HOW TO ENSURE TECHNICAL CONSISTENCY AND EXCELLENCE THROUGHOUT A MULTI-YEAR FLOOD STUDY PROGRAM

D Tetley[1], C Kinsey[2], C Ryan[3]
[1] Catchment Simulation Solutions, Sydney, NSW
[2] Campbelltown City Council, Campbelltown, NSW
[3] Catchment Simulation Solutions, Sydney, NSW

Abstract

Campbelltown City Council is currently completing a series of detailed flood studies across its Local Government Area (LGA). The studies will provide Council with a detailed understanding of main stream and overland flood behaviour across its jurisdiction.

A key objective of Council was to ensure the studies were completed in a technically robust, consistent and defendable manner regardless of the number of consultants involved. In order to achieve this, it was necessary to complete a range of additional LGA wide investigations to inform the detailed flood studies. These included hydrologic modelling and customised approaches to quantifying stormwater inlet capacity and hydraulic categorisation. This paper outlines why these additional investigations were necessary and how they will ultimately benefit Council, the general public as well as the consultants involved in preparing each of the detailed flood studies.

This holistic approach to Council's overall flood study program allows consultants to focus on the finer details of each catchment when conducting the detailed flood studies. This paper also outlines specific technical challenges that were overcome when conducting the flood studies. This included consideration of a hydrologic model with in excess of four thousand subcatchments and hydraulic models that included consideration of extensive sub-surface stormwater pipe systems as well as the impact of fences on flood behaviour. The technologies that were applied to overcome these challenges and their respective merits are discussed.

Introduction

Campbelltown City Council is charged with the responsibility of local land use planning and the management of flood liable land across the Campbelltown City Council Local Government Area (LGA). The Campbelltown LGA is located approximately 50 kilometres south-west of the Sydney Central Business District, occupies a total area of over 300 square kilometres and is home to approximately 150,000 people (Australian Bureau of Statistics, 2007).

The majority of the urbanised sections of the Campbelltown LGA drain to the Bow Bowing/Bunbury Curran (BBBC) Creek system. The BBBC Creek catchment is approximately 90 square kilometres in area and is highly urbanised with some semi-rural land uses along the western perimeter of the catchment. The catchment is drained by natural watercourses, man-made open channels as well as an extensive sub-surface piped drainage system. The catchment is also traversed by several key pieces of infrastructure including the Main Southern Railway Line and the Hume Highway/South-Western (F5) Freeway. The extent of the BBBC Creek catchment is shown in Figure 1.

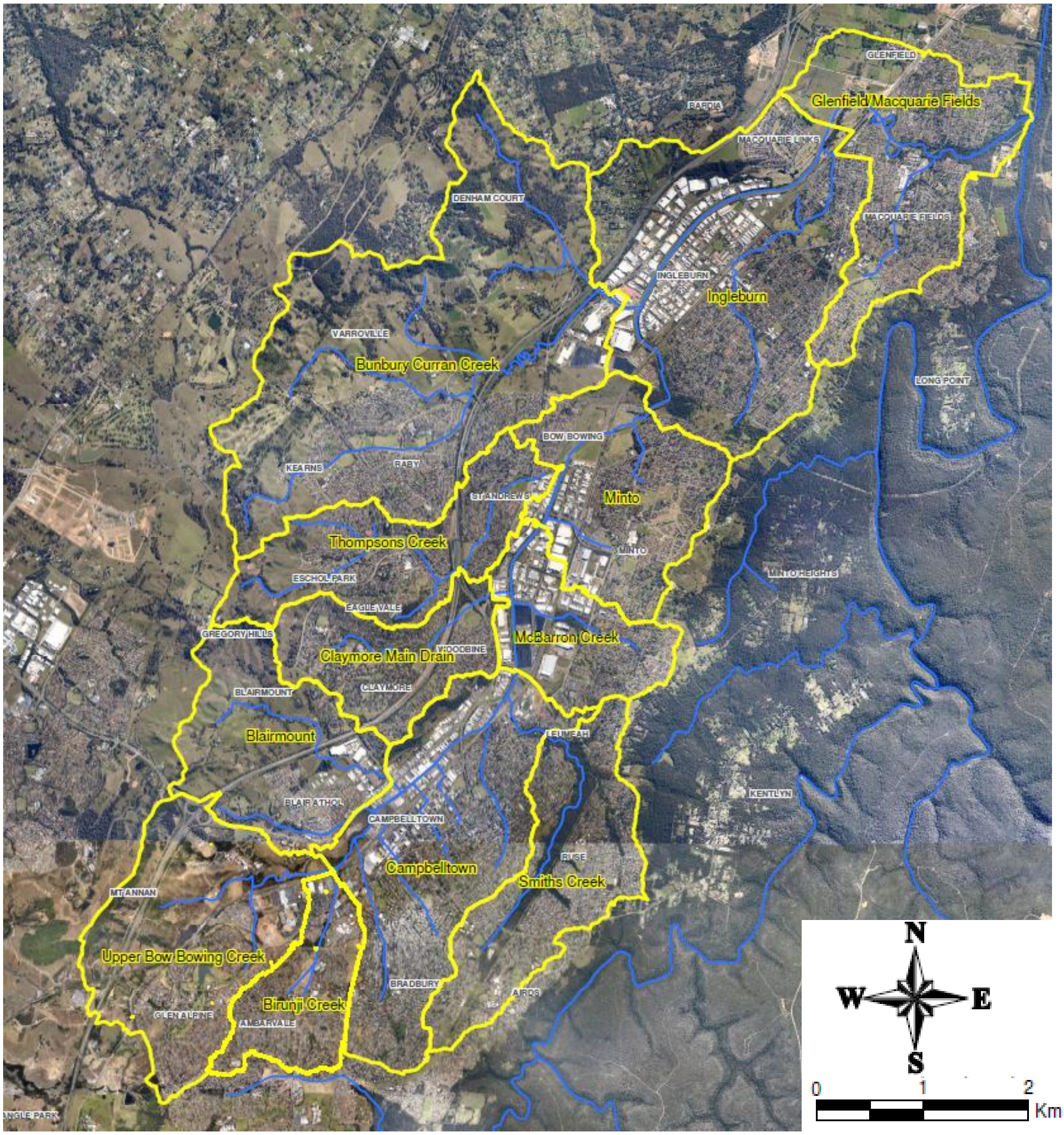

Figure 1: BBBC Creek catchment and detailed flood study areas

Through its Floodplain Rick Management Committee, Council is in the process of preparing a comprehensive Floodplain Risk Management Plan for the BBBC Creek catchment. However, the large size and high level of urbanisation of the catchment prevented the preparation of a single, sufficiently detailed study for the entire catchment.

As a result, Council subdivided the overall BBBC Creek catchment into twelve (12) smaller subcatchments/study areas (refer Figure 1). Detailed flood studies are to be prepared for each of the twelve study areas in a rolling program. The flood studies, in turn, will form the basis for the subsequent community consultation and development of Floodplain Risk Management Studies and Plans for each of the study areas.

Council, in conjunction with its consultants, is currently midway through preparing the detailed flood studies. During the preparation of the initial four flood studies it became apparent that there may be difficulties in maintaining consistency in hydrologic and hydraulic modelling approaches, and assumptions, across each of the twelve study areas if different consultancies are engaged to complete each of the flood studies.

Therefore, before proceeding with each of the detailed flood studies, Council decided to conduct a series of catchment-wide investigations aimed at ensuring consistency in modelling approaches and results across each of the detailed flood study areas. Further detailed information on each of these investigations is provided in the following sections.

The detailed flood studies have also presented a range of technical challenges owing primarily to the high level of urbanisation and the localised effects that this may have on flood behaviour. A brief overview of these challenges and how they were addressed is also presented.

The Importance of Technical Robustness and Consistency

Overview

The detailed flood studies that are being prepared for the BBBC Creek catchment will serve as reference documents for many years into the future. They will also form the basis for development of Floodplain Risk Management Studies and will also be used to assist Council staff in evaluating Development Applications (DAs) across each study area.

Therefore, it is important that each of the flood studies is prepared with the end objectives in mind and that they are prepared in a technically comprehensive, consistent and robust manner to ensure:

- The studies will stand the test of time;
- The studies and associated models can be used as part of the subsequent Floodplain Risk Management Investigations;
- Council can have confidence when presenting the results to members of the public; and,
- In the case of DAs, it is important that Council can evaluate each DA consistently based on the results presented in each of the flood studies.

Current Technical Guidance for Flood Studies

The NSW Government's 'Floodplain Development Manual' (2005) provides <u>general</u> guidance to consultancies and government agencies when preparing flood studies. As a result, the overall approach to completing flood studies should be similar irrespective of who prepares the study.

Detailed technical guidelines for the preparation of flood studies are prepared by many agencies worldwide. For example, the Southwest Florida Water Management District (SWFWMD) in conjunction with the Federal Emergency Management Agency (FEMA) provides comprehensive guidelines and specifications informing consultants on a range of technical aspects including (August, 2002):

- Digital Terrain Model (DTM) development;
- Data evaluation and assembly;
- Field reconnaissance;
- Subcatchment delineation;
- Modelling software;
- Hydrologic and hydraulic model inputs;
- Quality control procedures;
- Deliverables.

For example, Figure 2 and the following text is a small extract from the subcatchment / subbasin delineation section of the SWFWMD guidelines:

> “A depression that is 1 acre or greater in size and has an associated depth of 2-feet or more, shall have the contributing area delineated. In addition, local conveyance or collection systems (man-made channels, washes, etc.) that have a contributing area greater than or equal to 40 acres before discharging to a significant hydraulic control feature shall be broken out as a subbasin. Control features are defined as a depression area of 1 acre in size or greater with a capacity of 2-feet or more and structures such as bridges, culverts, dams, etc.). Local collection systems like driveway crossings and roadside swales, etc. are not to be inventoried. Multiple adjacent depressions, that are individually less than the one acre threshold but sum to or greater than the threshold volume, can be coalesced into one subbasin when deemed appropriate. Storage areas such as lakes, wetlands, ponds, and hydrated stormwater management storage areas (SMSAs) that are greater than or equal to five acres shall be broken out as a unique subbasin due to their uniform hydrology and their effect on direct runoff.”

These guidelines help to ensure that flood studies are completed in a consistent and reproducible manner irrespective of who conducts the study. Similar detailed technical guidelines are generally not available for consultants and agencies completing flood studies in NSW.

A limited amount of detailed technical guidance for flood study preparation in NSW is provided by various Office of Environment and Heritage (OEH) guidelines as well as documents such as ‘Australian Rainfall and Runoff’ (ARR) (Engineers Australia, 1987). However, these documents fail to provide complete guidance for all technical aspects of a flood study and fail to fully account for the requirements of contemporary computer modelling software. Therefore, differences can arise when different consultancies and agencies complete the detailed technical tasks involved in preparing a flood study (e.g., hydrologic and hydraulic modelling).

The upcoming revision of ARR will include consideration of 2-dimensional modelling requirements in urban areas and should go a long way to rectifying some of these deficiencies. However, in the interim, there is no single document that can provide consistent technical guidance for consultancies and government agencies when preparing flood studies.

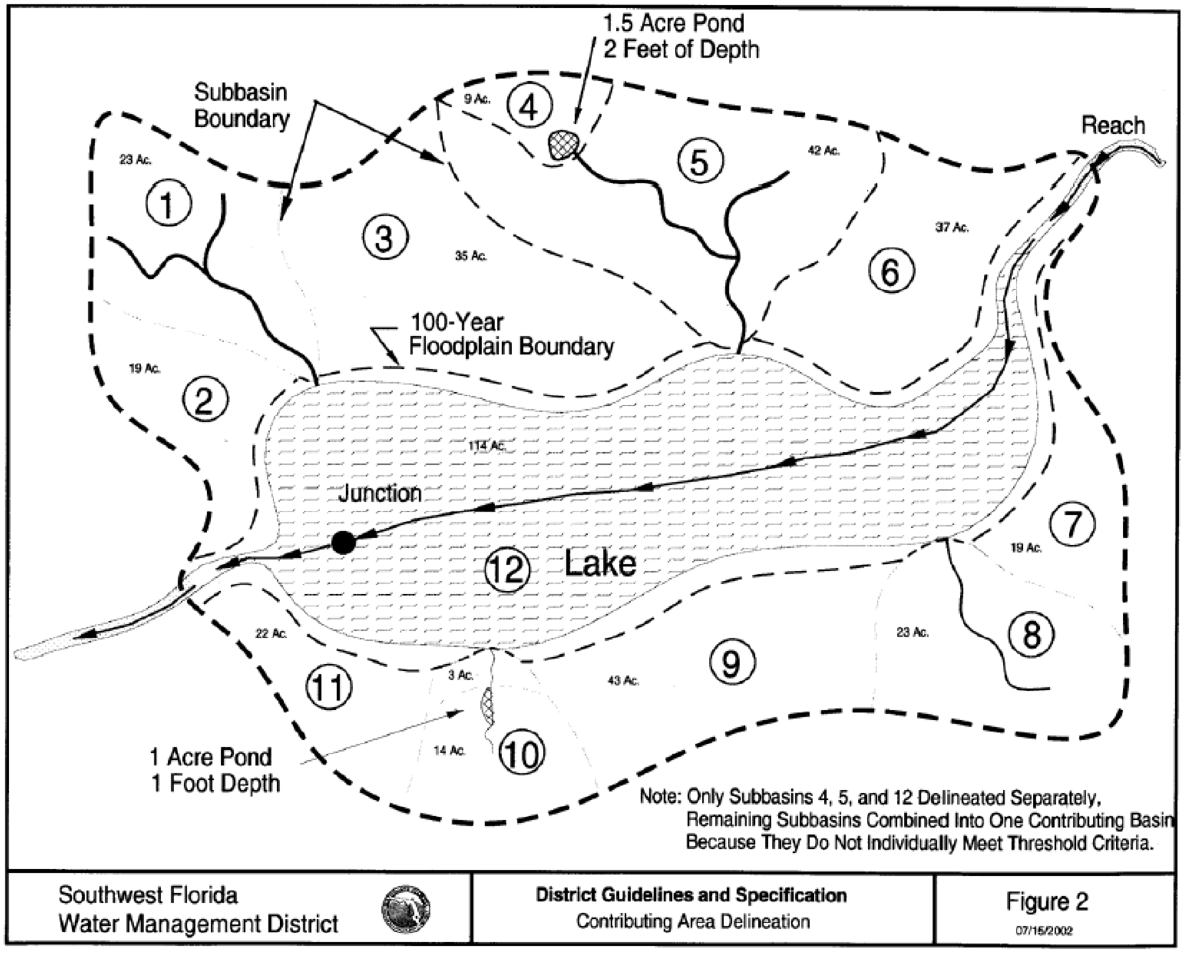

Figure 2: Extract from Subbasin Delineation Guidelines provided by Southwest Florida Water Management District (SWFWMD, 2002)

This limitation was identified by Campbelltown City Council during the preparation of the initial four detailed flood studies. Specifically, different hydrologic approaches were yielding different design flows at common study area boundaries, different capacity curves were being applied to define stormwater inlet capacity and different approaches were being used to define hydraulic categories.

In recognition of these differences, Council decided to complete additional catchment-wide investigations aimed at addressing these inconsistencies before completing each of the detailed flood studies. Further details of each of the investigations is provided in the following.

Catchment Wide Investigations

Hydrology

As discussed, differences in hydrologic results were identified during the initial four flood studies at common flood study boundary locations. The differences were attributed primarily to variations in the level of subcatchment detail provided across the urbanised sections of the catchment. This prompted Council to commission Catchment Simulation Solutions (CSS) to complete a detailed hydrologic investigation of the entire BBBC catchment. The study was commissioned to ensure a consistent approach to hydrology was adopted across all detailed flood study areas.

The BBBC subcatchment was subdivided into over 4,000 subcatchments to help ensure the hydrologic model was sufficiently detailed to represent the spatial variation in flows across each of the twelve study areas (refer Figure 3). This was aided with the CatchmentSIM software, which was used to automate the subcatchment delineation based on a 2 metre digital elevation model (DEM). It was necessary to use a small 2 metre DEM to ensure that details, such as the profile of a roadway, were represented in the DEM and, therefore, the subcatchment boundaries. The hydrologic model also included over 90 flood storage basins with custom outflow and storage relationships defined for each. The model was developed using the XP-RAFTS software.

All subcatchment boundaries were independently reviewed by an additional CSS staff member as well as Council staff. Adjustments were subsequently completed to subcatchment boundaries and subcatchment parameters by hand to address any review comments. A strong emphasis was placed on ensuring a suitably detailed and technically robust model was developed as any errors would permeate across multiple future flood studies.

Link lags were assigned based on a modified version of the Bransby-Williams formula. The modified approach took account of the fact that in-channel flows velocities are likely to be higher along constructed, concrete channels and comparatively lower along heavily vegetated, natural watercourses. As a result, a lag reduction factor was employed to adjust the Bransby-Williams lag based on the material types encountered along major flow paths. The resulting lag factors were verified against stream lags calculated based on velocity outputs from preliminary TUFLOW hydraulic modelling and a good correlation was observed.

This stage of work also involved simulation of all required design, sensitivity and climate change events and output of hydrographs in a format suitable for application in the selected hydraulic software (in this case TUFLOW). Therefore, by completing this detailed hydrologic investigation prior to each of the detailed flood studies, the “hydrology” component is effectively removed from each of the detailed flood studies. This ensures a consistent approach to hydrology is employed across all flood study areas and also offers opportunities for time savings in future flood studies as separate, detailed hydrologic investigations do not need to be completed.

Stormwater Pit Inlet Capacities

Each of the detailed flood study areas typically contains an extensive sub-surface, piped stormwater drainage system. For example, the Campbelltown Locality study area is approximately 10 km^2 in size and contains over 3,000 pipes and 3,000 pits. Accordingly, the stormwater system can have a significant impact on flood behaviour, particularly on urban overland flows during smaller floods. Therefore, Council placed a strong emphasis on ensuring that the stormwater system was reliably represented in each hydraulic model.

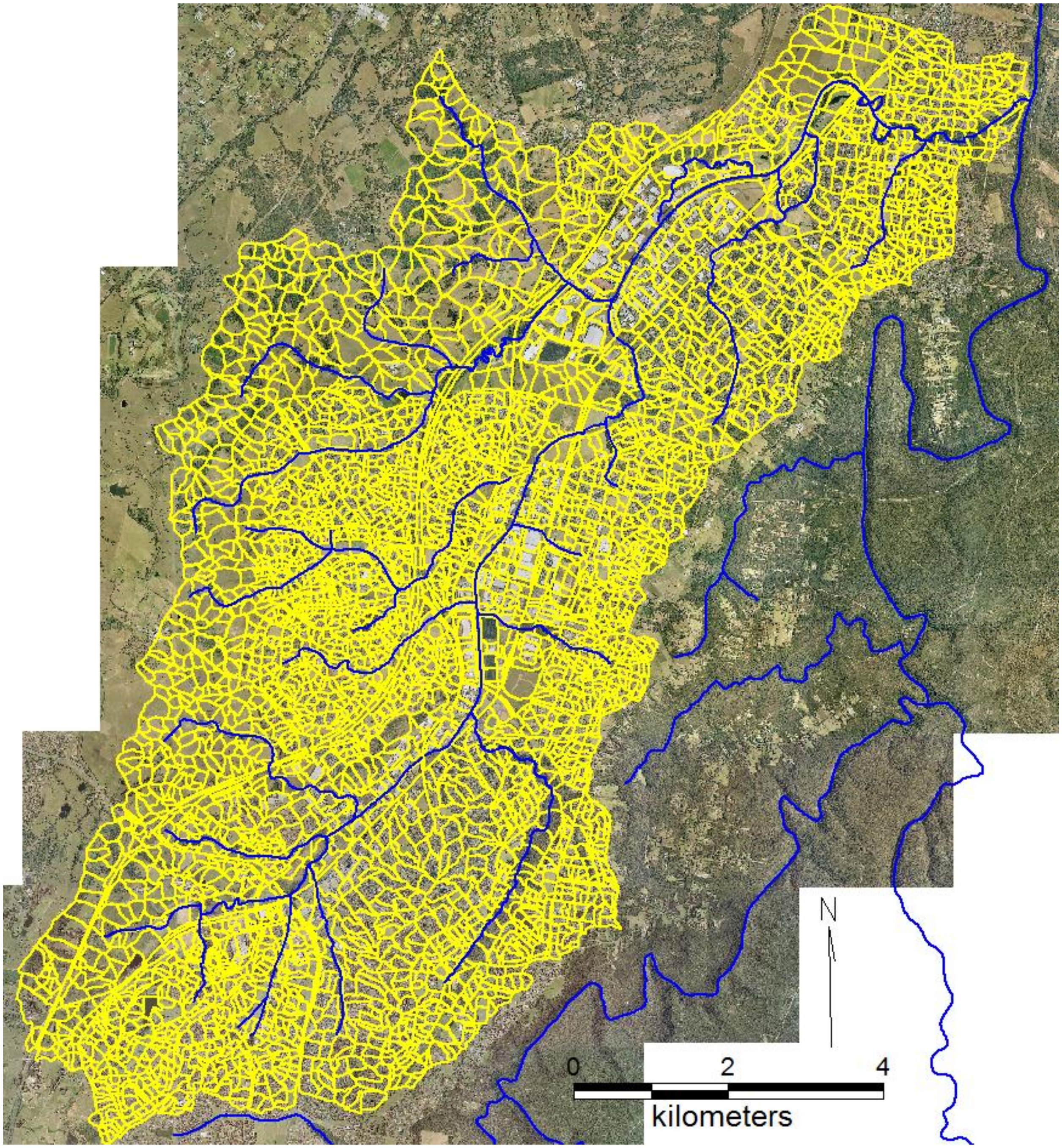

Figure 3: Subcatchment breakup for BBBC Creek Hydrologic model.

In this regard, Council asked CSS to develop custom inlet capacity curves for a range of different stormwater inlet types across the Campbelltown LGA.

A review of Council's stormwater asset layer showed that the pit types across the LGA could be placed into one of the following categories:

- Grate inlets,
- Kerb inlets, and
- Combination grate/kerb inlets.

Each of these broad categories can be further subdivided based on the size of each inlet (e.g., lintel length) as well as whether they are located “on-grade” or at a “sag” location. The inlet capacity of “on-grade” pits is also dependent on the approach grade.

It was evident that developing custom inlet capacity curves for every possible pit inlet type would be prohibitively time consuming. Therefore, some simplifications were necessary. These included:

- Approach grades were approximated for each pit type based on the averaged vectored slope of the subcatchment in which the pit was contained. The subcatchment slopes were extracted from outputs generated as part of hydrologic modelling project.
- The pits were subsequently placed in one of 3 slope groups:
  - <5% slope,
  - 5-10% slope, and
  - >10% slope.
- Pits dimensions were inspected and four different pit size groups were developed based on the most common dimensions for each pit type. Pits were subsequently placed into one of the four size groups;

The assumptions and simplifications still provided sixty different potential pit configurations. Custom capacity curves were developed for each with the assistance of the ‘Drains Generic Pit Spreadsheet’ (Watercom Pty Ltd, July 2005). The resultant curves were verified relative to capacity curves contained in Council’s Engineering Design Development Control Plan (DCP) (2009). Although Council’s DCP only provided capacity curves for a limited selection of pit types, the newly developed curves reproduced the DCP curves relatively well (refer Figure 4). The DCP capacity curves typically showed a lower inflow capacity due to the inclusion of a blockage factors.

The inlet capacity curves were subsequently prepared in a format suitable for direct inclusion in the TUFLOW hydraulic software. Accordingly, this information can be provided directly to subsequent flood study consultants to ensure consistent evaluation of stormwater inlet capacity in future flood studies. Although several simplifications were made, it should still provide a reliable representation of the capacity of various pit inlet types that are encountered across each of the detailed flood study areas.

Hydraulic Categories

Hydraulic categories are one of the fundamental outputs for any flood study completed in NSW. They provide valuable insight for Council staff regarding the potential for development across different parts of the floodplain to impact on flood behaviour along with areas that should be preserved for the conveyance of flood flows.

The NSW Government’s ‘Floodplain Development Manual’ (2005) only provides qualitative criteria for defining hydraulic categories. This is not unreasonable considering the wide variety of catchment types across NSW. The OEH’s ‘Floodway Definition’ guideline (2007) also provides some more definitive criteria for evaluating the suitability of floodway extents.

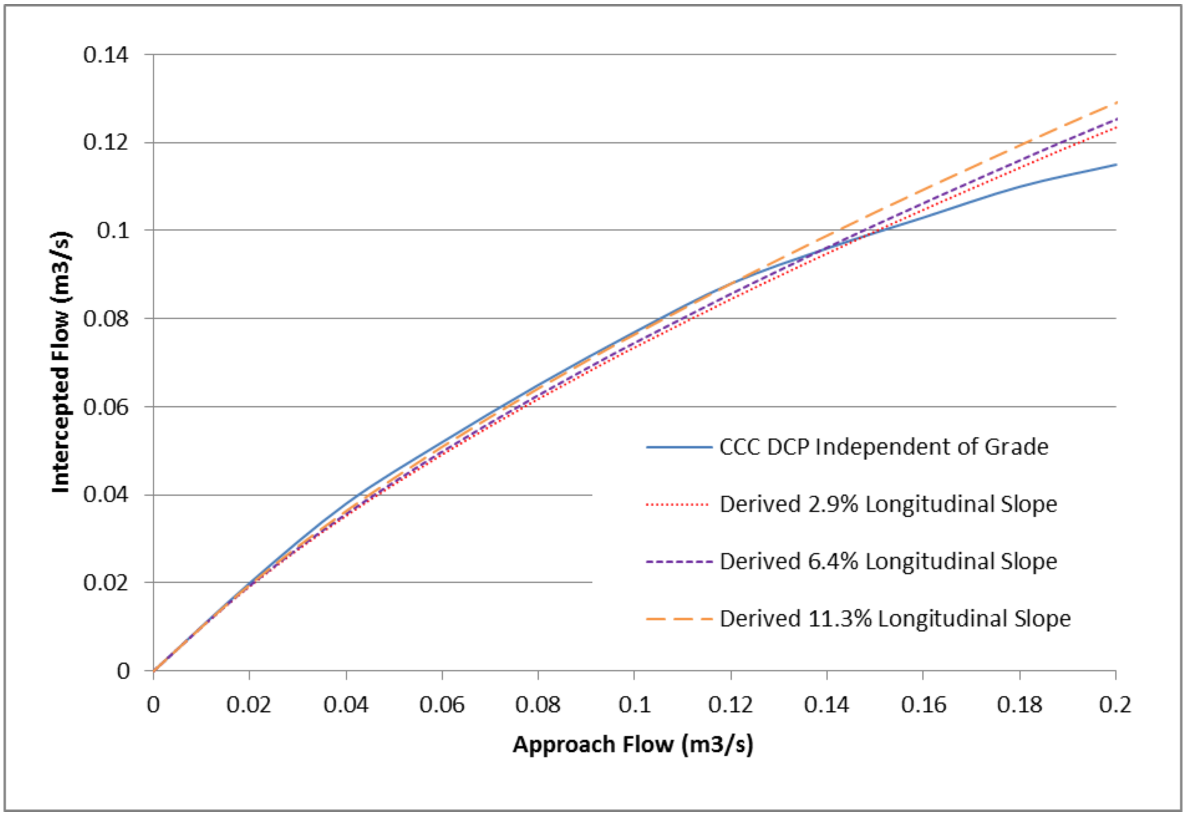

Figure 4: Comparison between newly derived stormwater inlet capacity curves and capacity curves presented in Campbelltown City Council's DCP (2009) for sag and on-grade kerb/grate inlet with 2.4 metre lintel

The lack of technical guidance can result in different hydraulic category definition approaches being employed. This makes it very difficult for Council staff to interpret the hydraulic categories and evaluate the suitability of potential developments across the floodplain consistently.

Council considered that it should be possible to develop a quantitative set of criteria for the BBBC Creek catchment due to the relative uniformity in development types, planning controls, stormwater design standards and topography.

Therefore, based on their experiences of flooding in the catchment, Council staff prepared a set of criteria for defining hydraulic categories based on floodwater velocity and depth. Council, in conjunction with CSS, decided that a single set of depth and velocity criteria would not be suitable for defining hydraulic categories across the entire catchment. Therefore, one set of depth and velocity criteria were developed for watercourses / "drainage" areas and a separate set of criteria were developed for "non-drainage" / urban areas. The resulting relationships are presented in Figures 5 and 6.

Council comissioned CSS to implement prcoedures to ensure consistent, catchment-wide application of the adopted hydraulic cateogory criteria. This was implemented by making use of a custom hazard category dynamic link library (DLL) that is included with the TUFLOW software (TUFLOW_USER_DEFINED_*.dll). The code for this particular DLL was obtained from the TUFLOW software developers and two of the non-used, inbuilt hazard categories were replaced with the two sets of hydraulic category criteria. The code was subsequently re-compiled to to form a new DLL.

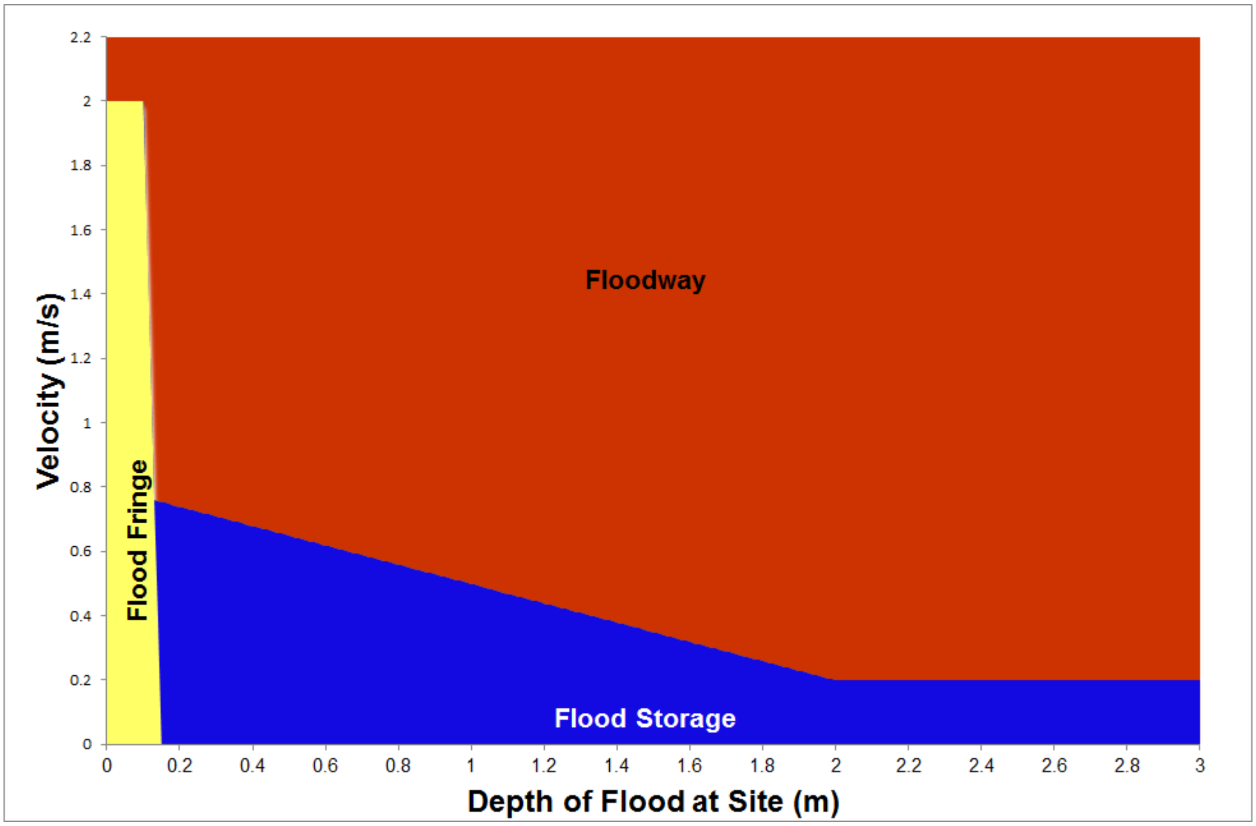

Figure 5: Adopted hydraulic cateogry criteria for drainage areas

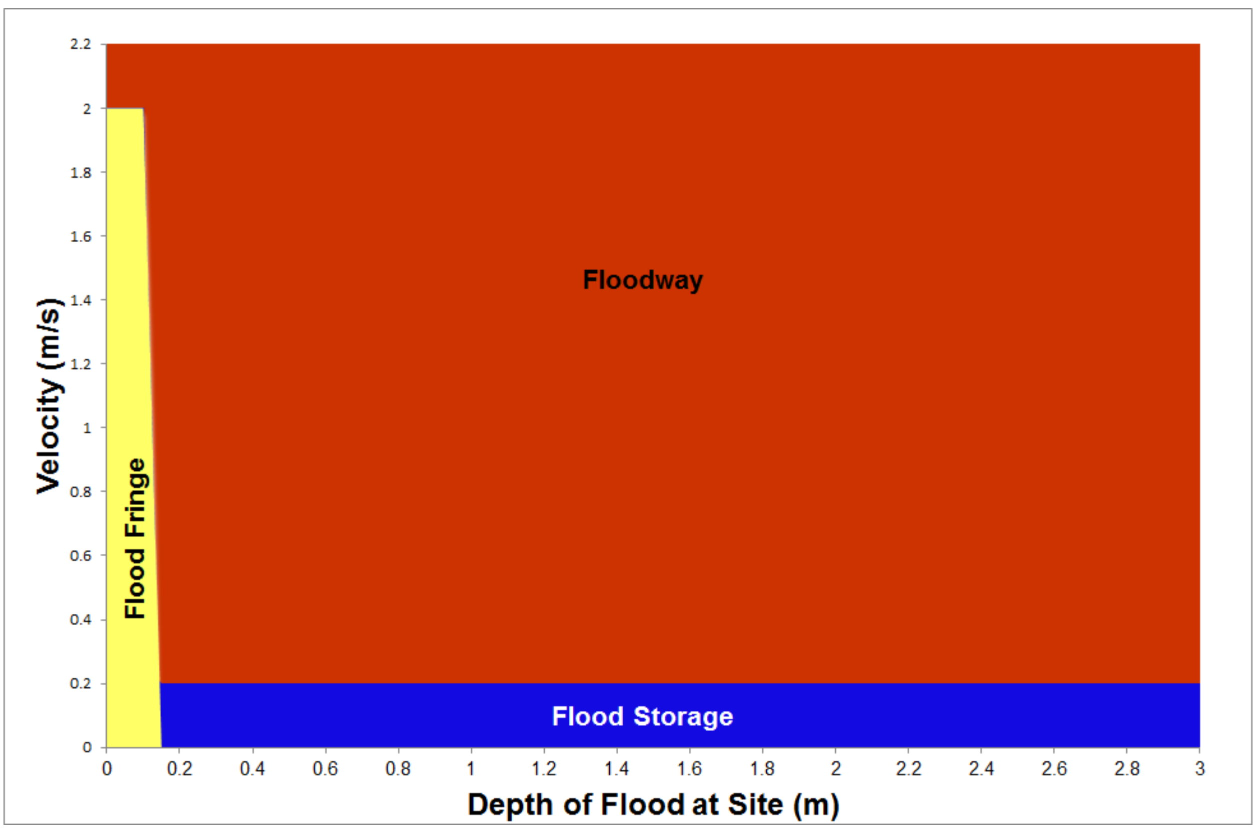

Figure 6: Adopted hydraulic cateogry criteria for urban / non-drainage areas

The DLL can be subsequently distributed to all future flood study consultants and included in the same directory as the TUFLOW executable. This will ensure that the appropriate hydraulic category crtieria will be automatically applied as part of each future TUFLOW model simulation.

Investigations Undertaken During Flood Studies

Overview

At the inception meetings for each of the detailed floods studies, Council clearly identified their expectations for each study. This included ensuring that all features likely to influence local flood behaviour were represented in the hydraulic model (e.g., fences). Unlike other hydraulic model inputs, there is not an extensive amount of literature on the best way to represent fences in hydraulic models. Therefore, Council asked two of the flood study consultants to investigate the best way to represent fences within the hydraulic model and present this as part of the study.

Modelling Fences

As shown in Figure 7, fences are a common urban flow impediment. However, fences are not typically included in hydraulic models as fence alignments are typically not available, there can be a wide variation in the types of fences and how they behave during floods and the complex micro-scale flow behaviour around and through fences is difficult to replicate in a broad-scale hydraulic model.

Figure 7: Example of flow impediment afforded by even relativity ‘open’ fences.

Nevertheless, several watercourses in the Campbelltown City Council LGA are flanked by relatively soild Colourbond^{TM} style fences. Council was of the opinion that this could have a significant impact of flood behaviour and thus requested that those fences in close proximity to watercourses be represented as a minimum.

The first difficulty associated with representing fences in a hydraulic model is associated with the fact that a GIS/CAD file containing fence alignments is required. Therefore, in most cases the fence alignments will need to be surveyed or they will need to be manually digitised based on aerial photography. Surveying the fence lines was considered to be prohibitively expensive and time consuming. Furthermore, manually digitising the fence lines can be hampered when the available aerial imagery is obscured by vegetation, which is quite common in the vicinity of watercourses.

Therefore, an alternative method based on existing GIS layers and the fact that fence lines will typically be aligned with property boundaries was employed. A review of aerial photography, cadastre (i.e., property boundaries) and zoning information contained in Council's Local Environmental Plan (Campbelltown City Council, 2002) was first completed to identify LEP zones where the majority of properties contained fences. This review indicated that areas zoned industrial, residential along with some "Special Uses" zones typically contained fences.

All property boundaries falling within one of the above identified zones were extracted from Council's cadastre layer. The resulting property boundaries were then intersected with Council's roadway layer so that all property boundaries adjoining roadways were removed. The resulting layer provided lines along each property boundary except those fronting roads, as shown in Figure 8.

As shown in Figure 8, the lines appear to provide a reasonable estimate of fence alignments across the catchment. A review of the fence lines generated was completed based on recent aerial photography to ensure they provided reasonable approximations. This review resulted in some minor modifications being completed by hand at several locations across each study area.

As discussed, a wide variety of fence types are typically located within any given catchment. These range from highly permeable wire mesh fencing to Colourbond^{TM} and brick type fencing that would provide a significant impediment to flow. Therefore, it was difficult to specify a single representative fence type for the entire study area.

However, it was recognised that even relatively permeable fence types can become partially blocked during the course of a flood. During the early stages of a flood, debris (e.g., leaves, branches) will be mobilised and conveyed down major flow paths until it reaches an obstruction whose aperture is too small to transmit the debris. Therefore, by the peak of the flood there is a significant probability that most fences will be at least partially blocked with debris. In recognition of this, it was considered that the adopted approach should allow for the representation of this partial blockage along fence alignments. An average blockage factor of 75% was considered appropriate.

Figure 8: Example of fences (yellow lines) extracted using cadastre, zoning and roadway GIS layers.

The fence lines were subsequently incorporated within the TUFLOW hydraulic software as a flow constriction layer. This approach was selected as it allows a blockage factor to be specified (e.g., 75%) and also allows for full conveyance of flows once the water level exceeds the height of the fence (for these investigations, a global fence height of 1.5 metres was adopted). Additional losses can also be included to represent micro-scale losses around fence palings, for example.

Unfortunately, no data is available across any of the flood study areas to verify the performance of the adopted approach. Nevertheless, the results from the hydraulic modelling indicate the velocity and depth outputs look reasonable. Figure 9 shows velocity vectors across a residential area with and without fences included in the hydraulic model. The velocity vectors from the simulation with fences included (black arrows) show reductions in velocity immediately upstream of each fence line (yellow) and localised increases in flow velocity as water ‘squeezes’ through the fence openings.

Although this approach does require the adoption of several assumptions, it provide a relatively quick and consistent approach for representing fences across large areas based on commonly available GIS layers.

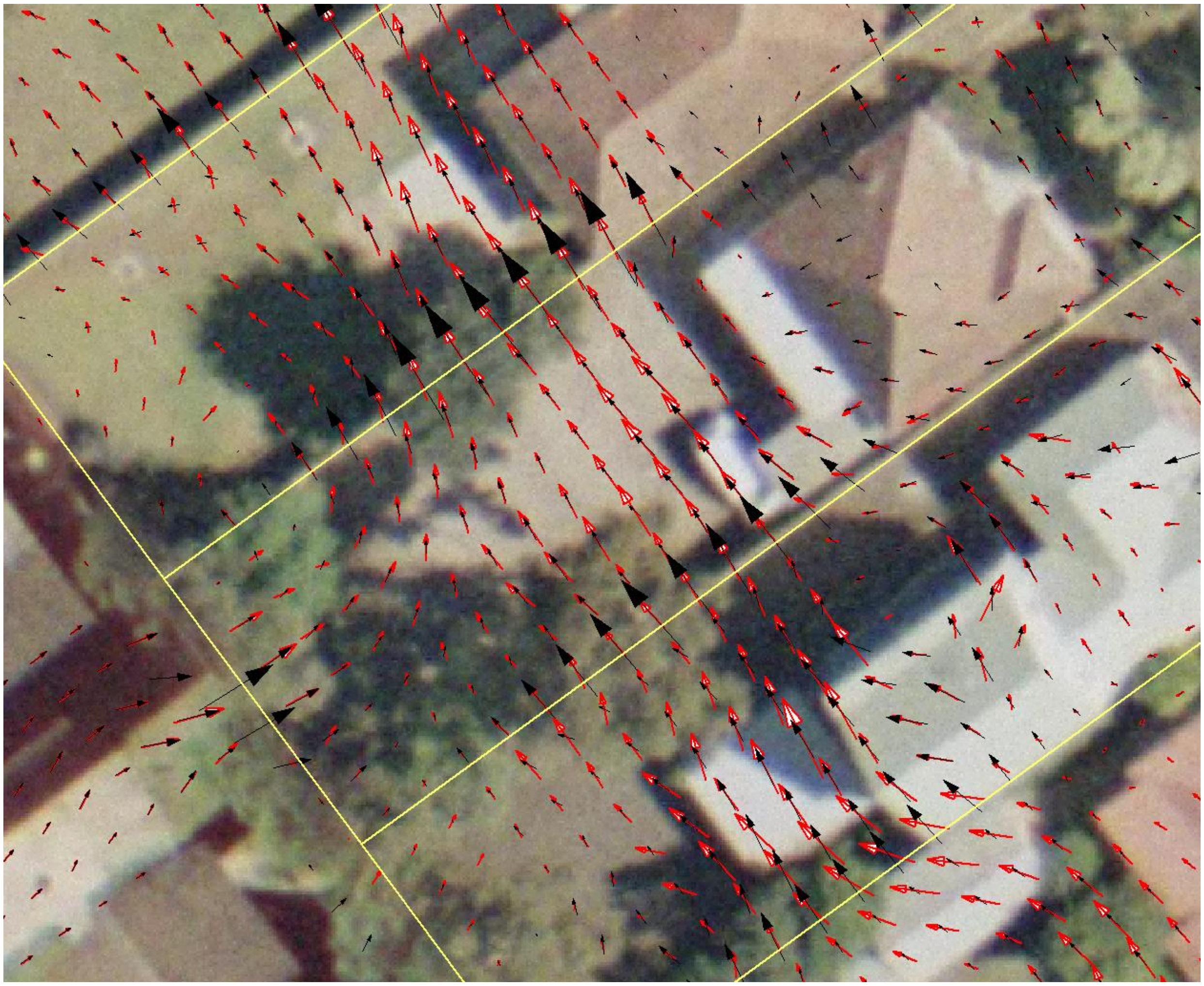

Figure 9: Peak flow velocity vectors with fences (black) and without fences (red) included in the TUFLOW hydraulic model

It is proposed to implement this approach to represent fences across all flood study areas by all consultants.

Discussion

The undertaking of detailed pre-flood study investigations did delay the initial stages of the flood study program while the investigations were completed. There was also additional up-front expenditure associated with completing these initial investigations.

However, this approach did yield a number of significant advantages, including:

- Council can be assured that these components of the flood study will be applied consistently across all flood study areas. This will greatly improve Council's ability to compare and defend the flood study results, and their interpretations, across the LGA regardless of the consultants involved.
- Separate detailed analysis of hydrology, hydraulic categories, and stormwater inlet capacity do not need to be repeated for each individual flood study. Accordingly, there

are likely to be cost and time savings which may recoup any initial cost and time outlays associated with the initial investigations.

As the studies will be used for multiple flood studies, it is also imperative that thorough review and verification activities are performed as part of each investigation.

Conclusion

The lack of definitive technical guidance for consultants when preparing flood studies in NSW can often result in inconsistent modelling approaches and results. The wide variety of catchment types across NSW makes it difficult to implement such a set of guidelines for all technical components of a flood study. Although, in general, flood studies prepared by most consultants will be prepared in a technically robust manner, there will typically be slight variations in modelling software, modelling inputs and modelling outputs. This becomes particularly evident when multiple consultancies are involved in a multi-year flood study program within the one LGA. These potential variations can make it difficult for Council to interpret the model results with consistency and confidence.

However, the variability in catchment types across individual LGAs is typically less significant, opening the door for LGA-based guidelines and/or investigations to be prepared to ensure technically consistency and robust technical application of modelling software as well as interpretation of model output. As part of a multi-year flood study program within the BBBC Creek catchment, Campbelltown City Council have taken a number of steps to help ensure consistency irrespective of who is involved in preparing each flood study.

This involved preparation of a number of catchment wide investigations aimed at defining hydrology, stormwater inlet capacity, hydraulic categories and flow obstructions (e.g., fences). The outcomes of these investigations combined with information contained in Council's Engineering Design for Development DCP (2009) (e.g., Manning's 'n' values, design rainfall) should help ensure consistent application of these technical components of each flood study.

Ensuring technical consistency across a multi-year flood study program is an item that is not part of the current flood study paradigm. Therefore, it often isn't given sufficient thought by Council's and their consultants at the outset of their flood study programs. This can lead to final flood study products that do not fully fulfil the original objectives.

The combined experiences of Campbelltown City Council as well as the consultants involved in preparing the studies during this process suggest that the additional up-front work is more than compensated by the consistent end products and the eventual time and cost savings.

Council Closing Comments

All models are only as good as the information going into them. Models are a living tool requiring constant updating as data processing improves, development in catchments change, modifications to the topography and conveyance systems occur and rainfall data and patterns are updated.

References

1. Australian Bureau of Statistics. (2007). *2006 Census QuickStats: Campbelltown (C) (Local Government Area)*. [ONLINE] Available at: http://www.censusdata.abs.gov.au/ABSNavigation/prenav/ProductSelect?newproducttype=QuickStats&btnSelectProduct=View+QuickStats+%3E&collection=Census&period=2006&areacode=LGA11500&geography=Local+Government+Area&method=&productlabel=&producttype=&topic=&navmapdisplayed=true&javascript=true&breadcrumb=LP&topholder=0&leftholder=0¤taction=201&action=401&textversion=false. [Accessed 09 November 11].
2. Campbelltown City Council (2002). *Campbelltown (Urban Area) Local Environmental Plan*.
3. Campbelltown City Council (June 2009). *Campbelltown City Council Development Control Plan (DCP), Volume 2, Engineering Design for Development*.
4. Engineers Australia. (1987). *Australian Rainfall and Runoff - A Guide to Flood Estimation.* Edited by D. Pilgrim.
5. Office of Environment and Heritage (2007). *Floodway Definition*. Version 1.0. Issued 15/8/2007
6. Southwest Florida Water Management District. (August 2002). *Southwest Florida Water Management District's Watershed Management Program Guidance for Digital Topographic Information, Watershed Evaluation, Watershed Management Plan, watershed Management Database Maintenance and Watershed Model Updates*. Last revised January 2011.
7. Watercom Pty Ltd (July 2005), *Generic Pits Spreadsheet*, Version 2, Available from: http://www.watercom.com.au/utilities.html