FLOOD MODELLING - THE BIG PICTURE

David Crompton
Floodplain Engineer Campbelltown City Council
Cathy Kinsey
Coordinator Stormwater and Structural Design Campbelltown City Council

Abstract
Flood modelling has become increasingly more complex in the last decade with improvements in computing power and the availability of electronic data enabling a higher level of detail to be analysed and presented. Campbelltown Council has undertaken flood modelling for the 90km2 Bow Bowing Bunbury Curran Creek catchment which is a mixed use rural urban fringe catchment in South-Western Sydney. This paper examines the requirements for preparing a flood study using the 1D/2D TUFLOW/Estry computing package and the problems that arose. Software issues with CatchmentSIM, XP-RAFTS, and TUFLOW/Estry were all encountered and modifications to each were required to achieve acceptable outcomes. Working with the software developers was an integral part of the Flood study. Data sourced from Council’s Asset register was not directly compatible with TUFLOW and had to be manually manipulated before importing. Despite these issues Council found that the effort was worth the time and delivered results that were substantially superior to any modelling which had previously been undertaken. To demonstrate this superiority, details of recent calibration runs are presented along with figures showing the benefits of adopting a smaller grid size that gives superior results at the cost of very long run times.

Key Words, Hydrology, Hydraulics, 1-Dimensional, 2-Dimensional, TUFLOW, Estry, XP-Rafts, CatchmentSIM, Flood Study, Asset Management

Introduction
The level of detail available in flood models has increased exponentially over the last 20 years. Has this made our life easier or harder? Is the level of information we get out of these models providing better quality information or is it just giving us nicer looking results? Is the time and money required to setup a One-dimensional (1D) / two-dimensional (2D) model really worth it? This paper will look at the data required to prepare a detailed and integrated 1D/2D flood model for a built-up urban fringe catchment in South-Western Sydney. The paper will focus on the data required and the ease (or not) with which it can be obtained and the processes required to transform these inputs into a reasonable and reliable model. The paper will also look at the importance of accurate and comprehensive stormwater asset management systems and some of the checking processes necessary to ensure that we have confidence in the results obtained. The issue of “fit-for-purpose” will also be investigated in terms of the level of detail required for different activities (broad scale planning purposes vs. development assessment of an individual site).

The focus of this paper is to investigate the benefits and challenges of undertaking a highly detailed flood study for a 90 km² urban catchment within the Sydney Basin using a combined 1D/2D computer model. It will explore the pitfalls and benefits of this type of modelling and examine the question, “are the results worth the effort?” Campbelltown City Council (Council) has recently completed a comprehensive flood study of the Bow Bowing/Bunbury Curran (BBBC) Creek Catchment. This catchment runs from southwest to northeast through a combination of formalised channels and natural creek lines, discharging to the Georges River at Glenfield. The topography is generally mild and
undulating with some steeper sections in the hills and a broad flat floodplain. This recently completed Flood Study has been modelled using the TUFLOW/Estry Model.

### Council's 2007 Flood Study

In 2003 it was determined that there was a need to review the existing Flood Mitigation Scheme in light of development that had occurred since its last review. The scheme had served Council well over the years but was in need of review to assess the impact of development on the performance of the BBBC Creek Catchment. Furthermore, with the development of new software now available to assess flooding, Council seized the opportunity to achieve improved outcomes both technically and in terms of presentation. Council’s review coincided with the introduction of the Draft Floodplain Management Manual 2001 by the then Department of Land and Water Conservation (now the Department of Environment and Climate Change) and the revised version of this document the “Floodplain Development Manual 2005” (FDM). A number of new elements required investigation for a more balanced approach to floodplain management.

The major new elements included in the FDM were:

- Investigation of the impacts of storm events up to and including floods caused by the Probable Maximum Precipitation (PMP) known as the Probable Maximum Flood (PMF);
- Investigations into the impacts of overland flows.

The limitation of Council's 1993 HEC2 model was that it did not investigate overland flow and only modelled the 100-year Average Recurrence Interval (ARI) flood events. While the flood volumes could be considered to have been quite accurately estimated, the way the hydraulics were being modelled resulted in overland flows not being considered and channel flows being overestimated. This approach was generally consistent with industry standards at the time.

It would have been an onerous task to try to identify all overland flow routes within the catchment to enable Council's existing 1D HEC2 model to be extended to cover the requirements of the FDM. The nature of 1D modelling is such that all structures must be input and manual identification of overland flow routes is required. Trying to complete this task in a complex urban environment like Campbelltown would be almost impossible. Campbelltown’s experience with 1D modelling reinforced the need for an integrated approach to asset data collection so that information which most Councils are collecting to satisfy the requirements of AAS27 can be used for flood studies as well.

Furthermore, Council’s existing model did not cater for the increase in development density of the past 10 years, nor did it have the advancement in computer modelling technologies and catchment delineation now available.

With this in mind, Council embarked on a new direction for modelling its floodplains, moving to a comprehensive 1D/2D model of the BBBC Creek Catchment.

Council undertook a tendering process for the complete investigation of the BBBC Creek Catchment where it was decided to undertake modelling using a computer package called TUFLOW (Two-dimensional Unsteady Flow), which includes the Estry model for modelling 1D elements. (In further discussion of the TUFLOW/Estry package, it will be referred to as TUFLOW for simplicity.) The study was to be completed using TUFLOW together with an updated RAFTS model as the input to this 2D model. Specialist consultant commenced the Flood Study with Council trained staff continuing with the project from April 2004. Council is fortunate to have a number of staff with a long history at Council with extensive experience with Stormwater systems. This knowledge base has been an invaluable resource in the development of an accurate flood study with a number of the preliminary results not meeting the “it just doesn't feel right” test.

Within TUFLOW, there are four possible ways to model the hydrology of the catchment:

- Use the hydrologic module in TUFLOW.
Use an external hydrologic package to model the hydrology and used the outputs from this model as inputs to TUFLOW.

Use an external hydrologic package to model hydrology outside a defined TUFLOW boundary and use either of the above methods within the TUFLOW boundary

Any combination of the above

Council decided to use the third method with RAFTS providing the hydrology, both external to and within, the TUFLOW boundary. This reduced the amount of computation required and was chosen as all previous modelling for the BBBC Catchment had been undertaken using RAFTS and a high degree of confidence was held in the results produced to date. Within Council's model, approximately 40 km\(^2\) was not modelled in TUFLOW. This allowed the areas external to the area of interest to be modelled using RAFTS alone, which gave very fast execution times (in the order of less than one minute for multiple runs). The RAFTS total hydrographs at the connection to the TUFLOW model were used as the upstream boundary conditions. The BBBC main channel and five (5) of the major tributaries were modelled using the RAFTS local hydrographs as input and allowing TUFLOW to determine the catchment hydraulics from these inputs. Using the first method (above) would have allowed the rainfall to be applied to each cell within the model and allow TUFLOW to determine the hydrology and the hydraulics but computation resources and run times would make this an unrealistic option.

Data Requirements for 2-D Modelling

It was identified early in the process that if Council wanted a comprehensive and accurate model, a large amount of base information would be needed.

- The information required included:
  - Airborne Laser Survey (ALS) of the catchment (which is the basis of the terrain model used in TUFLOW)
  - Large amounts of Council drainage asset information in the form of pit and pipe locations, levels and connectivity
  - Details of detention basin outlet structure details

Council's Assets Unit has collected information regarding over 20,000 drainage assets throughout the catchment, with this information being represented as Geographical Information System (GIS) layers. This data could not be directly imported into TUFLOW in the form that it had been collected, which created our first challenge. Council's Asset Unit's primary objective was to include the approximate location of the pipe information and its' associated asset information e.g. pipe diameter, condition rating, invert level etc. into Council's Assets System.

In TUFLOW, it is not only the location of the asset but the direction in which the line is drawn that matters. All 1D elements must be drawn from upstream to downstream. Furthermore, all pipe systems need to be snapped together at the pit to allow TUFLOW to read them. An example of Council's Asset information together with the required setup from TUFLOW is shown below. Every connection in the Assets database had to be manually checked for connectivity and the appropriate snaps created. Without this check, the water could not flow through the pipes, as the model could not determine the appropriate connectivity. This extra coding took considerable time.
In addition to the above problem, the Asset pipe information was recorded with the invert level relative to the surrounding ground level (e.g. 1.5 in the Asset system database indicates 1.5m below the existing ground levels). TUFLOW required that all level information be related to the adopted datum e.g., if the existing ground level at a pit was 68.5m the invert level required for TUFLOW would be 67.0m. The need for TUFLOW to use “real” invert information meant that manual calculations at each pit were required with additional information having to be sourced from either the field, design plans, Work-As-Executed plans, or Subdivision plans.

**Setup of TUFLOW model**

TUFLOW is a “computational engine that provides two-dimensional and one-dimensional solutions of the free-surface flow equations to simulate flood and tidal wave propagation. A powerful feature of TUFLOW is its 2D/1D dynamic linking, first pioneered in 1990, and subsequently enhanced to the point where it offers unparalleled flexibility and robustness.” ([TUFLOW Website](#)).

As Council’s Flood Study was to cover approximately 50 km², it was necessary to be realistic regarding the size of the grid created to cover this area. It needed to be large enough to have realistic run times and small enough to produce acceptable results. Within TUFLOW, each cell is delineated by a series of nine (9) points (one at each corner, one at the middle of each side and one in the centre of the cell), which are used to represent the underlying terrain, and the spacing of these points is related to the cell size. A 20m-cell size was first selected and a number of runs completed. These initial runs allowed Council to obtain a “feeling” for how TUFLOW would model our catchment. The 20m-cell size produced disjointed results and was considered inappropriate for this study. Council settled on a 10m-cell size for this study. This size cell size enabled a realistic run time (approximately 1 hour of model time correlated to 1.8 hours of real time) with a level of accuracy that allowed future broad scale planning of the floodplain to occur.

During the development of the model a number of areas were scrutinised in an attempt to use the 10m-cell model for micro planning purposes. This highlighted a number of inconsistencies with the flow regime and as a result, a number of sections of the model were rebuilt with additional information. Additional works have been undertaken on small sections of the catchment with a smaller cell size. In one instance a 2m-cell size was used over an area of 7.2km² and the run time increased to 1 hour of model time to 8.4 hours of real time. Identifying these minor issues resulted in all previously completed runs having to be rerun. This resulted in a considerable extra time to complete the study. The lesson to be learnt from this is that every time a model is scrutinised, more issues will be found. A model will never be perfect, but it is important to decide when it is “perfect enough” to use. If absolute perfection is required, a Flood Study will never be completed.

With recent advances in TUFLOW, it is possible to run a broad scale model on the outer reaches of the catchment (i.e. a 10m-cell size) together with a finer definition model (i.e. 2m-cell size) in the urbanised areas of the catchment. This highlights the issue of “fit for purpose”. A Flood Study must provide information for the entire catchment. Realistically, computing power and the nature of the Flood Study will indicate a broad scale approach. Council has undertaken a number of investigations on a consultancy basis for specific development proposals, which has reinforced the need to use a smaller cell size for micro planning purposes.

Early modelling results indicated a need to include a large amount of the 1D domain information in the model to ensure the accuracy of the model. This was a substantial commitment of time by Council, with the result being over 5,500 1D elements (approximately 2,500 pits and 3,000 pipes and culverts) requiring coding in this model. Council’s model was, for a while, the largest TUFLOW model ever created.

To obtain an appreciation of the amount of information needed to include 5,500 1D
elements, each pipe required six (6) pieces of information; an Identifying Number, Pipe type e.g. circular culverts, box culverts, Manning’s Number, upstream and downstream inverts and pipe size. As mentioned before, because of the setup of our assets information, a large majority of the 33,000 entries were completed manually.

Software/Data Issues

Software issues have had a major impact on the timely completion of this study and the accuracy of the results. The first issue arose with the ALS data. ALS data was captured in April 2004 but not received until Feb 2005 due to company amalgamations at the time. Another issue occurred with the age of Council’s existing RAFTS (1993) model. In the past 10 years, the size of lots has been generally decreasing and the size of the homes placed on these smaller blocks has increased. This increase in hard impermeable surfaces has altered the flow regime of the BBBC Creek Catchment and an extensive revision of the RAFTS model was needed.

In an attempt to simplify the creation of the RAFTS model, a software package that automated catchment delineation was needed, and a package known as CatchmentSIM was selected. CatchmentSIM was developed in 2002. It is a GIS based program, which uses the power of GIS interrogation techniques. It delineates a catchment to provide insight into the catchments response of each sub-catchment and resulting assignment of hydrologic modelling parameters. It does this by:

- Breaking up the catchment into a user defined number of sub-catchments;
- Determining each sub-catchment area and spatial topographic attributes such as slope and stream path lengths; and
- Analysing each sub-catchment's hydrologic characteristics such as percentage impervious which it determines by a user defined percentage impervious, which is attributed to landuse.

CatchmentSIM creates input files for many of widely used hydrologic programs available including RAFTS. Landuse was determined by Council’s landuse zones, which were imported into CatchmentSIM. Checking was required to ensure areas, which may be zoned for future residential, were modelled with the appropriate existing landuse (generally rural) for the existing model. The use of CatchmentSIM caused further delays, as an error was present within the software. The software developer couldn’t replicate the error occurring on Council’s system. It was later found to be caused by a file reference in the program, which had been placed to allow the developer to debug the program. The file location didn’t exist on Council’s system and created the error. When the developer ran Council’s files on his computer no error would appear thus making error analysis difficult.

One of the advantages of CatchmentSIM was that the input file for RAFTS could be created directly from the program. This, in theory, would allow the fast creation of a RAFTS model and timely completion of this section of the study. With the delineation completed, export to RAFTS was the next step, however, due to the size of model, a new script for the RAFTS input file had to be written. The script used in CatchmentSIM only allowed 400 sub catchments to be exported into the RAFTS files. Council’s model included 733 sub catchments. Two separate files had to be created and manually merged together before importing into RAFTS.

Once these issues were resolved, and the catchment delineation finalised, an issue with Council’s RAFTS program was identified. Council’s existing licence for RAFTS was limited to 600 nodes. RAFTS allows large catchments to be broken into smaller sub-catchments as long as the total number of nodes in each sub-catchment does not exceed the node limit of the license. It is possible, in this way, to have an almost unlimited number of nodes in a catchment. This resulted in three (3) separate models being created. One for Bunbury Curran Catchment (131 nodes), one for Thompson Creek catchment (69 nodes) and finally the largest model (532 node) for the remaining areas of the BBBC Creek Catchment. The
total hydrographs for the smaller upstream catchments were used as inputs to the larger BBBC Catchment model. This process is commonly used in RAFTS models but software issues arose. RAFTS was not reading the input files for the Bunbury Curran Creek Catchment or Thompson Creek Catchment correctly thus producing incorrect results. Because of the nature of the support structure of XP Software (the writers of RAFTS), Council was reporting the problem to the Help Desk based in the United States of America (USA) who then forwarded it to their Technical Support team based in Canberra to fix the problem. The repaired engines were then sent back the USA and forwarded to Council to test. A number of versions were required to produce correct outcomes. In all, this took a significant time to complete. With the hydrological issues out of the way Council finally embarked on the TUFLOW modelling.

In June 2006, it was decided that the model was at the point where the level of detail was considered sufficient and the final runs were to be completed. Yet, another software problem was encountered. Early results were telling us that the flows in the main channel had decreased by approximately 20% from 561 m$^3$/s (in the 1993 study) to 460 m$^3$/s. This didn’t pass the “does it feel right” test. Yet, try as we might, we could not find anything wrong with the construction of the model.

As Council had a good working relationship with the developer of the TUFLOW package, BMT WBM in Brisbane, we had them review the model. This review identified a problem with the setup of a number of our elements, where there was a considerable volume of water being "lost", thus reducing the flows. This was found by carrying out a mass balance check. This check ensures that the volume of water entering the model equals the amount exiting the model plus any volume remaining in the model at the conclusion of the run.

One of the locations where a large error was occurring was the outlet structure of Kooringa Detention basin. The outlet of the basin has a cross sectional area of less than 5 m$^2$. This element was directly connected to a series of large culverts under St Andrews road that have a cross sectional area of nearly 55 m$^2$. This considerable change in cross sectional area over a very short distance caused an instability in the model which resulted in a loss of over 80,000 m$^3$ of water.

It needs to be understood that in complex software such as TUFLOW, only hands-on experience results in the advanced knowledge needed to identify these types of errors. Even with detailed reading, the manual may not be enough to understand the complex checks undertaken.

A number of similar situations where there was a significant variation in cross sectional area over a very short distance occurred throughout Council’s model. These were rectified and an attempt to balance the model again was undertaken. However again, balancing of the model was unattainable.

Further reviews in September 2006 by BMT WBM identified a genuine issue in the software. This anomaly not only took a considerable amount of time to be identified by BMT WBM, but it had never been encountered in any other TUFLOW model created to date. The problem was finally tracked down to being a loss of connectivity between the 1D and 2D domains. Checks were available to map a mass balance error within either the 1D or 2D domain separately but no checks were available to detect losses across the 1D/2D interface. BMT WBM created new checks to identify these losses.

Within a complex model such as TUFLOW, there are many options for coding the network. Council had adopted the use of one method for transferring flows from the 2D to the 1D domain. There are situations where Council’s selected method would be appropriate, therefore, it was not an “error” as such, and was not picked up by the program's built-in error checking. However due to the local network configuration, it caused an instability which resulted in water “disappearing” at the 1D/2D interface.

The lesson learnt was that detailed checking of a model of this size is needed throughout
the development of the model and the importance of not waiting until the model is completed. It is also possible to get too close to a model when working on it day in and day out. Having someone removed from the model to undertake a review is money well spent. BMT WBM created a series of new check files to enable mapping of this error and Council modified the coding at the locations where water was being lost across the interface. Subsequently, a balanced model was achieved. Flows in the 100-year ARI 120 Min event (the peak event for most of the catchment) was within 7% of the new RAFTS flows and the volume difference was less than 2%.

TUFLOW has the ability to have variable 2D domains within a single model. Council looked at modelling the highly urbanised CBD catchment with a smaller 2m-cell size. This again produced an issue with TUFLOW, as this model utilised a number of 1D elements connecting to the multiple 2D domains in a manner that had not been tried in TUFLOW before. The problem was that the second and smaller domain was not establishing a connection to the 1D pipe information and causing TUFLOW to terminate during its checking phase. This error again proved difficult to rectify with BMT WBM needing a significant time to fix the problem. The improved results for a multiple domain model are shown on the next page and were worth the wait. Figure 1 shows the results of the TUFLOW model with a 10m cell used and Figure 2 shows the same area with a 2m-cell used.

The results show the significantly improved flow path definition with a large majority of the flows now contained within the road reserve. Where properties are shown to be affected in the larger cell model, this affectation is drastically reduced with the smaller grid size. It is even possible to delineate the deeper flows in the road gutters (seen in Figure 2 as darker blue/purple). This again highlights the issue of "fit for purpose". The 10m-cell is a good planning tool but the 2m-cell model provides a clearer picture of the likely flooding in a defined area. The 10m-cell shows a larger number of properties affected by flooding compared to the 2m-cell and may be an issue from a community perception perspective.

Council has been at the cutting edge of all three software packages (TUFLOW, CatchmentSIM and Rafts) and has pushed all packages to their limits. An open dialogue and positive relationship with the developers of each of the software packages was a critical part of successfully completing this project.

Council now has the knowledge of the software package to ensure better outcomes for the community. It is extremely important to remember that all computer packages are still in development. When these packages are emulating exceptionally complex concepts such as rainfall runoff routing and catchment hydraulics, the likelihood for error is increased. Users are an integral part of the program’s development and it is essential to provide feedback to software developers so that the industry may improve. It is an obligation on users to always question results that don’t “feel right”.

Calibration

One final note on the issue of calibration. On 10 February 2007, the Fishers Ghost Catchment in Campbelltown was hit by a large storm event. Preliminary investigation of the rainfall data indicated that it was somewhere between a 50 and 100 year ARI event.
Over 400 photos were taken during this event with a detailed analysis completed using tidemarks and surveyed cross sections within Bradbury Park.

Council was fortunate that this is a gauged catchment. Both a pluviograph and stream gauge are housed in the green box seen to the left of the bridge in the photo above. The surveyed peak flood level for this event was 73.70m AHD. Council’s TUFLOW model predicted a flood level of 73.95m AHD (or 13% higher) in the same location using the recorded pluviograph at the site. The model assumed uniform rainfall across the catchment which in reality is not how storms occur however, we achieved a model result that is close to the surveyed level. Additionally, the modelled hydrograph and recorded hydrograph at this location exhibited a near perfect match. These are great results which prove that Flood Modelling using this technology “really is worth the effort.”

Conclusions/Take Home Message

Going back the question asked at the beginning of this paper; “are the results worth the effort?” We think the answer is YES. Campbelltown City Council has produced a model that has redefined flooding in the LGA. This tool will be invaluable in future planning and assessment of the flooding situation in Campbelltown. Council has worked closely with the all software developers to produce a better outcome for Council and better software packages for the industry.

A commitment to undertake 2D modelling of this nature must not be underestimated. There has been a two and a half year commitment by Council’s staff to this project as well as a substantial commitment of funds to obtain the raw data and set up a computer model. An important development in enabling 2D modelling to be completed more efficiently is the exponential increases in the processing power of computers (Moore’s Law). At the start of the project, a typical run was taking 20% longer than now and with the development of dual-core processors, it is expected that run times will be dramatically reduced, making modelling with smaller grid sizes a viable option. Also, the importance of local knowledge cannot be overstated. Many improvements have occurred in the models because of the knowledge available within Council, and Council staff not accepting the answers, just because it was produced by a computer program. This has enabled ownership and understanding to be spread across our division and has produced a model that is useable, accurate, fit for purpose and has the confidence of the all staff.

The problems with integrating Council’s existing Asset information into TUFLOW has highlighted the opportunity to collect assets information in a form that optimises its use the across divisions.

References

1. Flood in Queens Street, Campbelltown Photo taken from Queen Street looking north from Lithgow Street, ca. 1910-1920. Campbelltown & Airds Historical Society
2. Campbelltown News - Tuesday 4 July 1950
3. Campbelltown Ingleburn News
   Tuesday 28 February 1956, pg 5
   Tuesday 21 November 1961, pg 1
5. TUFLOW Website: www.tuflow.com
Biographies

David Crompton has worked in Local Government for past 10 years. Previously as the Stormwater and Infrastructure Engineer at Botany Bay City Council and currently as the Floodplain Engineer at Campbelltown City Council. The past four (4) years he has been involved in the construction, analysis and enhancement of the Bow Bowing/Bunbury Curran Creek Tuflow Flood Model for an urban/rural fringe area with a catchment of 90 km².
Email: david.crompton@campbelltown.nsw.gov.au

Cathy Kinsey is the Coordinator Stormwater and Structural Design at Campbelltown City Council. She has worked in Local Government for 17 years and has extensive experience in strategic planning and the analysis and design of stormwater systems across Western Sydney.
Email: cathy.kinsey@campbelltown.nsw.gov.au