings (eg. bridges); and
- Dimensions and levels of the underground pipe system (down to 900 mm diameter).



Examples of a few of the many structures.

6 Hydrographic Data

Council surveyed several hundred flood heights reported by residents as part of a previous study. The types of information sought included:

- local knowledge and personal experiences in flooding and flooding patterns; and
- any flood marks or recollections of flood heights.

Flood marks were graded in terms of their reliability to represent the flood peak, and have been an invaluable source of data for calibrating the computer models.

Other hydrographic data collected are:

- Rainfall data from seven pluviographs within the study area;
- Harbour tide levels;
- Several water level gauges within the open channel system; and
- Flood extent surveys from past flood events.

The study is very data-rich in historical information compared with most flood studies carried out, and offers the challenge of a rigorous model calibration within a complex urban flooding problem.

7 Flood Behaviour

In minor rainfall events, floodwaters generally remain contained within the pipes, creeks and stormwater channels, with little or no overland flooding. Streets (gutters) may also act as a pathway for overland flows.

In larger events, the capacity of the stormwater drainage system can be exceeded. This occurs where pipes are too small to carry the floodwaters; pits and manholes are surcharged; and water starts to flow out of a stormwater channel and onto neighbouring streets and property. When this occurs, roads in particular become important secondary flow paths. In recent times, this occurred during the April 1988 and February 1990 floods where some thousands of properties were affected.

For very large rare and extreme floods, the floodwaters would continue to extend overland, causing major flooding and severe risk to the community.

The occurrence of elevated ocean levels from a large high tide, an intense low-pressure system and/or general sea level rise from global warming will further exacerbate flooding in the low-lying areas.

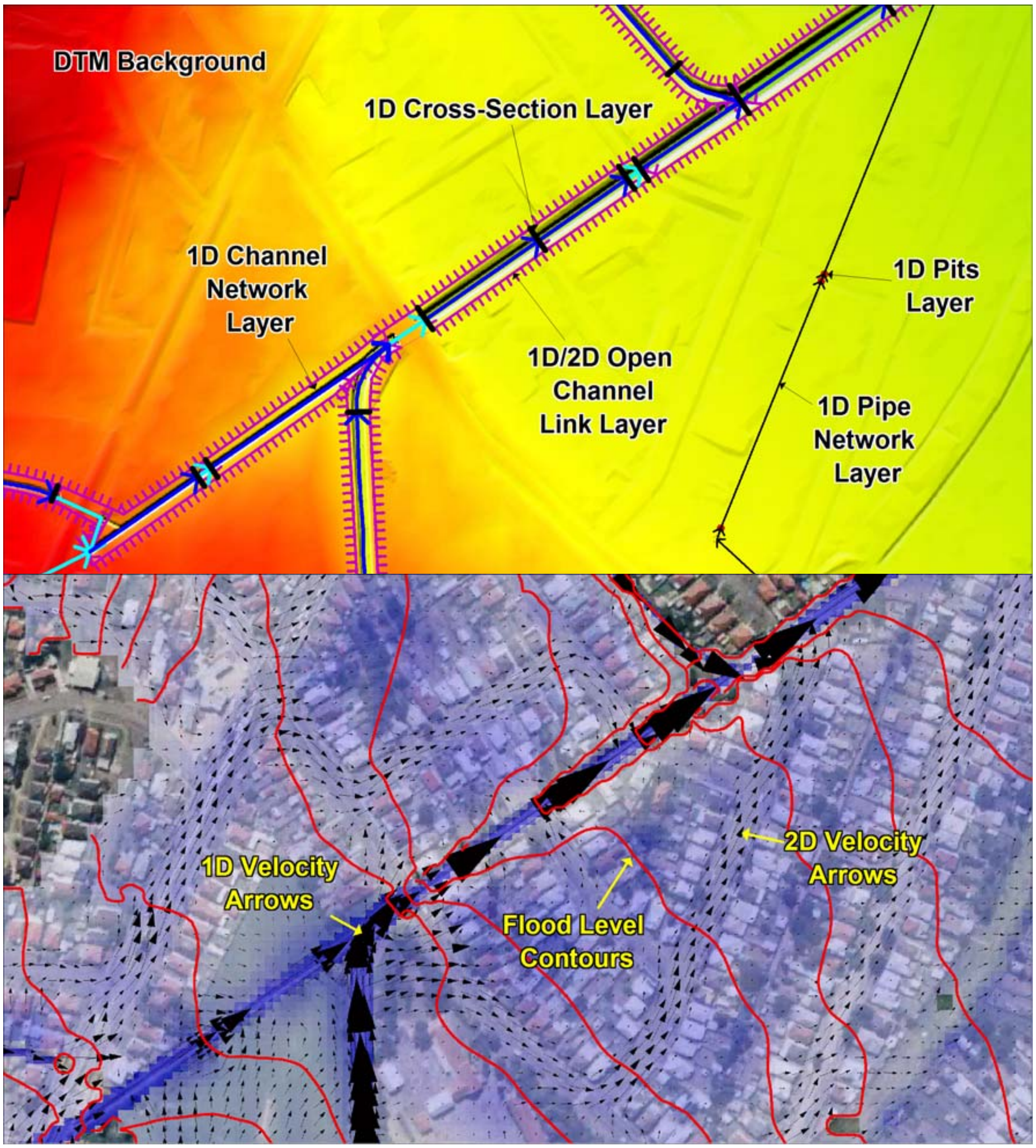
The above photo of the February 1990 flood, taken after the flood peak, illustrates the high velocities experienced, and reproduced by the TUFLOW model, in the concrete lined channels.
The floodwaters entering from the left as the flood receded was also reproduced by the model.

The computer models developed aim to reproduce the various physical processes described above for a range of flood severities.

The first process is that of converting rainfall to the flow of water in pipes and down streets, creeks and gullies feeding into the stormwater drainage system. This is referred to as hydrologic modelling.

The second process is to take these flows and simulate their passage down the larger creeks and stormwater channels all the way through to the harbour. This is referred to as hydraulic modelling. The hydraulic model also simulates the tidal conditions in the harbour.

The hydrologic and hydraulic models were calibrated to the most data rich floods of April 1988 and February 1990.



The top image shows the DTM in background with several TUFLOW GIS layers.
The bottom image shows the TUFLOW model output over the same area.

8 Hydrologic Model

The hydrologic modelling was carried out using the WBNM software over the entire catchment. To expedite the process, two hundred sub-catchments were automatically delineated from a catchment wide DTM using the StreamBuilder software.

Land-use categories, digitised for the entire catchment, were used to assign proportions of pervious and impervious fractions to the sub-catchments. The resulting GIS layers of sub-catchments and streams, along with GIS layers of rainfall distribution and pluviograph proximity, were then processed using in-house software to automatically generate the WBNM input data files.

9 Hydraulic Model

The study area presents a range of challenges for the hydraulic modelling, including:

- Several hundred rectangular culvert sections (one reach which exceeds 1.6km in length);
- Over a hundred bridges of many shapes and designs;
- Several hundred circular underground pipes;
- Steep concrete lined open channels that experience velocities up to 6m/s, and both sub-critical and super-critical flow regimes;
- Complex and variable overland flow along streets and through properties.

The first four dot points above are best represented using a 1D scheme as the flow is essentially in one dominant direction (eg. in the direction of the pipe), rather than spreading out over a floodplain.

The last dot point is most accurately modelled using a 2D solution as the flow paths often vary in direction as the floodwaters rise, spread out and then recede. 2D solutions allow floodwaters to vary in direction, and are ideally suited to modelling overland areas.

A TUFLOW 1D/2D model was therefore adopted as the best option for representing this array of 1D and 2D flow patterns. Its powerful 1D/2D linking options were critical to easily setting up the model, especially given that the several thousand 1D elements nearly all needed to be linked into the surrounding 2D domain.

The ability to develop a model of this complexity also benefited from TUFLOW's GIS layering of various types of data. This allows pipes, bridges, open channels, etc to be stored and managed in separate GIS layers.

Flooding with in the study area.
The top photo shows a hydraulic jump that has formed in an open channel. Review of the flow regimes in the model shows that a hydraulic jump would occur in the same vicinity.

10 Model Calibration

The hydrologic and hydraulic models were calibrated to the data rich floods of 1988 and 1990.

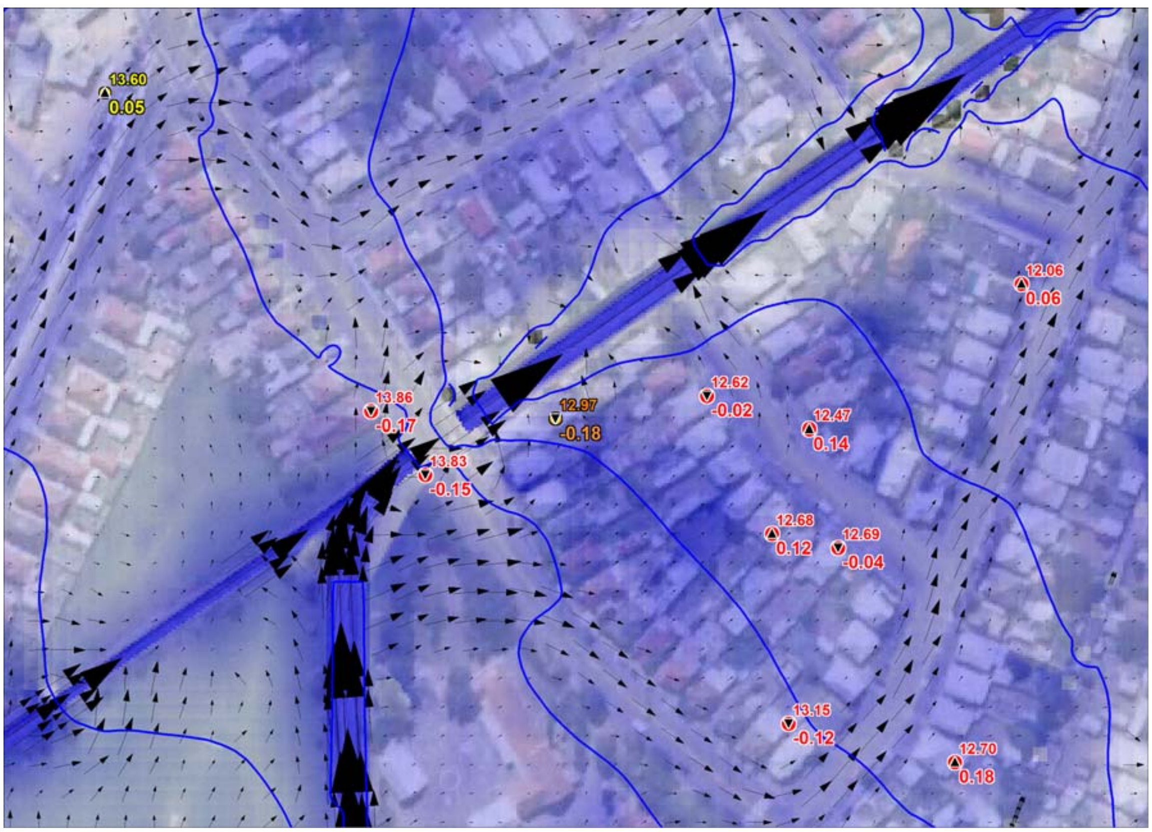
On the 2nd and 3rd of February 1990, around 300mm in a 48 hour period fell over the study area in several bursts. Five reliable pluviograph recordings within the study area were available, and five flood height gauges recorded the rises and falls of the flood within the stormwater channels. The first and largest peak caused the worst overland flooding around 3pm on the 2nd of February.

Previous investigations commissioned by Council identified around 160 sites within the study area provided information on the 1990 flood. Of these, around 70 identify a potential flood height to assist in the model calibration. These flood marks provide valuable information on flood levels away from the stormwater channels. In addition, there are a number of photographs and recollections that also assist in the model calibration process.

A similar, but lesser, data set was retrieved for the 1988 flood. As the 1990 flood was more widespread, had a greater and higher quality data set, it was chosen as the primary calibration event, while the 1988 flood was used as a secondary calibration event.

During the previous data collection study, the flood marks were graded according to their perceived accuracy. For example, a Grade 1 flood mark is a reliable representation of the flood peak (eg. watermark), while Grades 2 to 4 were progressively less reliable. Grade 5 was assigned to observations that could not be translated to a flood height.

The processing and presentation of TUFLOW model's calibration performance was greatly enhanced through using the flood mark grading and GIS. Figure ??? shows the recorded flood levels (smaller numbers) and the difference between the modelled and recorded level (larger numbers). Red fonts are



The above image shows how the TUFLOW model calibration to recorded flood marks was presented to Committee members in addition to the more traditional longitudinal profiles and time-series graphs. The red marks are Grade 1 marks, orange Grade 2 and yellow Grade 3.

the Grade 1 marks, orange Grade 2 and yellow Grade 3. Through displays such as this, the presentation of the model's calibration and general dissemination of material to the Flood Study Committee was very much enhanced.

Key observations from the calibration process were:

- Parameters adopted for both the hydrologic and hydraulic models fell within conventional bounds.
- Initially, the TUFLOW model was setup and calibrated using a coarse 20m resolution 2D grid, with the final calibration shifting to a 10m grid. This greatly expedited the calibration process as the 20m grid model had significantly shorter simulation times allowing quick turnover of the numerous model runs carried out.
- The video animations and GIS mapping of TUFLOW output was of significant benefit for the Committee to understand and comment on the computer modelling. Importantly it highlighted areas of concern. In one instance, the model predicted overtopping of a railway line and substantial inundation on the downstream side of the embankment. After ground survey of the railway embankment and tracks, this was subsequently shown by the model not to be the case (as previously indicated by several Committee members and local residents), highlighting the need for ground survey in critical areas where uncertainties in the DTM can have a significant influence on model predictions (it's amazing what a difference of 0.2m can make in a flat urban environment!).
- The absence of pipes less than 900mm in diameter causes excessive inundation in some of the lower-lying, flat, areas of the study area that rely on these pipes for stormwater drainage. As the costs of surveying these pipes were prohibitive within the study's budget, there therefore needed to be an appreciation of this issue by committee members and the community when reviewing predicted flood inundation maps.
- The modelling of large buildings remains a difficult issue. The options examined were: completely removing 2D cells within the building outlines; or allowing water through the buildings but applying a very high Manning's n roughness. The latter approach was adopted, but further research in this area would greatly benefit urban flood studies.
- In a similar vain, fences also pose a significant dilemma in urban hydraulic models. Of particular mention in this study was the delineation of fence lines using high resolution aerial photography along the open channels. The 1D open channel cross-sections extracted from the DTM also incorporated a third column representing the variation in roughness across the channel. Between the fences lower Manning's n values representing concrete and mown grass were used, while a much higher n value was used where the 1D cross-section extended into gardens due to the numerous and "impenetrable" fences both parallel to the open channel and between properties.

11 Onwards to Managing the Flood Risk

Some tasks remain in managing the flood risk. The Study will deliver to Council velocity and depth data for the entire study area for all design events. This will enable Council to map velocity depth products and determine provisional flood hazards in accordance with the NSW Floodplain Development Manual. This information will then determine final flood hazards in accordance with Council's currently adopted Flood Policy that very much recognises the unique challenges of urbanised flash flood catchments. Provisional flood-ways and storages will be determined in collaboration with the Committee as part of this study.

The foreshadowed separate Floodplain Risk Management Study will have a confident baseline set of design floods and a robust model that will enable a full suite of scenarios to be tested, analysed, and simply yet powerfully displayed to the community.

12 Community Consultation

The model calibration that used the historic data previously gathered was placed on public exhibition with the intention of clarifying the model's performance, and to seek any other data not previously collected to further improve and/or confirm the models' calibration. However, there was a surprisingly small attendance. We are unsure as to whether this is because of: the extensive resident surveys previously carried out; that there have been no floods of great concern since the 1990 event and therefore it is not a pressing issue within the community; poorly advertised; that it was just awful weather on the night (which it was!).

Council carried out a phone survey for some "hot spot" areas in the calibration using Council records of those residents whose property had not been sold since 1990. This helped resolve some issues in the calibration where no data on whether the land flooded or not in these events was otherwise available.

13 Conclusions

In conclusion, the challenges laid down to develop detailed and reliable flood management modelling tools for the Newcastle urban area have largely been met. The TUFLOW computer model is considered to be leading edge in its complexity, size and capabilities, and more than adequately meets the high standards and expectations laid down for the study. There are some weaknesses in the model such as not having pipes under 900mm in diameter due to the cost of surveying. These issues can be readily resolved in the future with further funding if required.

The study has demonstrated:

- The excellent detail that 1D/2D models can now represent complex urban areas.
- The fundamental importance of calibration data, and the need to manage data (much of the hydrographic data used in this study was officially lost, and only found by contacting a former employee of the local water board who had a 5¼" floppy diskette and obscure software to extract it!).
- The power of GIS to present and disseminate large amounts of information to committee members and other stakeholders.
- Persistence in seeking to resolve anomalies can pay off, but some things may never be explained where there are uncertainties.
- The confidence that one may now have in computer modelling of this nature.
- The benefits of taking on a challenge, innovating and succeeding.
- Australian products such as TUFLOW are at the technological leading edge.
- No matter how much you advertise, it's hard to get the community interested in a meeting on a cold, rainy night!

14 References

John G. Fryer, Harvey L. Mitchell and Robert Pâquet - Proposal for Integrating and Filtering Spatial Data by Surface Correlation Presented at the 13th Annual Colloquium of the Spatial Information Research Centre, University of Otago, Dunedin, New Zealand, December 2nd-5th 2001

Throsby, Cottage, CBD Flood Study References: www.newcastlefloodstudy.com

TUFLOW References: www.tuflow.com